ON

MOLECULAR AND MICROSCOPIC SCIENCE

VOLUME THE FIRST

By the same Author.

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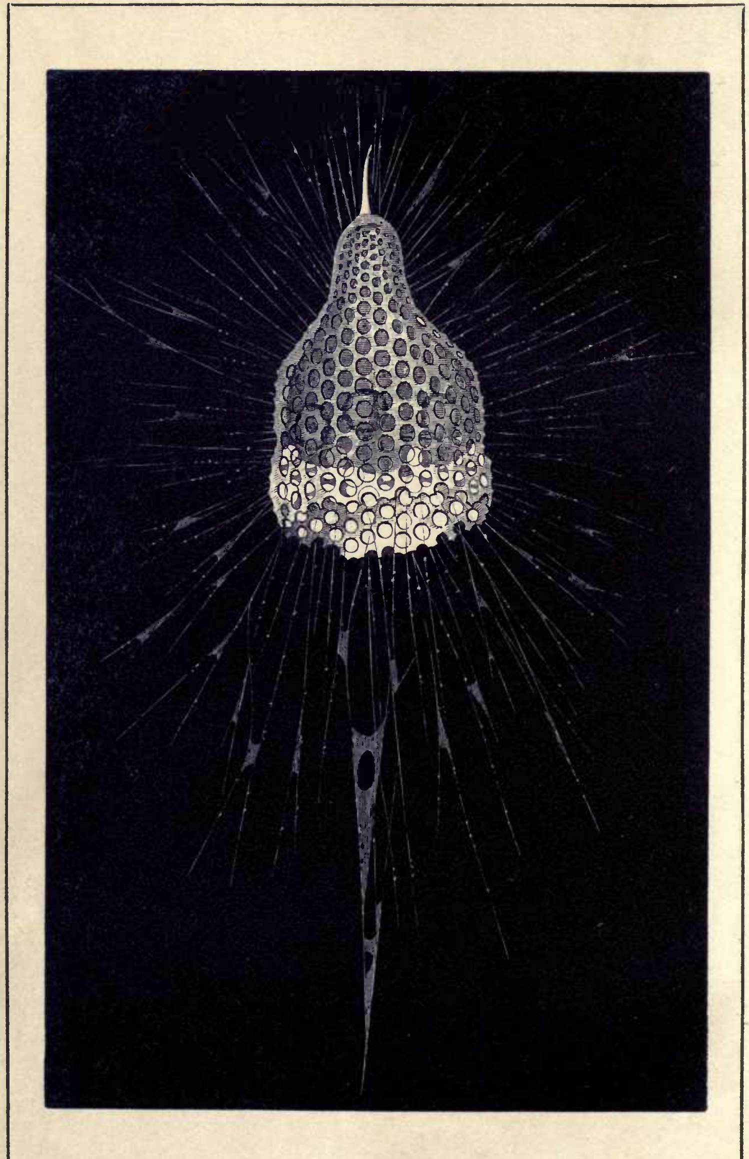
Fig. 89, *p.* 20.



EUCYRTIDIUM CRANOIDES.

[*Frontispiece to Vol. I.*

ON

MOLECULAR

AND

MICROSCOPIC SCIENCE

BY MARY SOMERVILLE

AUTHOR OF 'THE MECHANISM OF THE HEAVENS' 'PHYSICAL GEOGRAPHY'
'CONNECTION OF THE PHYSICAL SCIENCES' ETC.

Deus magnus in magnis, maximus in minimis—St. Augustine

IN TWO VOLUMES—VOL. I.

WITH ILLUSTRATIONS

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PREFACE.

Microscopic investigation of organic and inorganic matter is so peculiarly characteristic of the actual state of science, that the Author has ventured to give a sketch of some of the most prominent discoveries in the life and structure of the lower vegetable and marine animals in addition to a few of those regarding inert matter.

The Author feels bound to return her best thanks to kind friends — Sir John Herschel, Mr. Huggins, Mr. Gwyn Jeffrey, Prof. Tyndall, and Mr. T. Moore of Chelsea, who have aided in revising some of the sheets for press, and have thus counteracted the disadvantage under which she labours, of a residence abroad, and at a distance from libraries of reference.

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(*The Author is indebted to the works of Dr. Carpenter, Rev. M. J. Berkeley, Mr. Gosse, and Mr. Darwin, for the larger part of these Illustrations.*)

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Page 3, *line* 5 *from bottom*, *insert* the *before* earth

59, *line* 19, *dele* the

59, *line* 21, *dele* the

59, *lines* 20 *and* 22, *for* part *read* parts

100. *In the Table of Atomic Weights*, *read* Copper 32; Zinc 32·5; Rubidium 86; Cæsium 133

101, *lines* 10 *and* 33, *for* 32 *read* 32·5

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MOLECULAR AND MICROSCOPIC SCIENCE.

PART I.

ATOMS AND MOLECULES OF MATTER.

SECTION I.

ELEMENTARY CONSTITUTION OF MATTER.

THE INVESTIGATIONS which have revealed the most refined and wonderful relations between light, heat, electricity, and highly elastic media; the relation of these powers to the particles of solid and liquid matter, new methods of analysis, and the microscopic examination of that marvellous creation, animal and vegetable, which is invisible to the unaided eye of man, have brought a new accession to the indefinitely small within the limits of modern science.

Wherever the astronomer has penetrated into the depths of space, luminous points are visible; and since light merely consists in the undulations of the ethereal medium, matter must exist in every part of the universe of which man is cognizant, for although the luminiferous ether is so attenuated that its very existence is almost an hypothesis, its atoms are not more inconceivably small than those of highly elastic ponderable matter on earth. Atoms are the ultimate constituents of homogeneous simple substances; molecules, or groups of heterogeneous atoms united in definite proportions, constitute such as are compound. High pressure steam is invisible as it issues from the boiler, yet each of its molecules contains two atoms of hydrogen and one of oxygen. The perfume of a flower is a compound invisible substance formed of molecules.

We know nothing of the forms either of atoms or of those groups of atoms which we call molecules; but we cannot suppose them otherwise than as excessively hard, since conceive them how we will, we are sure that an atom, whatever be its form or nature, is ever the same. It never wears, it never changes, though it may have formed part of thousands of bodies and entered into thousands of combinations, organic and inorganic; when set free by their dissolution, it is ready to enter into a new series; it is indestructible even by fire, the same now as when created. Nor has the quantity of matter in our terrestrial abode ever been increased or diminished; liable to perpetual change of place and combination, the amount remains the same: the bed of the seas may be changed to dry land, and the ocean may again cover the lofty mountains, but the absolute quantity of matter changes not.

All substances, whether solid, liquid, or aëriform, are supposed to consist of hard separate atoms or particles, and in conformity with that supposition to be surrounded by the ethereal medium, otherwise they could not transmit light and heat, which are merely vibrations of that medium. Even the hardest and most compact substances are capable of compression, and have been compressed to an enormous degree by the hydraulic press; but it probably transcends mechanical force to bring their atoms into contact: in fact, no known substance is impervious to *both* light and heat, however thin.

By far the greater number of terrestrial substances consist of heterogeneous atoms chemically combined into atomic systems or molecules; but there are sixty-four which have never yielded to chemical analysis, and are therefore believed to be respectively formed of only one kind of atoms. Thirty-five of these are metals found either pure or as ores, and sixteen are metals existing naturally in chemical combination with alkalies, alkaline earths, or earthy bases, that is as salts, from which they have been obtained by the analytical power of electricity or other means. The thirteen remaining simple substances are non-metallic: some are aëriform, some solid, one liquid.

The alkaline metals are sodium, potassium, lithium, cæsium, rubidium, and thallium. They are distinguished by their energetic affinities for, and the simplicity of their compounds with, non-metallic elements. They are never met with native, and are amongst the most difficult metals to reduce from their ores, and their spectra are remarkable for simplicity. Sodium and potassium—which have been such important agents in spectrum science—were reduced from their alkalies of soda and potash by Sir Humphry Davy by means of the voltaic battery, a discovery which led the way to the reduction of many of the others. Lithium is a white metal which burns brilliantly in air and oxygen; it swims in naphtha, and is the lightest solid body known. Cæsium is the most energetic of all metals in its chemical affinities.

The metals of the alkaline earths are barium, strontium, calcium, and magnesium. They possess, like the preceding, energetic affinities for the non-metallic elements, and are reduced with difficulty from their ores. Barium is obtained from earth baryta: it is powerfully alkaline, and its salts are colourless and poisonous. Calcium is obtained from limestone, chalk, marble, and gypsum, which are amongst the most abundant constituents in the crust of the earth; it is a bright ductile metal of a bronze colour. Magnesium, which is a brilliant silver-white hard brittle metal, is obtained from magnesium limestone or dolomite. Although the ores of calcium and magnesium cover vast areas of the globe, the metals form a very small comparative proportion of them.

The metals derived from non-alkaline earths are glucinum, yttrium, thorinum, zirconium, and aluminium, which is the only one of any interest: it is now becoming a very useful metal. It combines readily with *oxygen to form clay. The ruby, sapphire, and oriental topaz are merely coloured varieties of corundum, which is nothing but crystallised clay. Rubidium, cæsium, and thallium were discovered by spectrum analysis.

The avidity of some of these metals for oxygen is quite remarkable: potassium and rubidium inflame when they touch ice or cold water; they decompose the water and combine with its oxygen. Calcium becomes luminous in warm water, and burns with intense light when heated to redness; but a magnesium wire burns with such intense brilliancy that it has been employed for photography, and will probably become useful for household purposes, as two ounces and a half of magnesium wire when burnt give a light equal to that of twenty pounds' weight of stearine candles.

The metals whose oxides are not reducible by heat without the aid of some form of carbon include nearly all the useful metals. They are all polyatomic, that is, they combine with other elements in the number of atoms varying from two to eight, and are divided into seven groups in regard to this property. For instance, zinc, copper, and cadmium are diatomic. Zinc is invaluable as a source of electric light and heat in the voltaic battery, and its vapour burns brilliantly. Copper is one of the most useful of metals, while cadmium is of no value at all. Nickel, cobalt, and uranium

* Clay is a silicate of Alumina. Ruby Sapphire &c on contrary are pure alumina +

form the triatomic group; they are remarkable for their complex spectra. Nickel is usually an ingredient in meteorites; cobalt is employed in pigments and in sympathetic inks; and the oxide of uranium is used to stain glass, and gives it some very peculiar properties, as will be shown. The precious metals have a feeble affinity for oxygen at any temperature, and their oxides are decomposed by heat alone, and sometimes even by the undulations of light.

Metals are excellent conductors of heat, but they vary exceedingly in that respect; both theory and experiment prove that the best conductors are invariably the worst radiators. In fact those atoms which transfer the greatest amount of motion to the ethereal medium, that is, which radiate most powerfully, are the least competent to communicate motion to each other, that is, to conduct with facility. Silver and copper are the best conductors of heat, but the worst radiators. These two metals are the best conductors of electricity, but it is influenced by temperature; for MM. Matthiessen and Von Bose's experiments have proved that all pure metals in a solid state vary in conducting power to the same extent between zero and 100° Cent., and that the alkaline metals conduct electricity better when heated than when cold.

All metals are capable of being vaporized, but at very different degrees of temperature. Platinum requires the heat of the oxy-hydrogen blowpipe, which by estimation amounts to 8801° Cent. This property makes it valuable for terminal points to the conducting wires of the voltaic battery and magneto-electric induction machine where great heat can be employed without fusing the platinum terminals. Copper is always employed for the conducting wire on account of its superior conductive power. The coil of wire in the magneto-electric machine, which is often miles long, is insulated by a coating generally of green silk thread. But in experiments of extreme delicacy where magnetism might vitiate the results, perfectly pure copper wire which is diamagnetic is used for the conducting wires in the thermo-electric pile of the goniometer, and the wires are coated with white silk thread, since it was discovered that the green dye contains some magnetic metal.

The mass of the metals however constitutes comparatively but a small part of the terrestrial globe, which is formed of chemical combinations of only thirteen simple elementary substances,—a wonderful manifestation of creative power that could form a world of such variety and beauty by means of atoms so little diversified; still more wonderful is it that four simple elements alone constitute the basis of nearly the whole organic fabric. The air we breathe, water, the bodies of men and living creatures, and the vegetation that adorns the earth, are chiefly combinations of three invisible gases, oxygen, hydrogen and nitrogen, with carbon, the purest amorphous form of coal.

Oxygen gas forms three-fourths of the superficial crust of the terrestrial globe, its productions and its inhabitants. At least a third part of the solid crust of the earth is oxygen in combination; it constitutes eight parts out of nine in water, and water covers three-fourths of the surface of the globe; it forms more than twenty parts out of a hundred of atmospheric air, and in the organic kingdom it is an essential constituent. Except in the atmosphere, oxygen is never uncombined, but may be obtained by distilling chlorate of potash, by the decomposition of water by voltaic electricity, and by other means. When pure it is a colourless, tasteless, inodorous, invisible gas; it is incombustible at ordinary temperatures, yet absolutely essential to combustion; no animal can live long in it, and none can exist without it. In the atmosphere oxygen is highly magnetic;

its magnetism increases with cold and decreases with heat; hence its intensity varies with night and day, winter and summer, but its magnetic property vanishes when it enters into composition.

Oxygen is perfectly quiescent and passive as a gas in the atmosphere, and as a constituent of water and solid bodies, yet that inactivity conceals the most intense energy, which only requires to be called into action. Thus combustion of extreme intensity takes place when ignited sulphur is put into a vessel containing oxygen gas; the metal potassium is instantly inflamed by it on touching water; some of its combinations with chlorine are highly explosive, and phosphorus burns in it with dazzling splendour. Thus a stupendous amount of energy is latent in oxygen under the most tranquil appearance.

M. Schönbein of Basle discovered that oxygen exists in another state, which has neither the extreme quiescence on the one hand, nor the intense violence on the other, of its ordinary form; and to express that intermediate condition, in which its activity is less in amount and different in quality, it has been called by another name, viz. ozone, from the following peculiarity.

It had long been observed that there is a peculiar smell when an electric machine is in activity, and when objects are struck by lightning; that smell Professor Schönbein ascertained to arise from the change of oxygen into ozone, and actually produced ozone by passing electric sparks through that gas. Ozone differs from oxygen in having a strong smell and powerful bleaching property; it purifies tainted air, changes vegetable colours, and stains starch prepared by iodide of potassium blue, which thus becomes a test of its presence; yet it certainly is oxygen in an allotropic or changed state, for it readily oxidizes or rusts silver and other metals, and when ozonized gas is sent through a red-hot tube, it comes out pure oxygen. According to the experiments of Messrs. Tait and Andrews, oxygen gas loses six eighths of its volume, and becomes four times more dense by the change; it contracts more readily with obscure electricity than with the spark. The experiments of Professor Tyndall on the absorption of radiant heat by gases give reason to believe that ozone is produced by the packing of the atoms of elementary oxygen into oscillating groups, and that heating dissolves the bond of union and restores the ozone to the form of oxygen. Ozone chiefly exists in air that has passed over a great expanse of sea, and the quantity is increased during the aurora, which alone might lead to a surmise of that phenomenon being electric.

The change of oxygen into ozone is not the only instance of Allotropism,—that is to say, the existence of the same substance in two states differing from each other in every respect,—for ozone itself is allotropic. Professor Schönbein has discovered that there are two kinds of ozone standing to one another in the relation of positively and negatively active oxygen; namely ozone and antozone, which neutralize each other into common oxygen when brought into contact. In this respect they are analogous to electricity, and, like electricity too, one kind cannot be produced without a simultaneous development of the other.

When a metal, such as silver for example, is oxidized or rusts, it gives polarity to the atoms of oxygen in the atmosphere and divides them into the opposite states of ozone and antozone; the ozone combines with the silver and rusts or oxidizes it, at the same time that the antozone is dissolved in the moisture or aqueous vapour in the air and forms peroxide of hydrogen. The oxidized or rusted silver, as well as every other oxidized substance, is an ozonide, while the peroxide of hydrogen is an antozonide.

Since both kinds of ozone are produced during the decomposition of water by electricity, and as sea air is always found to contain more or less free ozone, the ocean is probably an antozonide, for all the antozone formed by electricity during thunderstorms must be either dissolved in the sea-water, or carried into it in the form of peroxide of hydrogen by the rain. Ozone must be exceedingly abundant in the zone of calms and light breezes near the equator known as the variables, which is subject to heavy rains and violent thunderstorms, and also in the regions of the monsoons. On land one of the benefits arising from these formidable phenomena is the production of ozone, which oxidizes decomposing organic matter and hastens its decay, while the antozone, which is dissolved in the atmospheric vapour, forms the peroxide of hydrogen and frees the air from the antagonist principle.

The peroxide of hydrogen thus produced is a transparent colourless inodorous liquid with a metallic taste, and contains one equivalent of hydrogen and two of oxygen. It retains its liquid state under a great degree of cold, and mixes with water in any proportion. It has a strong bleaching property, instantly destroying vegetable colour. If exposed suddenly to a temperature of boiling water it is decomposed with violent explosion, and readily gives off oxygen at 59° Fahr. The mere touch of an oxidized metal, as the oxide of silver, completely and instantaneously decomposes it, and oxygen gas is evolved by the union of the ozone and antozone so rapidly as to produce a kind of explosion attended by an intense evolution of heat.

During the combustion of phosphorus in the atmosphere both kinds of ozone appear, and Professor Schönbein considers the slow combustion of that substance, which unites with the ozone and sets the antozone free, as the type of all the slow oxidations which organic and inorganic bodies undergo in moist atmospheric air; that true oxidation is always preceded by the appearance of the peroxide of hydrogen, and that this compound acts an important part in slow oxidations, and is deeply concerned in animal respiration, and in many other chemical actions going on in nature.

In confirmation of these views, it is certain that ozone is a powerful minister in the work of decay. If wood be made explosive like gun-cotton by a similar process, it becomes pulverulent after a time, and burns without exploding, though it still retains its shape. In the natural state of the wood the oxygen is passive and quiescent, for oxygen is a constituent of wood; in its second state it is explosive, and after a time that is succeeded by the semi-active state of ozone, which by a slow imperceptible combustion causes the wood to decay. Mr. Faraday observes that the force which would have been explosive had it been concentrated into one effort, expends itself in a long continued progressive change.

'The majestic phenomena of combustion bespeak our admiration and rivet our attention because of their imposing grandeur; yet these are but spasmodic efforts in the grand economy of the material world, occurrences of now and then. The slower but continuous progress of the elements to their appointed resting-place, the silent, tranquil, ever progressing metamorphic changes involved in the phenomena of decomposition and decay, these we count for nothing and pass unheeded by. Yet with all their majesty, with all their brilliancy, all their development of tremendous energy, what are the phenomena of combustion in the grand scheme of the universe compared with these? When the loud crash of the thunder or the lightning's flash awakens us from our thoughtless abstractions or our reveries, our feelings become impressed with the grandeur of Omnipotence and the might of the elements he wields, yet the whole fury of the thunderstorm—what is that in comparison with the electric energies which silently and continually exert themselves in every chemical change? Why, the electric force in a single drop of water, and disturbed when that water is decomposed, is of itself greater than in the electricity of a whole thunderstorm. Those of us who limit our appreciation of the powers of oxygen to the energies displayed by this element in its feebly active state, form but a very inadequate idea of the aggregate results accomplished by it in the economy of the world.' Oxygen is the only known gas that is allotropic, and is the only known substance that is doubly allotropic, that is existing in three different states similar to oxygen, ozone, and antozone.

Hydrogen when pure is an invisible gas without smell or taste; it is a constituent of various acids and alkalies, but is itself neither acid nor alkaline. It is highly inflammable, burning with a pale light, and, as already mentioned, a combined jet of oxygen and hydrogen produces heat of 8801°, which is so intense that nothing can withstand it. It is the lightest substance known. A balloon having the form of a globe ten feet in diameter, would hold 32½ pounds weight of common air, while two pounds weight of hydrogen gas would fill it. Associated with this small quantity of ponderable matter, hydrogen has an enormous power of combination, but its activity is only called forth by some exterior and exciting cause. A mixture of two measures of hydrogen and one of oxygen gas would remain inert for ever, but the instant an electric spark is sent through it, a bright flash and an explosion takes place, and the result is water: thus a tremendous force lies quiescent in that bland element.

Hydrogen gas is introduced into the atmosphere by imperfect combustion, but it is instantly diffused and becomes harmless, for aëriform fluids are capable of rapid and perfect diffusion through one another, each

too high

having a capacity peculiar to itself, which under the same circumstances is greater as its density is less; therefore hydrogen the lightest of gases not only rises in the air on account of its levity, but is more quickly and completely diffused than oxygen which is the support of life. Though hydrogen is inferior in density to every other gas, it surpasses them all in conducting electricity, just as silver and copper conduct electricity better than platinum, though far less dense. The great refrigerating power of hydrogen is owing to its extreme mobility and consequent rapid convection of heat, in which it surpasses all other gases. It is as permeable to radiant heat as atmospheric air, has a very high refractive power, a specific heat of 3·2936, and may be substituted in many chemical formulæ for a metal, without altering their character: hence it is sometimes called a metalloid.

The quantity of nitrogen gas or azote that exists in nature is enormous. It constitutes four-fifths of the atmosphere, whence it may be had in a pure state, as well as by chemical means. Like oxygen, this gas is permanently elastic, without smell, taste, or colour; it is neither acid nor alkaline, it does not change vegetable colours, it neither burns nor supports combustion, and is incapable when breathed of supporting animal life. It abounds in organic bodies, in all parts of the animal texture, in the blood, muscles, nerves, even in the brain; and is either a highly nutritious or poisonous principle in the vegetable kingdom.

Nitrogen gas is altogether passive; it has no affinity *(for the metals, and cannot be liberated from any of its compounds even by electricity. Excepting boron and titanium, it will not combine directly or spontaneously with any simple element, even under the highest temperature, but its indirect combinations are numerous and violent: those with hydrogen are either noxious or

* On contrary N is very easily liberated from its compds by electricity or otherwise. Chlorine [illegible]

poisonous, those with oxygen are all deadly poisonous. Had nitrogen combined spontaneously with either of these gases, especially with oxygen, life would have been impossible as the organized creation is constituted; its inertness renders its mixture with oxygen in atmospheric air innocuous. However, combinations of nitrogen and hydrogen, forming nitrate of ammonia, have been discovered in the atmosphere by Professor Schönbein, the union of evaporation, heat and air being the cause; and as evaporation is continually going on, he concludes that nitrate of ammonia, nitrates and other salts are generated in the moist air, and are speedily washed down in our rainy climates into the springs and rivers. He considers the formation of nitrates out of water as highly important for vegetation, because each plant becomes a generator of a portion at least of its azotized food, while the rain furnishes the ground on which it stands with a supply of the same.

In the atmosphere, nitrogen has all the mechanical properties of common air, but with a greater refractive power, and its specific gravity is nearly the same with that of oxygen. Since the atmospheric gases are the most permeable to radiant heat, the earth is in the most favourable circumstances for being warmed by the solar rays, and thus the properties of the elementary gases are admirably adapted for our comfort, nourishment, safety, and pleasure.

Carbon, which combined with the three elementary gases forms the basis of the organic creation, is widely distributed throughout the globe, in enormous coal formations, the vegetation of former ages. Diamond is its purest crystalline form; and charcoal, which is wood whence the volatile matters have been driven off by heat, is its purest amorphous state. To this simple substance and to hydrogen, we are indebted for terrestrial light and heat, whether our fuel be coal or wood, our light a candle or a lamp. The products of combustion are carbonic acid gas, whether pure or mixed with smoke, for ashes are the incombustible earthy matter mixed with coal or wood, and smoke is unconsumed carbon arising from the bad construction of our chimneys; so that the waste is enormous in a great city like London where coal is the only fuel. Light is given out by incandescent solid particles, which become luminous sooner than gas, for all gases have a feeble illuminating power, and heat results from the chemical combination of the carbon with oxygen, a process in which the chemical force merges into its correlative heat. Mr. Faraday observes, that had the result of the combination of carbon and oxygen been a gas only, we should have had very little light, and had it been a permanent solid, the world would have been buried in its own ashes.

Diamond and pure carbon leave no residuum when consumed; they combine with the oxygen of our atmosphere into carbonic acid gas, which is invisible, poisonous, and so heavy, that it may be poured from one vessel to another like water, thereby showing how much carbon it contains in an invisible state. The quantity of carbonic acid gas thrown into the atmosphere in this invisible yet ponderous state is immense, since six tons weight of atmospheric air rushes hourly through an average size blast furnace, carrying with it more than half a ton of carbon in the form of that gas, whose constitution and properties are always the same, whether it arises from combustion, fermentation, or respiration, which latter may be regarded as a slow combustion, consuming us to the bones if not supplied with carbon by means of food. It has been computed that two thousand million pounds weight of oxygen gas is daily converted into carbonic acid gas by these operations, and given into the atmosphere, which would soon be contaminated by its poison and suffocating quality, were it not for vegetables which decompose it, assimilate the carbon and set the oxygen free to mingle with the air and make it again fit for respiration. Carbon has a greater power of combination than any other simple substance except hydrogen.

Mr. Faraday compressed carbonic acid gas into a liquid by the pressure of its own elasticity when disengaged from combination in close vessels, a force equal to the weight of thirty-five times that of our atmosphere; and the liquid was reduced to a solid by M. Thilorier by rapid evaporation, during which the heat was given out so quickly by one part of the liquid, that the remainder was condensed into a substance like snow, which could be touched with impunity, but when mixed with sulphuric ether its temperature was reduced to 166° below zero of Fahrenheit's thermometer.

Carbon appears naturally under a great variety of forms, and exhibits one of the most striking instances of allotropism, the same substance showing the greatest contrast in appearance and physical properties. The diamond, the most resplendent, transparent, and hardest of gems, is identical with carbon, which is black, dull, opaque, and brittle. Both are combustible; carbon is easily ignited, but it requires a heat of 1860° to consume the diamond.

However numerous the crystalline forms assumed by substances either naturally or artificially may be, they are all capable of being grouped into geometrical systems; each system possessing its own allied and derivative forms capable of mutual variations among themselves, but the forms of one system never assuming those of the other. With that law, however, carbon and a few other substances are completely at variance. The diamond crystallizes in octohedrons, while graphite, which is also carbon, crystallizes in six-sided plates,—two forms that belong to different systems quite irreconcilable with one another: and thus carbon possesses the property of being dimorphous.

Sulphur is a simple inflammable mineral abounding in volcanic countries, either in a crystalline or amorphous state, and forming a constituent in organic substances, animal and vegetable. It is readily dissolved by bisulphide of carbon, by benzine, and by a moderate heat; and copper filings exposed to its vapour spontaneously take fire, the chemical force of combination merging into light and heat. Sulphuretted hydrogen gas, a combination of sulphur and hydrogen, forms naturally during the putrefaction of organic matter, and Mr. Faraday observes with regard to the affinities of sulphur, 'so numerous are its relations, so extensive its range of combinations, that we must consider it to be the very foundation on which chemical manufacture is built up.'

Though a simple substance, sulphur exhibits the two remarkable phenomena of dimorphism and the allotropic property. When reduced by heat to vapour and cooled slowly, it crystallizes in rhombic octohedrons; when merely melted and allowed to cool slowly, it takes the form of oblique rhombic prisms. Here the same atoms when in vapour and in a liquid state are acted upon by different forces; but however that may be, sulphur is another singular exception to the law of the immutability of the crystalline systems.

Sulphur becomes allotropic by the continued application of heat; that is to say, it entirely changes its appearance and character, though it remains chemically the same. Naturally it is yellow and brittle, but when fused, it is a colourless pellucid fluid which by continued heat is changed into a black tenacious substance that becomes like India rubber or gutta percha when thrown into water. In this allotropic state it is endowed with properties more powerful, energetic, and exalted; its tendencies to act chemically being increased like those of ozone. That this black tenacious substance is chemically the same with common sulphur there can be no doubt, for when it is exposed to greater heat, it again becomes a colourless pellucid fluid, which thrown into water resumes the form of brittle yellow sulphur.

These new arrangements among atoms of the same kind show that the immutability of matter is not without exceptions.

The animal kingdom is the great reservoir of phosphorus, a simple substance that is never found uncombined. It is sparingly met with in the vegetable kingdom, and still less in the mineral, but may be procured abundantly from calcined bones. When pure it is colourless, transparent, solid, extremely poisonous, and so inflammable that it must be kept in water. In air it is in continual combustion with oxygen, during which ozone is produced. When burnt in a current of air phosphorus leaves a residuum consisting of two substances, of which one is an acid, the other is red allotropic phosphorus, which has been extensively used * in the manufacture of lucifer matches, because its fumes ** are not deleterious, and because it inflames less easily than common phosphorus, to which it is reduced by heat or friction, which generates heat.

Silicon is a simple substance, never found alone, but when forty-eight parts of it are combined with fifty-two parts of oxygen gas it forms rock crystal, the purest form of silica or quartz. Silica is so abundant that it may be said to constitute the basis of the mineral world. The sand on the sea-shore, which is the debris of quartz rocks, shows how universally it prevails. It is even abundant in the vegetable kingdom, giving strength to the stalks and leaves of the grasses, and may be felt in the harshness of the beards of wheat and barley. Silicon

* The red substance left by burning phos in insufficient air is not red phosphorus but oxide of Phos

exists in three different states—the amorphous, which has no form; the graphic, which takes the form of small hexagonal plates; and that of octohedral silicon: hence this substance is dimorphous.

A singular analogy obtains between silicon and carbon: the amorphous form of silicon corresponds to charcoal, the graphic form of silicon corresponds to the graphic form of carbon, and the octohedral form of silicon to the diamond; yet the chemical relations between the two substances are very small.

Silica has hitherto been considered to be insoluble in pure water; at least M. Bischoff states that only one part of silica dissolves in 769,230 parts of water; but by a method hereafter to be explained, Professor Graham has actually obtained a limpid solution of silica in pure water.

Boron is a constituent of boracic acid, a natural production in Thibet and Monte Corbalo in Tuscany. It is a greenish-brown solid, insoluble in water, but when heated to about 600° it burns in open air with a vivid flame.

Fluorine is a constituent of a very beautiful mineral, well known as fluor spar, which is found in cubic crystals of a green, yellow, or purple colour. Hydrofluoric acid obtained chemically from the mineral is highly volatile and extremely corrosive.

Three of the non-metallic simple substances, chlorine, bromine, and iodine, are connected by the most remarkable analogies. They are marine productions, for chlorine is obtained from common sea-salt and in greater purity from rock-salt, both of which are compounds of chlorine and the metal sodium. When sea-water is evaporated, salt and a substance called bittern remain, which contains a salt whence bromine is separated.

Again, when kelp, the ashes of burnt seaweeds, is purified from the carbonate of soda and the chloride of potassium, a salt is left which is the iodide of potassium, whence iodine is obtained. Iodine is also found in sponges, oysters, and other low sea animals, as well as in certain mineral springs, and sometimes in combination with silver. These three elemental bodies have little affinity for one another, but they combine powerfully with other substances.

Chlorine is a yellowish-green gas, twice as heavy as atmospheric air, with a noxious suffocating smell and astringent taste. It has a powerful bleaching property, and when combined with water, which absorbs twice its volume of the gas, it is used for bleaching linen, in calico-printing, and other arts. The clear solution of chloride of lime is still more in use for the same purpose, as well as for an antidote against contagion and unwholesome smells. Carbon does not burn in chlorine gas, yet it is capable of supporting combustion, for oil of turpentine, phosphorus, thin leaves of tin and copper, and powdered antimony, take fire spontaneously in it. This gas shows its power by the development of intense heat, but not by brilliant light, because the results of its combustion are mostly vapours, or such gases as have a feeble illuminating power; so chlorine differs materially from oxygen in the phenomena of combustion. Mr. Faraday observes, however, that the bleaching powder is analogous to ozone in being an intermediate state, for chlorine is pernicious and violently destructive as a gas, perfectly innocuous and quiescent in common salt and in its other natural combinations, while in the bleaching substances its energy is subdued by art, so as to make it an important agent in various manufactures.

Providentially, chlorine is never found free; but in a combined state it exists in enormous quantities in the salt of the ocean, in salt lakes, brine springs, and in extensive deposits of rock-salt, as well as in organic liquids. It has a strong affinity for hydrogen, and forms muriatic acid. A mixture of these two gases remains inactive in the dark, but explodes in sunshine.

By chemical means chlorine is made to combine with oxygen so as to produce four substances, two of which are gases of such unstable equilibrium and weak affinity that the slightest cause makes them detonate violently; the other two are more stable, though they contain a greater quantity of oxygen. The only combination of chlorine with nitrogen is the most powerful and dangerous explosive compound known. Chlorine combines naturally with sulphur, and with the metals so as to form ores.

Common salt affords a remarkable instance of change of volume by chemical combination. Twenty-four parts in bulk of salt contain 20·7 parts of sodium and 23·3 parts of liquid chlorine; hence by chemical combination a bulk of 44 is compressed into a bulk of 24, yet that great compression is consistent with perfect transparency, crystallized salt being perfectly transparent to light, and more so as regards radiant heat than any other substance. Thus chemical affinity does what no mechanical power could accomplish.

At an ordinary temperature and barometric pressure, bromine is an orange red, extremely volatile fluid, which congeals and becomes brittle at a temperature a little below the zero of Fahrenheit's thermometer, and if combined with water at that degree of cold it crystallizes in octohedral crystals which are permanent even at 50° Fahr. Bromine is very poisonous, corrodes the skin, has a disagreeable taste, and a smell similar to that of chlorine, but more pungent and hurtful. It possesses a powerful bleaching property, does not conduct electricity, and like chlorine a taper will not burn in its gas, though it spontaneously sets fire to phosphorus, and some of the metals. Reasoning from analogy Professor Schönbein believes that chlorine and bromine are not simple substances; he considers them to be ozonides analogous to the peroxides of manganese, lead, &c. He believes chlorine to be the peroxide of murium, and bromine to be the peroxide of bromium. Professor Tyndall's experiments on the absorption and radiation of gases show that the action of these two substances is very different from that of the simple gases.

Iodine is a dark purple solid, crystallized in scales or elongated octohedral plates. It slowly evaporates at ordinary temperatures, and at that of 350° Fahr. it is volatilized into a beautiful violet coloured gas which changes starch into a bright blue, and for that reason a little starch will detect the millionth of a grain of iodine in composition. Iodine is slightly soluble in water, has a hot acrid taste, and although used in medicine it is poisonous when taken in large doses. Its bleaching properties are inferior to those of its congeners, but its chemical combinations are the same. With hydrogen it forms a highly explosive compound, which detonates with the slightest pressure.

These three simple substances are analogous in almost every respect. They all possess a bleaching property, many of their compounds are exceedingly explosive, combustible substances do not burn in their gases, while their gases set fire spontaneously to substances generally reckoned incombustible. Hence, though not combustible, they support combustion, but in a very different manner from oxygen. Chlorine and the gases of bromine and iodine diluted with common air, do not transmit blue and violet light; that is to say, the spectrum of a sunbeam transmitted through them is deprived of its most refrangible coloured rays, and that which remains is crossed by more than a hundred equidistant dark lines; their spectral properties however will be given hereafter. They resemble oxygen in one respect—that when a current of electricity is passed continuously through a glass tube filled with any of these three gases, much attenuated, they slowly combine with the platinum wire of the negative pole of the battery inserted in the tube. The electricity by degrees passes in diminished quantity, and at last ceases altogether, showing that matter, however attenuated, is requisite to conduct it.

According to the experiments of M. Dumas, the volatility of a compound is in the inverse ratio of the condensation of the substances composing it, and simple bodies come under the same law. For example, chlorine is more volatile than bromine, and bromine is more volatile than iodine; hence according to that law, chlorine is the least dense of the three, bromine is intermediate, and iodine is the most dense, which is actually the case: for chlorine is a gas, bromine a liquid, and iodine a solid at ordinary temperatures, which proves that there is a sequence in the intensity of the cohesive forces in this triad.

SECTION II.

ON FORCE, AND THE RELATIONS BETWEEN FORCE AND MATTER.

FORCE is only known to us as a manifestation of divine power which can neither be created nor destroyed. The store of force or energy in nature is ever changing its form of action, its amount never. It may be dispersed in various directions, and subdivided so as to become evanescent to our perceptions; it may be balanced so as to be in abeyance, or it may become potential as in static electricity; but the instant the impediment is removed the power is manifested by motion. Whatever form force may assume it has invariably a compensation or equivalent, whether in the heavens or on the earth. The total sum of the living forces, vis viva, or actual energy of the planets is the same every time they return to the same relative positions with regard to one another, to their orbits and to space, whatever may have been their velocities or mutual disturbances. In the ocean, the energy by which 25,000 cubic miles of water flow over a quarter of the globe in six hours, is exactly equal to the force or energy that makes it ebb during the succeeding six hours. A body acquires heat in the exact proportion that the adjacent substances become cold; and when heat is absorbed by a body, it becomes an expansive energy at the expense of those around it, which contract. Chemical action many miles distant from the electro-magnet, as in telegraphs, is perfectly

+ This not true — Tidal wave moves with this veloc[ity] but there is no current of such velocity equivalent to the dominant chemical action in the battery. The two electricities, positive and negative, are developed in equal proportions, which may be combined so as to produce many changes in their respective relations, yet the sum of the energy of the one kind can never be made in the smallest degree either to exceed or to come short of the sum of the other.

The mechanical energy of machinery or working power is exhausted by the very act of working, and cannot be restored except by the action of other forces. In clock-work, the weight must sink to move the wheel, and when the weight is down, the store of energy is gone, and can only be restored by raising the weight through the expenditure of energy in the human arm, and the expenditure of human energy must be restored by food and rest. The heat given off from the bodies of men and animals is restored by the combustion of the oxygen inhaled during respiration and the carbon of the food, and the light and heat given out by the combustion of fuel, whether in the form of coal or wood, is compensated by the light and heat of the sun stored up in living vegetables. It is this equivalent for force or energy which prevails in every department of nature that constitutes the universal and invariable law of the Conservation of Energy, 'a principle in physics as large and sure as that of the indestructibility of matter or the invariability of gravity. No hypothesis should be admitted nor any assertion of a fact credited, that denies this principle. No view should be inconsistent or incompatible with it. Many of our hypotheses in the present state of science may not comprehend it, and may be unable to suggest its consequences, but none should oppose or contradict it.'[1] Thus, 'there is a definite store of energy in the universe, and every natural change or technical work is produced by a part only of

[1] Professor Faraday.

this store, the store itself being eternal and unchangeable.'[2]

Cohesion is a force which acting at inappreciably small distances unites atoms and molecules of the same kind into solids, liquids, and aëriform fluids, exactly according to the law of the conservation of energy; for it requires the very same amount of force to dissolve their union as to form it. Cohesion varies with temperature both in simple and compound bodies, for metals can be fused and vaporized by artificial heat, and ice becomes water and aqueous vapour as the seasons change from winter to summer.

In solids the force of cohesion is so strong, that their atoms and molecules always retain their respective places; that power is so weak in liquids, that their atoms and molecules are capable of motion among themselves, and in gases and the ethereal medium the atoms are free and have no cohesion whatever. The resistance offered by substances to compression is an equal and contrary force.

The reciprocal attraction between solids and liquids in capillary tubes is a case of cohesion. If a glass tube of extremely fine bore be plunged into a glass of water or alcohol, the liquid will immediately rise in the tube above the level of that in the cup, and the surface of the little suspended column will be a hollow hemisphere. If on the contrary mercury be the liquid, it will not rise so high in the glass tube, and the surface of the little column will be a convex hemisphere. There is a reciprocal attraction between the glass tube and the liquid, and another between the particles of the liquid itself; and the effect is produced by the difference between the two. In the first case the attraction of the glass is greater than that of the liquid, and in the second it is less; hence the water rises higher in the tube than

* not accurate

² Professor Helmholtz.

* Can be proved that liquid rises whenever the attraction of ring of tube for liquid > ½ attraction of liquid for itself

the mercury, and its surface is concave, while that of the mercury is convex. The elevation or depression of the same liquid in different tubes of the same matter is in the inverse ratio of their internal diameters, and altogether independent of their thickness; whence it follows that molecular action is insensible at sensible distances, for when tubes of the same bore are wetted throughout their whole extent with water, mercury will rise to the same height in all of them whatever be their thickness or density, the film of water being sufficient to intercept the molecular action, and to supply the place of a tube by its own capillary attraction. The action of this force is daily seen in the absorption of water by sponges, sugar, salt and other porous bodies, and it is a most important agent in the circulation of fluids in animals and vegetables.'

Every atom of matter is subject to the force of gravitation, but each substance has its own peculiar weight of specific gravity, that is to say, the same bulk of different substances contains different quantities of matter. Since nothing is known of absolute weight it is necessary to have some standard of comparison, and for that purpose pure water at the temperature 39° Fahr. (that of its maximum density) is chosen for solids and liquids; while for gases and vapours atmospheric air at the temperature of sixty degrees of Fahrenheit's thermometer, and a barometric pressure of thirty inches, is assumed as the unit of specific gravity.

The foot-pound, which is the unit of mechanical force as established by Mr. Joule, is the force that would raise one pound of matter to the height of one foot; or it is the impetus or force generated by a body of one pound weight falling by its gravitation through the height of one foot. Now impetus or vis viva is equal to the mass of a body multiplied by the square of the velocity with which it is moving: it is the true measure of work or mechanical labour. For if a weight be raised ten feet, it will require four times the labour to raise an equal weight to forty feet. If both these weights be allowed to fall freely by their gravitation, at the end of their descent, their velocities will be as one to two, that is as the square roots of their heights, but the effect produced will be as their masses multiplied by one and four; but these are the squares of their velocities. Hence impetus or vis viva is equal to the mass multiplied by the square of the velocity. Thus impetus is the true measure of the labour employed to raise the weights, and of the effect of their descent, and is entirely independent of time.

It is well known that iron becomes red-hot by percussion or impetus. The atoms of the iron are thrown into vibration, and these minute motions communicated to the nerves produce the sensation of heat. Now the mechanical labour required to raise the hammer to any number of feet is equal to the weight of the hammer multiplied by that number of feet; but the impetus or mechanical effect of the fall of the hammer is equal to its mass multiplied by the square of the velocity, that is to the vis viva: hence the quantity of heat generated is proportional to the vis viva. The circumstances being the same, if the mass be doubled the amount of heat is doubled; and if the velocity be doubled the amount of heat is quadrupled. If the weight and the perpendicular height through which a body has fallen be known, the quantity of heat generated may be determined. The same amount of heat is generated by the same amount of force, whatever that force may be, whether impetus, friction, or any other.

Dr. Thomson has put in a strong point of view the quantity of heat that might be generated by percussion or impetus. He computed that if by any sudden shock the earth were arrested in its orbit, the heat generated by the impulse would be equal to 11,200 degrees of the centigrade thermometer, even if the capacity of our planet for heat were as low as that of water; it would therefore be mostly reduced to vapour, and should the earth then fall to the sun as it certainly would do, the quantity of heat developed by striking on the sun would be 400 times greater. It is even supposed that the light and heat of the sun are owing to showers of bodies falling on the surface with impetus proportionate to his attraction, for had he been in combustion he would have been burnt out ages ago. The masses of meteoric iron and stone that occasionally fall on the earth show that matter may be wandering in space; the vast zone of smaller bodies that in their annual revolutions round the sun come within the earth's attraction in August and November, when thousands of them take fire and are consumed on entering our atmosphere, show that a great amount of matter of small dimensions exists within our own system. Much may be beyond it which drawn by the sun's attraction may fall on his surface.

When a body is heated, it absorbs one part of the heat; the other part raises its temperature. The part absorbed increases the bulk or volume of the body, the expansion being the exact measure, or mechanical equivalent of the heat absorbed. In fact the coefficient of expansion is the fractional part of the expansion in length, surface, or volume of the body when its temperature is raised one degree. When the body is cooled, its volume is diminished, and then the contraction is an exact measure, or mechanical equivalent of the heat given out, and thus expansion and contraction are correlatives with and represent heat and cold.

Specific heat is the quantity of heat required to raise a given bulk or a given weight of a body a given number of degrees. In the one case it is distinguished as the specific heat for a constant volume, in the other for a constant weight.

Although the specific heat of a substance remains the same, its sensible and absorbed heat may vary reciprocally to a great extent.

As there can be no direct measurement of heat indedendent of matter, its mutations and action on matter are the sole means we have of forming our judgment concerning its agency in the material world.

Mr. Joule has proved that the quantity of heat requisite to raise the temperature of a pound of water one degree of the centigrade thermometer is equivalent to the mechanical work or force that would raise the same mass of water to the height of 1,389 feet. This is the unit, or mechanical equivalent of heat.

In fact, for every unit of force expended in percussion, friction, or raising a weight, a definite quantity of heat is generated; and conversely, when work is performed by the consumption of heat, for each unit of force gained, a unit of heat disappears. For since heat is a dynamical force of mechanical effect, there must be an equivalence between mechanical work and heat as between cause and effect. That equivalence is a law of nature. The mechanical force exerted by the steam engine is exactly in proportion to the consumption of heat, neither more nor less; for if we could produce a greater quantity than its equivalent we should have perpetual motion, which is impossible. When steam is employed to perform any work, the temperature of the steam is lowered; the heat that disappears is transformed into the force that performs the work, and is exactly proportional to the work done, and vice versâ.

The heat which is the motive force in the steam engine is due to the chemical combination of the carbon of the fuel with the oxygen of the atmosphere. A pound weight of coal when consumed in one of our best steam engines produces an effect equal to raising a weight of a million of pounds a foot high, yet marvellous as that is, the investigations of recent years have demonstrated the fact, that the mechanical energy resident in a pound of coal and liberated by its combustion is capable of raising to the same height ten times that weight.[3] The quantity of coal existing in the whole globe is believed to be inexhaustible, hence the energy in abeyance is incalculable. The chemical energy continually and actually exerted in the great laboratory of nature is greater than that which maintains the planets in their orbits.

The act of the combination of the atoms of carbon and oxygen in combustion is 'now regarded exactly as we regard the clashing of a falling weight against the earth, and the heat produced in both cases is referable to the same cause;'[4] so chemical combination in combustion is only a particular case of falling bodies. *Drummond's light, the most brilliant of artificial illuminations, is produced by a simultaneous shower of the atoms of oxygen and hydrogen gas upon lime; and platinum, the least fusible of metals, is vaporized by a similar shower from the oxy-hydrogen blowpipe, and thus impetus generates both light and heat, for although the atoms are too small to admit of an estimation of their individual vis viva, there can be no doubt that like causes produce like effects.

In what manner or under what form magnetism and electricity exist when quiescent in matter we know not, but the compass needles show that numerous lines of magnetic force, subject to periodic and secular variations, perpetually traverse the earth and the ocean; and that waves of magnetic force occasionally sweep rapidly over great tracts of the globe. These phenomena would seem to stand in some periodic connection

[3] The address of the president, Sir William Armstrong, C.B., to the British Association at Newcastle-on-Tyne, 26th August, 1863.

[4] J. Tyndall, Esq., on Force.

* chemical collision of O + H atoms with each other - not with the lime -

with the solar spots. Professor Lamont of Munich has discovered that a permanent and regular current of electricity is propagated parallel to the equator all over the earth, and another similar to it in the atmosphere. Besides these, there are currents of electricity in the surface of the earth, sometimes in one direction and sometimes in another, which decrease with the depth; and M. Lamont conceives that this electric system is the cause of terrestrial magnetism. Electricity of intense power and inappreciable quantity certainly exists in abeyance in the atmosphere and in all terrestrial matter till the equilibrium between the antagonist forces be disturbed, and then it bursts forth with terrific violence in the lightning flash and stunning crash of thunder. Since it requires electricity equivalent to that in activity during a thunderstorm to form one drop of water, what must that power have been which the Omnipotent wielded when he created that deep over the face of which 'darkness brooded.'

Electricity, though the most formidable power in nature, is made available to man by the voltaic battery, and by the electro-magnetic induction apparatus, in the battery of which it is generated by the chemical action of dilute sulphuric acid on zinc. The positive and negative electricities thus produced pass in opposite directions through the two conducting wires of the machine by a continuous transmission of force or vibration from atom to atom, a circulation that is accompanied by a continual development of heat in overcoming the resistance it meets with in the wires. The electricity decreases as the heat increases, and vice versâ; the action is reciprocal. Thus electricity is merely a transmission of force. Mr. Joule has proved that the quantity of heat produced in a unit of time is proportional to the strength of the current, whatever may be its direction, and that its power to overcome resistance is as the square of the force of the current. The force is exactly in proportion to the chemical action which produces it, and that is measured by the quantity of zinc consumed in the battery. Thus chemical action produces electricity, and conversely electricity is a powerful agent in the chemical composition and decomposition of matter.

The light and heat of the electric spark are intense though instantaneous; but a powerful induction apparatus like Ruhmkorff's gives so rapid a succession of sparks that the light and heat are sensibly continuous and of great intensity. The light and heat, powerful as lightning itself, are produced by the combined currents of two batteries, each consisting of fifty Bunsen elements of moderate size. This formidable united current passes through a circuit of thick copper wire coated with silk thread, with an intensity of perpetually renewed heat that no substance can resist. When the copper conducting wires are fitted with charcoal terminals and brought near to one another, the dazzling lights emanating from each pole combine in one blaze of insupportable brilliancy. The most refractory substances, silica, alumina, iron and platinum, when placed between the poles, immediately melt like wax, and volatilize. Charcoal is so good a conductor of electricity that when the terminals are in contact they complete the circuit, and neither light nor heat appear. Air and glass are non-conductors, yet the spark has passed through several inches of air and perforated a mass of glass two inches thick. A long electric spark combines or decomposes a greater quantity of gas or vapour than a short one, and for a given induction apparatus and induction current, M. Perrot has shown that there exists a length of spark corresponding to a maximum chemical action.

Professor Seebeck of Berlin discovered that electric currents are produced by the partial application of heat to a circuit formed of two solid conducting substances as antimony and bismuth soldered together,—another proof of the correlation of heat and electricity.

There cannot be a doubt that the atoms of a conducting wire are in motion, and that they successively take definite and momentary positions during the passage of an electric current, after which they return successively to their normal state. When electricity is invariably sent from the same pole of an inductive apparatus through the wire of a telegraph, in a very short time the wire is torn or divided into small sections, which destroy its continuity; but when the electricity is sent from each pole alternately, the conducting wire is not injured. As each atom of the wire has its own electricity, this seems to indicate that during the successive transits of the same kind of electricity, the pole of each individual atom is attracted more and more in the same direction, till at last they no longer return to their normal state, the cohesive force is overcome, and a rupture takes place, the more readily if there be any imperfection in the wire. Since the electricity from the other pole of the machine would have the same effect, but in the contrary direction, an alternate motion in the atoms must maintain the continuity of the wire.

A closed current of electricity or magnetism is accompanied by a simultaneous current of the opposite force in the tangential direction equal in quality and intensity. Thus the electric and magnetic currents, which are merely transmissions of energy, differ by moving at right angles to one another; their effects are alike, yet they are not identical.

The amount of the chemical action of light has been determined by Professor Roscoe to be directly proportional to the intensity of the light; and when the light is constant the amount of action is exactly proportional to the time of exposure. It appears that equal volumes of chlorine and hydrogen explode in sunshine, but combine slowly in shade; and as the combined gases are absorbed by water as soon as combined, the gradual diminution of the volume of the mixed gases during the time of absorption is a measure of the amount of action exerted by the light.

Professor Wm. Thomson has computed, by the aid of Poullet's data of solar radiations and Mr. Joule's mechanical equivalent of heat, that the mechanical value of the whole energy, active and potential, of the disturbances kept up on the ethereal medium by the vibrations of the solar light in a cubic mile of our atmosphere, is equal to 12,050 times the unit of mechanical force: that is to say, twelve thousand and fifty times the force that would raise a pound weight of matter to the height of one foot. The sensible height of the atmosphere is about forty miles, whence some idea may be formed of the vast amount of force exerted by the sun's light within the limits of the terrestrial atmosphere. The green mantle which clothes the earth proves under a beautiful form the influence of light on the organic world.

It has been proved that at *any given* fixed temperature the amount of light and heat absorbed and that which is emitted remains constant for *all bodies.* The greater the amount absorbed, the greater the amount radiated. The molecules or atoms of the bodies in consequence of the law of resonance emit those ethereal undulatory motions which have been previously impressed upon them, as a musical instrument resounds in answer to the note impressed upon it. The whole is referable to molecular or atomic motion, for in absorption the vibrations of the ether are communicated to the atoms, and in radiation, the vibrations are returned again to the ether. This principle is known as the law of exchange.[5]

Matter has a decomposing and an elective power with regard to both radiant light and heat; most coloured bodies, such as flowers, green leaves, dyed cloth, &c., though seen by reflection, owe their colour to absorption. The light by which they are seen is reflected, but it is not in reflection that the selection of the rays is made which causes the objects to appear coloured. When light falls upon red cloth, a small portion is reflected at the outer surfaces of the fibres, and this portion, if it could be observed alone, would be found to be colourless. The greater portion of the light penetrates into the fibres, when it immediately begins to suffer absorption on the part of the colouring matter. On arriving at the second surface of the fibre, a portion is reflected and a portion passes on, to be afterwards reflected from, or absorbed by, fibres lying more deeply. At each reflection the various kinds of light are reflected in as nearly as possible the same proportion, but in passing across the fibres while going and returning they suffer very unequal absorption on the part of the colouring matter; so that in the aggregation of the light perceived the different components of white light are present in proportions widely different from those they bear to each other in white light itself, and the result is a vivid colouring.

In certain substances however, as gold and copper, the different components of white light are reflected with different degrees of intensity, and the light becomes

[5] The Law of Exchange was independently proved by Messrs. Tyndall, Kirchhoff, Angström, and Balfour Stewart.

coloured by these reflections. Gold is yellow by reflection; red cloth is red by absorption. In the same sense, physically speaking, in which the red cloth is red, gold is not yellow but blue or green; such is in fact the colour of gold by transmission through gold leaf, and therefore gold is greenish blue by absorption. In this case we see that while the substance copiously reflects and intensely absorbs rays of all kinds, it more copiously reflects the less refrangible rays with respect to which it is more intensely opaque. In general absorption and radiation are independent of colour.

There is a vast diversity in the property which substances possess with regard to the transmission of radiant light and heat; glass, for instance, transmits light abundantly, but is impervious to heat from non-luminous sources; while other substances, which are altogether opaque to light, transmit heat copiously, as the bisulphide of carbon, which of all liquids is the most diathermic, while water in all its forms is almost impervious to heat.

Sir William Herschel discovered that invisible rays of high heating power exist beyond the red end of the solar spectrum, and Mr. Tyndall has shown that the reason of a substance being impervious to the light of the most brilliant flame and at the same time pervious to these extra red rays is, that the intercepted rays of light are those whose periods of recurrence coincide with the periods of oscillation possible to the atoms of the substance in question. The elastic forces which separate these atoms are such as to compel them to vibrate in definite periods, and when their periods synchronize with those of the ethereal waves, the latter are absorbed. Thus transparency in liquids as well as in gases is synonymous with *discord*, while opacity is synonymous with *accord* between the periods of the waves of ether and those of the body on which they impinge.

All ordinary transparent and colourless substances owe their transparency to the discord which exists between the oscillating periods of their molecules and those of the waves of the whole visible spectrum. The general discord of the vibrating periods of the molecules of *compound bodies* with the light-giving waves of the spectrum may be inferred from the prevalence of the property of transparency in compounds, while their greater harmony with the extra red periods is to be inferred from their opacity to the extra red rays. Water illustrates this transparency and opacity in the most striking manner. It is highly transparent to the luminous rays, which demonstrates the incapacity of its molecules to oscillate in periods which excite vision. It is as highly opaque to the extra red oscillations, which proves the synchronism of its periods with more of the longer waves. If, then, to the radiation from any source water shows itself to be eminently or perfectly opaque, it is a proof that the molecules whence the radiation emanates must oscillate in extra red periods.

It has been already mentioned that many substances which transmit radiant heat freely radiate badly, and vice versâ. Rock-salt is extremely permeable to radiant heat but radiates feebly; the reason according to Mr. Tyndall is, that the motion of the molecules of the salt, instead of being expended on the ether between them and then communicated to the ether external to the mass, is transmitted freely from molecule to molecule.

Alum is exactly the reverse. Mr. Balfour Stewart proved that alum is an excellent radiator, and Mr. Tyndall proved it to be a very bad conductor, imparting freely and with ease the motion of its molecules to the external ether, and 'for that very reason it finds difficulty in transferring the motion from molecule to molecule. The molecules are so constituted that when one of them approaches its neighbour, a swell is produced in the intervening ether; this motion is immediately communicated to the ether outside, and is thus lost for the purposes of conduction.'[6]

Melloni had investigated the laws of the radiation and absorption of radiant heat in solid and liquid matter; but its radiation and absorption by gases and vapours was unknown previous to the experiments of Mr. Tyndall.

The apparatus employed was a horizontal brass tube four feet long, between two and three inches in diameter, polished inside, and closed air-tight at each end by a plate of rock-salt, which transmits more heat than any other substance. The air could be pumped out of the tube by one pipe, and the gas or vapour for the experiment introduced by another. Close to one end of the brass tube there was a thermo-electric pile connected with its goniometer. On each side of this arrangement there was a vessel of water kept at the boiling point. These two vessels were so placed that when the rays of heat from one of them passed through the exhausted tube, and fell upon one face of the thermo-electric pile, their effect was so neutralized or balanced by the rays of heat falling on the opposite face of the pile from the other, thus the needle of the goniometer was steadily maintained at zero, and its deflection instantly showed the absorbent effect produced by any gas or vapour that was admitted into the exhausted tube.

Since aqueous vapour has a very exalted absorbent power, a gas or vapour was rendered perfectly dry before its absorbent capacity was determined. For that purpose the pipe that introduced it into the brass experimental tube was so constructed that the gas had first to pass over fragments of pumice-stone wet with strong sulphuric acid, which absorbed its moisture and dried it. Common atmospheric air, however, was not

[6] Tyndall on Heat.

only dried in this manner, but it was deprived of its carbonic acid by passing over caustic potash, and many other precautions were taken to prevent the possibility of error.

Under the ordinary pressure of the atmosphere, when the experimental tube was exhausted, the needle of the goniometer stood at zero, but as soon as pure dry atmospheric air was introduced into the tube its absorption caused the needle to move from zero to 1°.

The tube was again exhausted; the needle stood at zero, but was deflected from zero to 1° as soon as the tube was filled with oxygen. A similar experiment was made with nitrogen and hydrogen with the same result. Thus, dry air and the elementary gases, oxygen, nitrogen, and hydrogen, have the same absorptive power, and consequently they all deflected the needle of the goniometer one degree. The whole amount of radiant heat that passed through the exhausted tube produced a deflection of 71° 5′; hence taking as unit of heat the amount that would deflect the needle one degree, the number of units expressed by 71° 5′ is 308, consequently the absorption of each of these four gases amounts to $\frac{100}{308}$, or 0·3 per cent. The most delicate tests could not show any difference between the three first, but Professor Tyndall had reason to believe that hydrogen has the lowest absorptive power of all gases and vapours, though he was unable to express the amount. The absorptive power of all four is very much less than that of every other gas or vapour, and invariably deflects the needle to 1°, which thus becomes the unit of comparison.

Olefiant gas, the most luminous of the constituents of coal gas, possesses the highest absorptive power of the permanent gases. When sent into the exhausted tube it deflected the needle of the goniometer from 0° to 70° 3′, which is equivalent to 290 units. The whole heat that passed through the exhausted tube before the gas was admitted produced a deflection of 75° or 360 units, consequently more than $\frac{7}{10}$ths or 81 per cent. of the whole heat was cut off by the olefiant gas. Such opacity to heat in so transparent a gas is quite marvellous. A current of it was sent into the open air between the thermo-electric pile and one of the sources of heat, and although it was perfectly invisible, it instantly deflected the needle of the goniometer from 0° to 41°.

In order to ascertain the relation between the density of the gas and the quantity of heat extinguished or absorbed, an ordinary mercurial gauge was attached to the air-pump. The experimental tube was exhausted, and the needle of the goniometer stood at zero. Then, from a graduated glass vessel, measures of olefiant gas, each amounting to the $\frac{1}{50}$th of a cubic inch, were successively sent through the drying pipe into the exhausted tube. The amount of the heat absorbed and the depression of the mercurial column corresponding to each measure of gas as it was introduced, was registered from one to fifteen measures. This experiment showed that for very small quantities of gas, the absorption is exactly proportional to the density or tension. One measure of the gas only produced a depression of the mercurial column amounting to the $\frac{1}{367}$th part of an inch, or about the $\frac{1}{15}$th of a millimetre.

In many of the vapours of volatile liquids, the preceding law only prevails to a certain amount of pressure differing in each case, beyond which increase of tension produces diminished effects. In sulphuric ether the change begins at the eleventh term.

In bisulphide of carbon the law changes after the sixth measure, &c.

In order to adapt the apparatus for experiments on coloured gases, a glass experimental tube 2 ft. 9 in. long, and 2 ft. 4 in. in diameter, was substituted for the brass tube, and, instead of boiling water, sources of radiant heat having a constant temperature of 270° Cent. were adopted.

The following table shows the absorption of a number of gases at a common pressure or tension of one atmosphere.

Dry air	1	Carbonic acid	90
Oxygen	1	Nitrous oxide	35·5
Nitrogen	1	Sulphuretted hydrogen	390
Hydrogen	1	Marsh gas	403
Chlorine	39	Sulphurous acid	710
Hydrochloric acid	62	Olefiant gas	970
Carbonic oxide	90	Ammonia	1195

The absorptive power of ammonia is so great, that although as transparent in the glass tube as if it had been a vacuum, a length of three feet of it would be perfectly impervious or black to the heat here employed, yet even this does not express the energy which it exhibits under one inch of pressure.

When the relative absorptive actions of gases and vapours is compared, it must be under the same amount of pressure. Hence, for one inch of tension, the absorptive action of

Dry air	= 1	Carbonic oxide	750
Oxygen	1	Nitric oxide	1590
Nitrogen	1	Nitrous oxide	1860
Hydrogen	1	Sulphide of hydrogen	2100
Chlorine	60	Ammonia	7260
Bromine	160	Olefiant gas	7950
Hydrochloric acid	1005	Sulphurous acid	8800

Thus, for a tension of an inch of mercury, the absorption of ammonia exceeds that of air more than 7000 times; the action of olefiant gas is 7950 times, and that of sulphurous acid 8800 times, greater than the absorption of air.

The effect produced by $\frac{1}{30}$th of an inch of tension of air and the elementary gases is equivalent to that produced by one inch in the others, so the unit representing the absorption of these four gases is only the $\frac{1}{30}$th part of the unit in the preceding table.

It appears from the preceding tables of comparative absorption that chlorine, a highly-coloured gas with a specific gravity of 2·45, has an absorptive power expressed by 39° under the pressure of one atmosphere, while, at the same tension, hydrochloric acid, a chemical compound of chlorine and hydrogen which is perfectly transparent, with a specific gravity of only 1·26, has an absorptive action amounting to 62, whence it appears that the chemical change which renders chlorine more transparent to light, makes it more opaque to obscure heat. Again, bromine, which is far less permeable to light than chlorine, and has a specific gravity of 5·54, has an absorptive power of 160 under a tension of one inch; while hydrobromic acid, which is perfectly transparent to light, has an absorptive action for obscure heat amounting to 1005. This is a striking instance of transparency to light and opacity to heat being produced by the very same chemical art.

The enormous difference between the absorptive power of compound and simple gases and vapours is ascribed to their atomic structure; in fact the radiant and absorptive powers augment as the number of atoms in the compound molecule augments. The three elementary gases are formed of simple atoms, the compound gases and vapours consist of different kinds of atoms chemically united into groups. Both are free to receive the vibratory motions of the ether which constitute heat; but single atoms must produce a less effect than when a number of them are united into a molecule. The atoms are loaded by their chemical union, which offers a greater surface of resistance to the vibrations of heat, and renders the motion of the molecule more sluggish and more fit to accept the slowly recurrent waves of the obscure heat that strike upon it.

Thus when atoms of hydrogen and nitrogen are mixed in the proportion of three to one, the absorption of the mixture is represented by unity; but when they are chemically united in ammonia, the absorption is 1190 times as great. Atoms of hydrogen and oxygen mixed in the proportion of two to one absorb very feebly; when chemically united into a molecule of aqueous vapour the absorptive power is enormous. The absorptive power of nitrous oxide, a chemical compound of oxygen and nitrogen, exceeds that of dry air 250 times; a convincing proof that the atmosphere is a mixture and not a compound gas. Olefiant gas at five inches of tension absorbs 1000 times that of its constituent hydrogen. In fact all the compound gases and vapours far surpass the simple elementary gases and dry atmospheric air in their capacity for absorption.

Chlorine and bromine, which have so many singular properties in common, have this peculiarity also, that though simple substances respectively formed of homogeneous atoms, their absorptive powers are similar to those of compound substances, for the absorptive power of chlorine is 60 times that of the elementary gases, and that of bromine 160 times. This high absorptive power is ascribed by Professor Tyndall to their atoms being united into groups which act powerfully as oscillating systems, instead of the feeble action of single atoms.

Ozone is an analogous instance of the presumed union of homologous atoms into oscillating groups. By comparing the absorptive effect of ozonized oxygen obtained from the electric decomposition of water with that of the same oxygen deprived of its ozone by passing it over a very strong solution of iodide of potassium, Professor Tyndall found that ozonized oxygen possesses an absorption force 136 times greater than that of pure oxygen. The quantity of ozone producing this astonishing effect was too small even to admit of estimation, far less of measurement. This result induced Professor Tyndall to believe that ozone is produced by the packing of the atoms of elementary oxygen into oscillatory groups; and that heating dissolves the bond of union and allows the atoms to swing singly, thus disqualifying them from either intercepting or generating the motion which as systems they were competent to intercept and generate.

The indefinitely small and invisible constituents of perfumes of plants and flowers are proved to be compound bodies by their absorptive and radiating properties. The dried leaves of a flower or aromatic plant such as thyme were stuffed into a glass tube 18 inches long and a quarter of an inch in diameter. It was then inserted between the drying pipe of the machine and the experimental glass tube, which was exhausted, and the needle of the goniometer stood at zero. Then when the air admitted into the drying pipe passed over the thyme and carried its aroma into the experimental tube, the needle was deflected, and from thence the absorption of the thyme was computed to be 33 times greater than that of the air which carried it. By the same process it was found that the absorption of peppermint was 34 times, spearmint 38 times, lavender 32 times, and wormwood 41 times greater than that of the dry air, which was unity as usual. When small equal squares of bibulous paper rolled into cylinders and moistened with an aromatic oil, were substituted for the dried herbs, the absorption corresponding to the deflection of the needle was for dry air, equal to 1,—

Patchouli	30	Orange	67
Sandal wood	32	Thyme	68
Geranium	33	Rosemary	74
Oil of cloves	33·5	Oil of laurel	80
Otto of roses	36·5	Chamomile flowers	87
Bergamot	44	Spikenard	355
Lavender	60	Anise seed	372
Lemon	67		

The absorption of thyme and lavender shows how much aroma is lost when plants are dried. So great is the absorption of heat, that the perfume of a flower-bed may be more efficacious than the entire oxygen and nitrogen of the atmosphere above it.

The enormous absorption and consequently radiating power of the perfumes of plants and flowers is a proof that their constituent parts are molecules and not simple atoms, incredible as it may seem. The absolute weight of the substances producing these wonderful effects is unknown, but there must be great differences: some perfumes are carried to vast distances, others are less volatile, and that of mignonette was remarked by Dr. Wollaston to be absolutely so heavy that it was quite as powerful below a balcony containing a box of that plant, as in the balcony itself.

The perfumes during the experiments adhered to all parts of the apparatus so pertinaciously, that after a continued stream of dry air had been pumped through the tube till the exhaustion seemed to be complete and the needle stood at zero, after a few minutes' repose, the residue of the perfume came out so powerfully from the crannies of the apparatus as almost to restore the original deflection. 'The quantities of those residues must be left to the imagination to conceive. If they were multiplied by billions they probably would not obtain the density of the air.'

The absorptive power of the odour of musk was 72 or 74 times that of the air that conveyed it into the experimental tube; the quantity that produced it was quite inappreciable, yet the perfume was so persistent that the pieces of the apparatus through which it had passed had to be boiled in a solution of soda before they were fit for other experiments.

The absorption of many gases and vapours having been determined, their radiation was measured by a

* why should it seem incredible?

very simple arrangement. The thermo-electric pile was raised on a stand with a screen of polished tin in front of it. A heated copper ball in a perforated ring on a low stand was placed behind the screen; all direct radiation from the ball was thus cut off, but the heated air rising in a column above the screen radiated its heat on the pile and deflected the needle of the goniometer 60° when the ball was red-hot; but the radiation of the hot air was neutralized by another source of radiant heat on the opposite side of the pile which kept the needle steadily at zero. Then a purified gas or vapour conveyed by a pipe into the perforated ring which held the ball rose mixed with the heated air above the screen, but the radiation of the gas or vapour alone was shown by the deflection of the needle, because that of the air was compensated. With this apparatus Professor Tyndall proved that the amount of the absorption of each gas and vapour is exactly equal to the amount of its radiation. He has shown that this result is a necessary consequence of the dynamical nature of heat. For as no atom or molecule is capable of existing in vibrating ether without accepting a portion of the motion, the very same quality whatever it may be that enables it to do so, must enable it to impart its motion to still ether when plunged into it. 'Hence from the existence of absorption we may on theoretic grounds infallibly infer a capacity for radiation; from the existence of radiation we may with equal certainty infer a capacity for absorption, and each of them must be regarded as the measure of the other.' This reasoning, founded simply on the mechanical relations of the ether and the atoms immersed in it, is completely verified by experiment.

Hitherto the absorption and radiation of heat by the same thickness of different gases and vapours have been compared with each other, but in a recent series of experiments Mr. Tyndall has compared the action of different thicknesses of the same gas or vapour on radiant heat. The experiments extend from a thickness of 0·01 of an inch to that of 49·4 inches. The instrument employed for ascertaining the action of the smaller thickness was a horizontal hollow cylinder closed at one end by a plate of rock-salt. A second cylinder was fitted into this with its end also closed by a plate of rock-salt. This cylinder moved within the other like a piston, so that the two plates of rock-salt could be brought into flat contact with one another, or could be separated to any required distance, and the distance between the plates was measured by a vernier. At one end of the cylinder there was a source of constant heat, and the differential goniometer already described at the other. With this apparatus Mr. Tyndall found that olefiant gas maintains its great superiority over the other gases in absorptive power at all thicknesses. A layer of that gas not more than 0·01 of an inch thick intercepted about one per cent. of the total radiation. This great absorption corresponded to a deflection of 11° of the needle of the goniometer, and such was the delicacy of the apparatus that it would be possible to measure the action of a layer of this gas of less thickness than a sheet of writing paper. A layer of olefiant gas two inches thick intercepts nearly 30 per cent. of the entire radiation. A shell of olefiant gas two inches thick surrounding our globe would offer no appreciable hindrance to the solar rays in coming to the earth, but it would intercept, and in great part return, 30 per cent. of the terrestrial radiation; under such a canopy the surface of the earth would probably be raised to a stifling temperature.

The apparatus for measuring the action of the greater thicknesses of gas was a hollow brass cylinder 49·4 inches long, closed at both ends by plates of rock-salt, and divided internally into two compartments or chambers by a third plate of rock-salt movable in the interior; the source of heat being at one end and the differential goniometer at the other.

Carbonic oxide and carbonic acid are pervious to a vast majority of the rays of radiant heat. When the cylinder was filled with carbonic oxide gas and so divided, by moving the internal plate of rock-salt, that a stratum of the gas 8 inches long was next to the source of heat, and that 41·4 inches long farthest from it, the 8 inches of gas intercepted 6 per cent. of the whole radiation. But when the plate of rock-salt was moved till the column 41·4 inches long was next to the source of heat, and that of 8 inches farthest from that source, or behind the long one, the absorption of the 8 inches was sensibly zero. In like manner eight inches of carbonic acid gas when in front of a column of 41·4 inches of the same gas absorbed 6¼ per cent. of the whole radiation, while placed behind that column the effect was nearly zero. The reason is that when the 8-inch stratum is in front, it stops the main portion of the rays which give it its thermal colours,[7] while placed behind these same rays have been almost wholly withdrawn, and to the remaining 94 per cent. of the radiation the gases are sensibly permeable.

It is inferred from an extension of this reasoning that the sum of the absorptions of the two chambers taken separately must always be greater than the absorption effected by a single column of the gas of a length equal to the sum of the two chambers; this conclusion is illustrated in a striking manner by the experiments. It is also found that when the mean of the sums of the absorptions is divided by the absorption of the sum, the quotient is sensibly the same for all gases. It may farther be inferred that the sum of the absorptions

[7] Analogous to transparent media which receive their colour by stopping or absorbing some of the colours of white light and transmitting others.

must diminish and approximate to the absorption of the sum as the two chambers become more unequal in length, and that the sum of the absorptions of the two chambers is a maximum when the medial plate of rock-salt divides the long tube into two equal parts.

When air enters an exhausted tube it is heated dynamically by the collision of its particles on the sides of the tube as it rushes in to fill the vacuum; and when the tube is exhausted again by the air pump, chilling is produced by the application of a portion of the heat of the air to generate vis viva. This dynamic principle occurred in some of the experiments, and was dexterously adopted and applied to the solution of a striking and unprecedented problem: 'To determine the radiation and absorption of gases and vapours *without any source of heat external to the gaseous body itself.*'

The two external sources of heat being therefore dispensed with in the absorptive apparatus, the thermo-electric pile was presented to the cold glass tube which was exhausted, and the needle of the goniometer stood at zero. Nitrous acid on entering the exhausted tube became heated and radiated its heat upon the adjacent face of the pile which deflected the needle of the goniometer through 28° in the direction that indicates absorption. As the heat of the gas became gradually exhausted, the needle returned slowly to zero. The pump was now worked, the rarefied gas in the tube was chilled, and the adjacent face of the pile gradually poured its heat on the chilled tube till the temperature of the pile was so much lowered, that the needle was deflected 20° on the negative side of zero, that is on the side denoting radiation.

When olefiant gas entered the exhausted tube, the needle showed an absorption of 67°, and when the gas was pumped out again, the needle showed a radiation amounting to 41°. When the gas was then pumped out, very dry atmospheric air was introduced into the tube,—the needle pointed to 59° indicating absorption; and when it was pumped out again the needle swung to nearly 40° on the other side of zero, indicating radiation. Remembering that the radiation and absorption of dry air only produce a deflection of 1°, it is evident that the preceding great deflection of the needle is entirely owing to the action of the small residue of olefiant gas that remained in the exhausted tube. In order to ascertain how much the quantity of a gas or vapour might be reduced before its action became insensible, the vapour of boracic ether, which has the greatest absorptive energy, was chosen.

The mercurial gauge for measuring the pressure or tension of the vapour already mentioned remained attached to the apparatus. When one-tenth of an inch of the vapour of boracic ether was admitted into the exhausted tube, the barometer stood at 30 inches: hence the tension of the vapour within the tube was the $\frac{1}{300}$th part of an atmosphere. Dynamically heated by dry air the radiation of the vapour produced a deflection of 56°. Again the tube was exhausted to 0·2 of an inch and the quantity of vapour was thereby reduced to $\frac{1}{150}$th of its first amount; the needle was allowed to come to zero, and the residue of the vapour produced a deflection of 42°. The pump was again worked till a vacuum of 0·2 of an inch was obtained, this residue containing of course the $\frac{1}{150}$th of the quantity of ether present in the tube; and on dynamically heating the residue, its radiation produced a deflection of 20°.

Thus it is evident that the tension of the ether in these experiments was continually diminished by the 0·2 of an inch, consequently its quantity was continually diminished by its $\frac{1}{150}$th part, accompanied by a corresponding decrease in the deflections of the needle. The final result of this process showed that the radiation of an amount of vapour in the tube possessing a tension of less than the thousand millionth of an atmosphere is perfectly measurable. The temperature imparted to this infinitesimal quantity of matter did not exceed 0·75 of a centesimal degree. The molecules which constituted this intensely attenuated vapour, though inconceivable, had as true an existence as the suns which constitute the star-dust of the nebulæ. 'A platinum wire raised to whiteness in a vacuum by an electric current, becomes comparatively cold in a second after the current has been interrupted; yet that wire, while ignited, was the repository of an immense amount of mechanical force. What has become of this? It has been conveyed away by a substance so attenuated that its very existence must for ever remain an hypothesis. But here is matter that we can weigh, measure, taste, and smell; that we can reduce to a tenuity which, though expressible by numbers, defeats the imagination to conceive of it. Still we see it competent to arrest and originate quantities of force which on comparison with its own mass are almost infinite, a small fraction of this force causing the double needle of the galvanometer to swing through considerable arcs. When we find ponderable matter producing these effects, we have less difficulty in investing the luminiferous ether with those mechanical properties which have long excited the interest and wonder of all who have reflected upon the circumstances involved in the undulatory theory of light.'

The dynamical principle was next applied to determine the radiation of a gas through itself; or through any other gas having the same period of vibration. For that purpose Mr. Tyndall made use of the hollow cylinder 49·4 inches long already mentioned, closed at both ends by plates of rock-salt, and divided internally into two chambers by a movable plate of the same substance.

All sources of heat being dispensed with, the chamber next the voltaic pile contained the gas which was to act as an absorber, and the more remote as a radiator.

Heat is evolved in air when its motion is arrested; on entering an exhausted tube, the more rapid the motion the greater the heat. Both chambers of the cylinder were at first filled with the vapour to be examined, the usual pressure being the $\frac{1}{60}$ part of an atmosphere. But the vapour entered so slowly, and the quantity was so small that the radiation due to the warming of the vapour by its own collision was insensible. The needle of the goniometer being at zero, dry air was allowed to enter the chamber most distant from the pile; this air became heated dynamically by the collision of its particles against the sides of the tube, communicated its heat to the vapour, and the vapour immediately discharged the heat thus communicated to it against the pile. This case not only resembles, but is actually of the same mechanical character as, that in which a vibrating tuning fork is brought into contact with a surface of some extent. The fork, which before was inaudible, becomes at once a copious source of sound. What the sounding board is to the fork, the compound molecule is to the elementary atom. The tuning fork vibrating alone is in the condition of the atom radiating alone; the sound of the one and the heat of the other being insensible. But in association with sulphuric or acetic ether vapour the elementary atom is in the condition of the tuning fork applied to its sounding board, communicating motion to the luminiferous ether through the molecules, as the fork through the board communicates its motion to the air.

Mr. Tyndall's experiments show the great opacity of a gas to radiations from the same gas, and may likewise show the remarkable influence of attenuation in the case of vapour. The individual molecules of a vapour may be powerful absorbers and radiators, but in their strata they constitute an open sieve through which a great quantity of radiant heat may pass. In such thin strata, therefore, the vapours as used in the experiments were generally found far less energetic than the gases, while in thick strata the same vapours showed an energy greatly superior to the same gases, but the gases were always employed at a pressure of one atmosphere.

Lastly Mr. Tyndall examined the diathermancy of the liquids from which his vapours were derived, and the result leaves not a doubt that both absorption and radiation are phenomena irrespective of aggregation. If any vapour is a strong absorber and radiator, the liquid from whence it comes is also a strong absorber and radiator.

Perfectly dry pure air is as pervious to light and heat as a vacuum itself; consequently, if the atmosphere was quite pure and dry, the rays of the sun would fall on the earth with unmitigated force during the day, and would be radiated back again and dissipated in space during the night to the destruction of vegetation. But the earth is protected from these extremes by the absorptive power of aqueous vapour, which is always present more or less in the atmosphere; even when the air is so transparent that distant objects seem to be near, it is loaded with vapour in an elastic invisible state, which a change of temperature may condense into cloud or precipitate in rain.

The absorptive power of aqueous vapour was determined by placing tubes containing fragments of glass moistened with water between the drying apparatus and the experimental glass tube of the instrument, so that perfectly pure dry air in passing over the wet fragments of glass carried a portion of aqueous vapour with it into the exhausted experimental tube, and the deflection of the needle of the goniometer showed that the absorptive power of the aqueous vapour exceeded that of the dry air 80 times. Now since in the atmosphere there is one molecule of aqueous vapour with an absorptive power of 80 for every 200 atoms of oxygen and nitrogen whose absorptive power is 1 like that of one of its constituent atoms, it follows by comparison that the absorptive power of the molecule is 16,000 times greater than that of an atom of either oxygen or nitrogen. From this enormous opacity to obscure heat 'it is certain that more than ten per cent. of the terrestrial radiation from the soil of England is stopped within ten feet of the surface of the soil; remove for a single summer night the aqueous vapour from the air which overspreads the country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature.'

The quantity of vapour in each place varies with the latitude, the season, and other circumstances; but whenever the amount of heat radiated from the earth surpasses the absorption, the remainder passes through the vapour into space, and for the same reason the residue of that coming from the sun passes through the vapour and comes to the earth, so that whatever may be the local differences it has been decidedly proved with regard to the whole globe, that the quantity of heat annually received from the sun is annually radiated into space; the latter is a force lost to the earth, nevertheless it does not interfere with the law of the conservation of force which extends to the universe.

By observations made during ten scientific ascents in a balloon to very great altitudes, Mr. Glaisher has proved, that the theory of the uniform decrease of temperature with increase of elevation is no longer tenable. Since the absorptive force of aqueous vapour is 16,000 times that of dry air, the whole of the heat radiated by the full moon is intercepted by our atmosphere. It raises the temperature of the higher regions, dissolves the vapour, dissipates the clouds, prevents the formation of more, and allows the heat radiated from the earth to pass freely into space: thus confirming the common, and almost universal, belief that the full moon dispels the clouds. The absorptive power of aqueous vapour is so enormous that even the planet Mercury may be habitable should his atmosphere contain a sufficient quantity of it to mitigate the heat of the sun.

No doubt all the heat from the stars must be absorbed by the atmosphere, but their photographs show that it is pervious to the chemical rays. Those from Sirius, the nearest and brightest of the stars, travelling through 180 millions of millions of miles and decreasing in quantity inversely as the square of the distance, + still have sufficient energy to give a perfect photographic impression of its spectrum; but Sirius is sixty times larger than the sun, and is many times more luminous. A photograph of the spectrum of Capella has been taken, though three times more distant than Sirius. Photographs of double stars of the sixth and seventh magnitude show that actinic rays from immeasurable distances in space have power sufficient to decompose matter in unstable equilibrium on the surface of the earth.

The chemical power of the moon's light only surpasses that of Jupiter in the ratio of 6 to 4 or 5, and Jupiter's light has twelve times more actinic energy than that of Saturn. For such comparisons a standard of photographic intensity is requisite.

A paper coated with chloride of silver can be prepared which has a constant degree of sensitiveness, and Dr. Roscoe has proved that a constant dark tint is

\+ But not decreasing in brightness nor in photographic intensity in that ratio because the apparent produced on this standard paper by a constant quantity of light, the tint being the same, whether light of the intensity represented by 1 acts for the time represented by 50, or light represented by 50 acts for the time represented by 1; or in other words the amount of the chemical action of light is directly proportional to the intensity of the light, and when the light is constant, the amount of action is exactly proportional to the time of exposure.

The ratio of the chemical action of the rays of light falling directly from the sun to the chemical action of the light diffused over the whole sky can be determined by means of an instrument, in which the shadow of a little ball is made to fall on a sensitive paper so as to intercept the direct rays of the sun, and allow it to be impressed by an action of the light diffused over sky alone; this compared with a similar paper, on which both the direct and indirect light has fallen, gives the ratio required. From this it appears, that the relative amount of chemically active light which comes directly from the sun, is very much less than the amount of his direct visible light. For while Professor Roscoe was making experiments at Manchester on the maximum effect of the chemical action of light, he found when the sun had an altitude of 20°, that of 100 chemical rays which fell on a piece of standard paper, only about 8 came from the direct light of the sun; while on the contrary, of 100 rays of visible light, 66 came directly from the sun, and only 40 from the light diffused over the whole sky, so that the diffused light is richer in chemical rays than the direct solar beam, 'a startling result,' but borne out by observations not only made at Manchester and in its vicinity, but at Kew, Heidelberg, and at Pará on the Amazon nearly under the equator.

On account of the increasing rarity of the atmosphere, the greater the height above the level of the sea, the less the amount of diffused light and consequently of actinic power. Hence photographers have to expose their plates for a much longer time to the light on the snowy peaks of the Alps and other great heights than in England or at the level of the sea. During Mr. Glaisher's tenth balloon ascent simultaneous observations were made at Greenwich Observatory and in the balloon, when at more than three miles above the surface of the earth, the standard paper exposed to the full rays of the sun was not as much coloured in half an hour as the corresponding paper at Greenwich in one minute.

By a series of observations at Heidelberg, Kew, and Manchester, it has been proved that the very small relative chemical action of the sun's direct light decreases rapidly with his altitude, and at these three places of observation, it has frequently happened when the sun's altitude was very low, as at 12°, that his direct light made no impression on a sensitive paper. 'The sun's light had been robbed of its chemical power in passing through the air.' This singular result is ascribed by Professor Roscoe to what he calls the opalescence of the atmosphere.

Opalescent glass, slightly milky liquids, pure water with particles of sulphur floating in it, are impervious to the chemical rays, whence Professor Roscoe infers that the atmosphere, more especially its lower regions, possesses that property in consequence of multitudes of solid particles floating in it. What they are is unknown, but infinitesimal particles of soda seem to be everywhere, and no doubt particles of other substances mixed with them may be often seen as motes dancing in the sunbeams. Besides, it is clearly proved that myriads of the eggs and germs of organized beings, though invisible to the naked eye, are continually floating in the air, and that they are more abundant in the lower than in the higher strata of the atmosphere. Since opalescent matter reflects the blue rays of light and transmits the red, Professor Roscoe ascribes the blue colour of the sky and the bright tints at sunrise and sunset to the opalescent property of the air.

The atmosphere is permeable to every kind of chemical rays, which is far from being the case with bodies on earth, some of which though transparent to all the visible rays, vary greatly in their transparency to the chemical rays.

The atoms and molecules of matter not only have the power of turning the rays of the solar beam out of their rectilinear path, but of changing their refrangibility.

The myriads of ethereal waves or rays of light that constitute the seven colours of the solar spectrum, decrease in refrangibility and increase in rapidity of vibration and length of wave from the extreme violet to the end of the red; each ray having its own rate of vibration, its own length of wave, and its own colour. From the middle of the yellow, which is the luminous part of the spectrum, the chemical spectrum extends invisibly, but with increasing refrangibility and increasing velocity of vibration, to a point far beyond the violet. On the contrary, the heat spectrum, which may also be said to begin in the yellow light, extends invisibly but with decreasing refrangibility, and decreasing velocity of vibration to some distance beyond the visible red.

The rays of heat are absorbed by the humours of the eye, but were they to reach the retina we should see that they differ from one another as much as those of the luminous spectrum; the chemical spectrum from its greater length is still more diversified.

The whole of the solar spectrum, visible and invisible,

They probably would not produce the impression of light at all is crossed at right angles to its length by innumerable dark rayless lines, differing in breadth and intensity. Sir John Herschel discovered vacant spaces in the extra-luminous part of the heat spectrum, and more recently M. Edouard Becquerel, by throwing the solar spectrum upon a daguerreotype plate, discovered that the chemical spectrum given by a glass prism, from its beginning in the yellow to its extreme point beyond the violet, is crossed by rayless lines, and that the lines in the part passing through the visible spectrum coincide exactly with the rayless lines in the luminous part. This coincidence was confirmed by the independent researches of Dr. Draper at New York. By means of the rayless spaces or black lines in the visible spectrum, M. Kirchhoff has proved that thirteen terrestrial substances are constituents of the sun's atmosphere.

The length of the undulations of the ether which produce the impression of the extreme violet rays of the solar spectrum on our eyes, is the seventeen millionth part of an inch; the length of the ethereal undulation that produces the sensation of the extreme red is the twenty-six millionth part of an inch; the ethereal undulations beyond these limits are invisible to human eyes. Nevertheless certain substances have the power of increasing the length of the vibrations, and reducing the rays of the spectrum to a lower grade in the scale of refrangibility, so that the invisible rays of the chemical spectrum have thus been brought within the limit of human vision.

For example, the chemical rays shine as visible light when they fall on glass tinged with the oxide of uranium. When these dark rays fall upon the glass, they put the whole of its molecules into vibrations, the same with their own, while at the same time they give a more rapid vibration to a certain number of the same molecules. The whole of the molecules restore their vibrations to the surrounding ether. Those having the same velocity with the chemical rays make no sensible impression on our eyes; but the ~~more rapid~~ vibrations come within the limits of the visible spectrum; they have consequently a lower refrangibility, and shine as visible light. It is called degraded light on account of its lower position in the prismatic scale, but more frequently fluorescent light, because fluor spar was the first solid known to possess the property. A number of substances are fluorescent, both solid and liquid, organic and inorganic.

If in a dark room a non-fluorescent body be illuminated by a sunbeam passing through glass stained deep blue by cobalt, it will reflect blue light; but it will appear to be perfectly black if it be viewed through glass tinged yellow by silver; while a piece of canary glass, which is highly fluorescent, will shine with a vivid light under the same circumstances. All the molecules of the canary glass give back to the ether the undulations that have been impressed on them by the blue light; while a certain number of them possess the power of receiving and giving back more rapid vibrations to the ether. The yellow glass held before the eye is impervious to the undulations of the blue rays, but transmits those of the fluorescent light, which emanate from the smaller number of molecules, and which thus become in reality new centres of light, different from the sun's light, though dependent upon it: the one terrestrial, the other celestial. Since the vibrations of the fluorescent light are more rapid than those of the blue light their colour is lower in the prismatic scale. The vibrations of the molecules in a fluorescent substance are analogous to those of a musical cord, which give the fundamental note or pitch and its harmonics, for the whole of the musical cord while vibrating the fundamental note divides itself sponta-

*. There is much confusion in the above. Fluorescent light is always degraded chemical rays but it is degraded as low as the blue

neously into parts having more rapid vibrations, which give the harmonics. Professor Stokes of Cambridge, who made this beautiful experiment, computed that the vibrations which produced the fluorescent light were a major or minor third below the pitch or vibrations of the blue light.

One of the first discoveries of fluorescence was made by Sir John Herschel—certainly the first who observed the property in a liquid. He found that the blue light which emanates from all parts of a solution of the sulphate of quinine, especially from its surface, is fluorescent, and that the light transmitted through the liquid, though sensibly like the incident white light, is no longer capable of producing fluorescence; it has been deprived of its chemical rays by absorption.

The chemical rays having been rendered visible by an increase in the length of the periods of vibration, unsuccessful attempts have been made to change the periods of the rays of heat beyond the red end of the spectrum so as to bring them within the limits of vision. The idea of effecting such a change by employing a substance opaque to light, but pervious to heat, is due to Dr. Akin; but it has since been accomplished by Dr. Tyndall, who, in the course of his experiments on radiant heat, found that a solution of iodine in the bisulphide of carbon excludes the most dazzling light, but transmits the rays of heat freely. He employed a mirror, lined in front with silver, to concentrate the rays emitted from the charcoal points of the electric lamp, and interposed a vessel containing the solution in question, so that the rays of heat alone were brought to a focus almost undiminished. When the solar spectrum was examined, the point of maximum heat was found to be as far beyond the extreme red on one side as the green rays on the other. In the spectrum of the electrical light the point of maximum heat was also found to lie beyond the extreme red, but the augmentation of intensity was so sudden and enormous as far to exceed the maximum heat of the sun previously determined by Professor Müller. Aqueous vapour powerfully absorbs radiant heat; so a solar spectrum beyond the earth's atmosphere might probably exhibit as great intensity as the electrical light. With the apparatus described oxidizable substances burst into the flame of common combustion when put into the focus; but when the chemical action of the oxygen of the atmosphere was excluded by igniting substances in vacuo by the invisible rays of heat, their periods of vibration were so changed as to bring them within the limits of vision. When the electric light is very powerful, a plate of platinized platinum in vacuo is raised to white heat at the focus of invisible rays; and when the incandescent platinum is looked at through a prism, its light yields a complete and brilliant spectrum. 'In all these cases we have a perfectly invisible image of the charcoal points formed by the mirror; and no experiment illustrates the change of heat into light' more strongly than the following:—When the plate of platinum or one of charcoal is placed in the focus, the invisible image raises it to incandescence, and thus prints itself visibly on the plate. On drawing the coal points of the lamp apart, or causing them to approach each other, the thermograph follows their motion. By cutting the plate of carbon along the boundary of the thermograph, a second pair of coal points may be formed of the same shape as the original ones, but turned upside down; and thus by the rays of the one pair of coal points which are incompetent to excite vision, we may cause a second pair to emit all the rays of the spectrum. Fluorescence and calorescence act in contrary directions. Fluorescence causes the molecules of a fluorescent substance to oscillate in slower periods than the incident

* This is right - But compare with X pp 59 + 60

light, while calorescence causes the molecules of a substance to oscillate in longer periods than the incident light. The refrangibility of the rays is lowered in the first case, and raised in the second.

Substances differ as much in their transmission of the chemical rays as those of light and heat. Glass is impervious to the most highly refrangible chemical rays, while rock crystal transmits them with the greatest facility; and on that account the absolute length of the spectrum was not known till the light was refracted by prisms of rock crystal. Besides, the number, position, and intensity of the chemical rays vary with the source of light. Some flames have scarcely any chemical rays; that of the oxy-hydrogen blowpipe, though intensely hot, has very few, and even the solar light is inferior in that respect to electricity. The electric spark from the prime conductor of a common electrifying machine, or the discharge of a Leyden jar, emits rays of very high refrangibility, far surpassing those which emanate from the sun. For, when the electric light from a highly charged Leyden jar was refracted by two quartz prisms and thrown by Professor Stokes on a plate of uranium glass, the chemical spectrum was highly luminous, and six or eight times as long as the visible spectrum. An equally extensive spectrum was obtained from the voltaic arc taken between copper points; it consisted entirely of bright lines. The long spectrum also appeared on the uranium glass when the spark refracted by quartz prisms was obtained from the secondary terminals of an induction coil in connection with the coatings of a Leyden jar. It consisted of bright lines, but was not so luminous as that from a powerful voltaic battery. On changing the metals of the points between which the sparks passed, the bright lines were changed, which showed that they were due to the particular metals.

The heat of the electric spark volatilizes the metals which form the points of the conducting wires; and all volatilized metals give characteristic spectra, both visible and chemical. The visible part differs from that of the solar spectrum in being crossed by bright lines instead of dark ones; but the number, intensity, and position of both the visible and invisible lines change with each metal. The changes in the invisible part under consideration may be readily observed by throwing the spectra either on a fluorescent or collodion plate. For example: in the spectrum from the spark between thallium points thrown on the latter, Dr. Miller found that there were two strong groups of lines in the least refrangible part of the spectrum; at a little distance from these there were three groups, the two first less intense than the third; several rows of feeble dots followed, and the chemical spectrum terminated rather abruptly with four nearly equidistant groups. This spectrum bears a resemblance to those of zinc and cadmium, less strongly to that of lead. Dr. Miller found that the photographic spectra of iron, cobalt, and nickel, also have a strong analogy, but that the metals arsenic, antimony, and tin showed as great a difference in the invisible as in the visible part of their spectrum.

The fluorescent spectra of seventeen metals were examined by Professor Stokes of Cambridge; several of them showed luminous lines of extraordinary strength, especially zinc, cadmium, magnesium, aluminium, and lead, which in a spectrum not generally remarkable contains one line surpassing perhaps all other metals in brilliancy. Some other metals exhibit in certain parts of their spectra lines that are both bright and numerous; on the whole some parts of the spectra are strong and tolerably continuous, while in others they are weak. This grouping of the lines is most remarkable in copper, nickel, cobalt, iron, and tin. Of all the metals examined, magnesium gave the shortest spectrum, ending in a very bright line, beyond which however excessively faint light extended to a distance equal to that of the long spectra. Aluminium on the other hand exceeded all the other metals in richness of the rays of the very highest refrangibility. All the strong lines mentioned lie in that part of the spectra.

In the course of these experiments Professor Stokes observed that even quartz of a certain thickness is not transparent to invisible lines of the highest refrangibility, for the highest aluminium line, which is double, could only be seen by rays passing through the edge of the prism. This leads to another branch of the subject, namely, the absorption of the invisible rays by solids, liquids and gases. Mr. Wm. Allen Miller has shown from his own experiments that bodies pervious to the chemical rays in the solid form, are so also in the liquid and gaseous form; that colourless transparent solids which absorb the photographic rays, absorb them more or less also in their liquid and gaseous states. He has moreover found that the following substances have the same maximum transparency:—rock crystal, ice, and fluor spar among solids, water among liquids, the three elementary gases and carbonic acid among gaseous substances. The most opaque to the invisible rays are, nitrate of potash, bisulphide of carbon, and sulphuretted hydrogen. It appears that a thin plate of mica is intensely opaque to all the invisible rays except a small portion of them of the lowest refrangibility.

The absorptive property however is partial: an absorptive substance either cuts off a portion of the light of a fluorescent spectrum or stripes it with dark lines: each substance absorbs rays peculiar to itself. Those employed by Professor Stokes were the alkaloids and glucosides, and he assumed the spectrum of tin for their examination because it has a long interval of continuity.

The fluorescent property of yellow uranite was discovered by Professor Stokes some years ago, and now he has added another fluorescent mineral in adularia or moonstone; from its natural faces and planes of cleavage alike a beautiful blue fluorescence emanated under the induction spark. As the same was observed in colourless felspars generally, Professor Stokes concluded that fluorescence is an inherent property in the silicate of alumina and potash constituting the crystal of moonstone. The blue fluorescence extended to a very sensible though small depth within the substance.

A particular variety of fluor spar found at Alston Moor in Cumberland, which is very pale by transmitted light, shows a strong blue fluorescence, and is eminently phosphorescent on exposure to the electric spark. It is the same kind of crystal in which Sir David Brewster originally discovered the property of fluorescence. On presenting such a crystal to the spark passing between aluminium terminals, besides the usual blue fluorescence, there was another of a reddish colour extending not near so far into the crystal, produced by the rays belonging to the strong lines of aluminium of extreme refrangibility.

The cube of fluor spar which showed these effects was externally colourless to the depth of $\frac{1}{20}$ of an inch; then came one or two strata parallel to the faces of the cube showing the ruddy fluorescence, while the blue fluorescence extended to a much greater depth and had a stratified appearance. This crystal was eminently phosphorescent, its blue phosphorescence being arranged in strata parallel to the face of the cube like the blue fluorescence, but it was not perceptible beyond a very moderate distance below the surface at which the exciting cause entered, that cause being the photographic rays of extremely high refrangibility of the electric spark—taken, as in all these experiments, between the secondary terminals of an induction coil in connection with the coatings of a Leyden jar, and refracted by quartz prisms.

Mr. Stokes has employed fluorescence as a means of tracing substances in impure chemical solutions. When a pure fluorescent substance is examined in a pure spectrum it is found that on passing from the extreme red to the violet and beyond, the fluorescence commences at a certain point of the spectrum, varying from one substance to another, and continues from thence onwards more or less strongly in one part or another according to the particular substance. The colour of the fluorescent light is found to be nearly constant throughout the spectrum. 'Hence when in a solution examined in a pure spectrum we notice the fluorescence taking as it were a fresh start *with a different colour*, we may be pretty sure that we have to deal with a mixture of two fluorescent substances.'

Experience as well as theory shows that rapid absorption is accompanied by copious fluorescence. But experience has hitherto also shown what could not have been predicted, and may not be universally true, that conversely absorption is accompanied in the case of a fluorescent substance by fluorescence.

The phosphorescent light of insects, fish, and plants is owing to chemical action, which produces many luminous phenomena; but a great number of inorganic and organic substances shine in the dark with a phosphorescence which is nearly allied to fluorescence. It is produced by exposure to the sun, by heat, electricity, insulation, cleavage, friction, and motion. For if a bottle containing nitrate of uranium be shaken, it shines spontaneously with a vivid light; even the hand shows phosphorescence in the dark after being exposed to the sun.

The essential difference between fluorescence and phosphorescence consists in the time during which the light lasts. Fluorescence ceases almost immediately after the exciting cause is withdrawn, while a phosphorescent body whether excited by heat, solar light, or electricity, lasts a much longer time; besides, the fluorescent rays are generally of lower refrangibility. Light and heat are temporarily absorbed and given out again by every body on the surface of the earth, more or less, that are exposed to the sun's light. The nights would be much darker even when illuminated by the stars were it not for earth light, for the molecules restore to the ether, in the form of phosphorescence, the undulations they have received from the sun's light during the day. The snow and ice blink of the sailors is a striking instance; generally, however, it is of much shorter duration. The phosphorescent property is nearly allied to electricity, for bodies that are bad conductors are apt to become phosphorescent, while good conductors of electricity rarely if ever show it. Ozone must be phosphorescent, for oxygen exhibits persistent light when electric discharges are sent through it, and Mr. Faraday saw a flash of lightning leave a luminous trace on a cloud which lasted for a short time.

In the solar spectrum the chemical or actinic rays produce phosphorescence, which the red rays have the power to extinguish. M. Nièpce de St-Victor found that solar light impresses its vibrations so strongly on substances exposed for a short time to its influence that they not only shine in the dark, but that the phosphorescent light they radiate has chemical energy enough to decompose substances in unstable equilibrium, and leave daguerreotype impressions of great delicacy and beauty.

The polarization of light and heat affords a remarkable instance of the elective power of matter. Light and heat are said to be polarized, which, having been once reflected, are rendered incapable of being again reflected at certain angles. For example, a ray incident on a plate of flint glass at an angle of 57° is rendered totally incapable of being reflected at that same angle from another plate of flint glass in a plane at right angles to the first. At the incidence of 57° the whole of the ray is polarized: it is the maximum of polarization for flint glass, but there is a partial polarization for every other angle; the portion of the ray polarized increases gradually up to the maximum, as the incidence approaches to 57°. All reflecting surfaces are capable of polarizing light and heat, but the angle of incidence at which the ray is totally polarized is different in each substance. Thus, the angle of incidence for the maximum polarization of crown glass is 56° 55′, and no ray can be totally polarized by reflection from the surface of water unless the angle of incidence is 53° 11′. As each substance has its own maximum polarizing angle, the effect is evidently owing to the action of the molecules of matter, and not to any peculiarity in the light or heat.[8]

Light and heat are also polarized by refraction, for certain substances, especially irregularly crystallised minerals like Iceland spar, possess the property of dividing a ray of light or heat passing through them in certain directions into two pencils, namely, the ordinary and extraordinary rays. The first of these is refracted according to the same law as in glass or water, never quitting the plane perpendicular to the refracting surface, while the second does quit that plane, being refracted according to a different and more complicated law. Hence, if a crystal of Iceland spar be held to the eye, two images of the same object will generally be seen of equal brightness. But when they are viewed

[8] 'Connection of the Physical Sciences.'

* This a property but not a definition

through a plate of tourmaline it will be found that while the spar remains in the same position the images vary in relative brightness as the tourmaline is made to revolve in the same plane; one increases in intensity till it arrives at a maximum, at the same time that the other diminishes till it vanishes, and so on alternately at each quarter revolution of the tourmaline, proving both rays to be polarized. For in one position the tourmaline transmits the ordinary ray and reflects the extraordinary, and after revolving 90°, the extraordinary ray is transmitted and the ordinary ray is reflected.

The undulations of the ethereal medium which produce the sensation of common light, are performed in every plane at right angles to the direction in which the ray is moving, but the case is very different after the ray has been polarized by passing through a substance like Iceland spar, for the light then proceeds in two parallel pencils whose undulations are still indeed transverse to the direction of the rays, but they are accomplished in planes at right angles to one another. The ray of common light is like a round rod, whereas the parallel polarized rays resemble two long flat rulers, one of which lies on its broad surface, and the other on its edge. By a simple mechanical law, each vibratory motion of the common light is resolved into vibratory motions at right angles to one another.

The polarization of light and heat by refraction is not owing to the chemical composition, but to a want of homogeneity in the molecular structure of the substances through which they pass; for regular crystals and substances which are throughout of the same temperature, density, and structure, are incapable of double refraction. The effect of molecular structure is strikingly exhibited by the circular polarisation in the dimorphic crystals of quartz. In one form the plane of polarization revolves from right to left, and in the other that plane revolves from left to right, although the crystals themselves differ apparently by a very slight and often almost imperceptible variety of forms.

Thus polarization forms the most admirable connection between light, heat, and crystalline structure; showing peculiar arrangements of the molecules in regions otherwise unapproachable, and too refined for our perceptions. Besides, the gorgeously coloured images displayed by depolarization are splendid examples of the power of matter in decomposing light.

The perfect correspondence of the properties of the symmetrical, elastic, and optical axes of crystals with light and heat is another instance of the connection between the latter and crystalline form.

The axis of symmetry is that direction or imaginary line within a crystal, round which all the parts or particles are symmetrically arranged. A medium is said to be elastic which returns to its original form with a resilient force after being relieved from compression, and the axis of elasticity of a crystal is that direction in which it is most elastic. The optic axis is that line or direction through which light passes in one beam according to the law of ordinary refraction. Crystals may have one, two or more optical axes according to their form. Doubly refracting crystals such as Iceland spar have only one principal optic axis in which the whole beam passes according to the ordinary law; in every other direction the beam of light is divided into two polarized rays, one of which called the ordinary ray passes according to the ordinary law, while the other, known as the extraordinary ray, traverses the crystal in a different direction, with more rapidity and according to a different and more complicated law. The velocity of this extraordinary ray is a maximum when at right angles to the principal optical axis, and a minimum when parallel to it.

In perfectly regular crystals like the cube or die, the octohedron, &c., there are three axes of symmetry and of equal elasticity at right angles to one another. In these regular crystals all the axes are optical, so that they have no double refraction.

Right square prisms have two equal rectangular axes of symmetry, two axes of equal elasticity, and one optical axis.

All crystals of the pyramidal and rhomboidal systems have one axis of symmetry, two axes of elasticity, one optical axis; and form coloured circular rings traversed by a black cross when viewed by depolarized light.

Lastly oblique prismatic crystals which have three unequal axes of symmetry have three axes of unequal elasticity, two optical axes; and by depolarization give coloured lamnescata, that is coloured figures having the form of the figure 8 which are traversed by a black cross in two opposite quadrants, and when the crystal is made to revolve, the same figure, but in the complementary colours and traversed by a white cross, appears in the other two quadrants.

The right and left-handed circular polarization of quartz, according as certain facettes of the crystal are turned to the right or left, and the property of double refraction being exclusively possessed by crystals of the rhomboidal form, are striking instances of the connection between the geometrical arrangement of the molecules of matter and the optical and thermal forces, for the polarization of heat and all its consequences are in every respect analogous to those of light, and similar phenomena would be seen were heat visible.

Heat changes the position of the optical axes of crystals. When applied to a crystal of sulphate of lime, the two optical axes gradually approach to each other and at last coincide; if the heat be continued and increased, the axes open again, but in a direction at right angles to their former position. Thus the force of heat throws every molecule in the body into correlative motion. The angles of all crystals that are not of the octohedral group are changed by heat and vary with the intensity; the difference between the length of the greatest and least optic axes in such crystals diminishes as the temperature is raised, increases when it is lowered, and is constant at a given heat. In Iceland spar heat indirectly affects the doubly refracting power, for the expansion of the crystal in the direction of its axis is accompanied by contraction at right angles to it, which brings the crystal nearer to the cubical form, and consequently diminishes its doubly refracting power.

According to the researches of M. Angström, in crystals with different axes of elasticity the velocity of the molecular vibrations is different in different directions when they are heated. In rock crystal and tourmaline the heat radiates from a surface cut parallel to the axis of the crystal; in felspar the radiating surface is at right angles to the symmetrical axis.

The optical axes of crystals are also affected by pressure. Doubly refracting crystals with one principal axis acquire two when the pressure is perpendicular to it. The new principal axis coincides with the line of pressure or is at right angles to it according as the crystal is positive or negative, that is, according as the extraordinary ray is refracted to or from the optic axis of the crystal. The colours produced by polarization are affected by compression and dilatation according as the crystal is positive or negative.

Sir David Brewster is of opinion that all the properties of double refraction and the gorgeous phenomena of polarization, whether by crystals or produced in various substances permanently or transiently by heat, cold, rapid cooling, compression, dilatation, and induration, are wholly the result of the forces by which the atoms are held together; but these phenomena may rather be said to depend upon a reciprocal action between an irregular molecular structure and the agency of light and heat: which indeed seems to be confirmed by the transit of these two forces through right and left-handed quartz, for there is no reason to believe that there is any difference in the form of the particles in these two crystalline substances.

The experiments of M. Becquerel show that electricity is a power which makes the atoms of matter aggregate in crystalline forms; for he has succeeded in forming crystals of gold, silver, cobalt, nickel, platinum, and a variety of the gems undistinguishable from those in nature, by exposing saturated solutions of these substances for a very long time to feeble voltaic electricity; and crystals of earthy matter have been obtained in the same manner. The electric and magnetic state of mineral veins in mines which contain a vast variety of crystals, metallic and non-metallic, strongly favours this view of the origin of crystalline form.

M. Regnault has proved that the ratio between the specific heat and the weight of the atoms of matter is intimately connected with the mode of their aggregation; and indeed if it be considered that the atoms have not only specific heat and weight, but specific affinity, electricity, magnetism, consequently polarity, and probably specific forms, these peculiar forces must necessarily influence the structure of crystals according as they combine with or oppose the natural or artificial forces acting upon them, or upon their dissimilar faces, and this may be the cause of the great variety of forms that matter appears under. Carbonate of lime alone assumes more than 1,200 different modifications of its primitive type, but whatever be the variety of forms which any one substance may take, they are found to be all compatible with and derivative from a common type. The circumstances which have caused dimorphous crystals to deviate from the general law have not yet been explained.

It is very singular that when chlorate of soda is dissolved in water the solution does not possess the property of circular polarization, but when evaporated and allowed to crystallise, some of the crystals turn light to the right, and others to the left. Now if all the crystals that have the same property be picked out and dissolved in water a second time, the liquid will still have no circular polarization, but when allowed to crystallise, some of the crystals make light revolve through them to the right and others to the left as before. From this it is supposed that the atoms of liquids, which are free to move in every direction, already possess part of the characters which the change to solidity renders evident and permanent.

Although the relations between the force of magnetism and the atoms of matter do not exhibit such brilliant phenomena as light does, they are nevertheless most interesting and wonderful. Mr. Faraday discovered that all substances, whether solid, liquid, or aëriform, are either magnetic like iron, or diamagnetic like bismuth, the latter being by far the most numerous. Thus if a bar of iron be freely suspended between the poles of an extremely powerful magnet or electro-magnet, it will be attracted by both poles and will rest or sit axially, that is, with its length between the poles or in the line of magnetic force; whereas an equal and similar bar of bismuth so suspended will be repelled by both poles and will rest or sit equatorially, that is with its length perpendicular to the line of magnetic force. Magnetism and diamagnetism are both dual forces, but they are in complete antithesis to one another, which is strikingly illustrated by their action on crystalline matter.

A sphere of amorphous substance freely suspended under magnetic influence is indifferent, that is to say it has no tendency to set one way more than another; but a sphere cut out of a crystal whether magnetic or diamagnetic, is more powerfully attracted or repelled in one direction than in any other, which shows a connection between the magnetic forces and crystalline structure.

Crystals of carbonate of iron and carbonate of lime are isomorphous, that is, they have exactly the same crystalline form, but the carbonate of iron being highly magnetic is most powerfully attracted in the direction of its greatest optical axis which therefore sets axially, that is, in the line of magnetic force; while the principal optic axis of the carbonate of lime, which is diamagnetic, is most powerfully repelled and therefore sets equatorially. In both cases the antithetic forces follow the same law of decrease in intensity from the greatest optical axis to the least.

A bar of soft iron sets with its longest dimensions axially, but a bar of highly compressed iron-dust, whose shortest dimensions coincide with the line of pressure, sets equatorially, because it is most powerfully attracted in the line of greatest density. A bar of bismuth sets equatorially, but a bar of highly compressed bismuth dust, whose shortest dimensions coincide with the line of pressure, sets with its length axially, because it is most strongly repelled in the direction of its greatest density. Hence the action of magnets upon matter is most powerful in the line of maximum density, the force being attractive or repulsive according to the kind of magnetism possessed by the atoms. It follows therefore that the density is greatest in the line of the principal optical axis, and gradually decreases to the least optical axis, where it is a minimum.

The position which crystals take with regard to the magnetic force depends also upon their natural joints of cleavages, and upon their power of transmitting electricity. The diamagnetic force is inversely as the conducting power of bodies, and the conducting power of crystals is a maximum in the planes of their principal natural joints. Hence the action of the diamagnetic power is least in the natural joints, and conversely the magnetic force is greatest. In fact, the magnetic phenomena of crystals depends upon unequal conductibility in different directions, and their set is determined by the difference between the forces of attraction and repulsion of the poles, for one pole of the magnecrystallic axis is attracted and the other repelled. It is unnecessary to give more examples to show the action of the magnetic forces upon the atomic structure of crystals.[9]

Magnetism changes the relations and distances between the ultimate atoms of matter, a circumstance which probably depends upon their polarity. It changes steel permanently, iron temporarily, and it elongates a bar of iron, which loses in breadth what it gains in length; and as heat is developed in one direction and absorbed in the other, the temperature of the bar remains the same. Heat being an expansive force, diminishes the magnetism of iron and nickel in proportion as it increases the distance between their atoms, till at length they lose their cohesive force altogether. But there seems to be a temperature at which the magnetic force is a maximum, above and below which temperature it diminishes. Thus the magnetism of cobalt increases with the temperature up to a certain point; it then decreases as the temperature increases, and it loses its magnetism altogether when the heat amounts to 1996°.

Sir Humphry Davy and M. Arago noticed that the voltaic arc takes a rotatory motion on the approach of a

[9] 'Connection of the Physical Sciences.'

magnet; and the effect of magnetism on the stratified appearance of the electric light in highly rarefied air shows how powerful its action is. In the year 1858, Mr. Gassiot published a series of observations on stratified light; subsequently various publications appeared on the subject both by Mr. Gassiot and by Professor Plücker, who made a series of very interesting observations on the nature of the stratifications, but more especially on the effects produced when they are under the influences of magnetism. Since that time, Mr. Gassiot has published several papers on the subject, and still continues his experiments on the stratifications of electric light, which give a visible proof of the connection between electricity and magnetism. He first showed that the stratified character of the electric discharge through highly attenuated media is remarkably developed in the Torricellian vacuum; latterly he has made his experiments by passing electricity through closed glass tubes of various lengths and internal diameters, filled with highly attenuated gases and vapours.[1] Two among the many brilliant experiments of this gentleman may be selected as illustrations of the property of electric light.

One of these closed glass tubes containing a highly attenuated gas was 38 inches long with an internal diameter of about an inch, and had the extremities of two platinum wires fused into the same side 32 inches apart. When these wires were put in connection with the wires of an induction battery and brought into contact, and the electricity passed through the tube, the luminous appearances at the extremities or poles of the platinum wires were very different, but simultaneous.

[1] They are called vacuum tubes, and are filled while open by putting one end in communication with the vessel in which the gas is generated, and the other end in communication with an air pump. As soon as the atmospheric air is pumped out, the gas rushes in and fills the tube, the communication with the vessel containing the gas is cut off by fusing up that end of the tube, and as soon as the gas is sufficiently rarefied the other end is fused up also. An electrical discharge that will not pass through one inch of air, will pass through thirty or forty inches in a vacuum tube.

A glow surrounded the negative pole, and in close approximation to the glow, a well defined black space appeared, while from the positive pole there issued in rapid succession a series of alternate dark and brilliantly luminous curved strata, which formed a column of stratified light, the concavities of the strata being turned to the positive pole. The stratifications do not extend to the black band round the negative wire or ball, which is quite different to the dark intervening space between the stratified discharge and the luminous negative glow. On making and breaking the electric circuit, the stratified discharge emanates from each pole alternately, the concavities of the strata turning alternately in different directions; in fact the whole phenomena are reversed, but not changed. 'The stratified discharge arises from the impulses of a force acting on highly attenuated but resisting media,' a new proof of the wonderful power inherent in highly attenuated gases; the number of stratifications given out at each discharge, depending upon the intensity of the electricity and rarity of the gas.

Fig. 1.

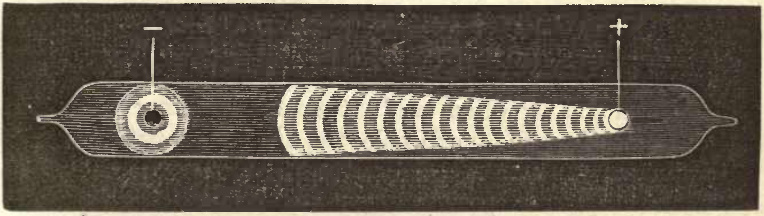


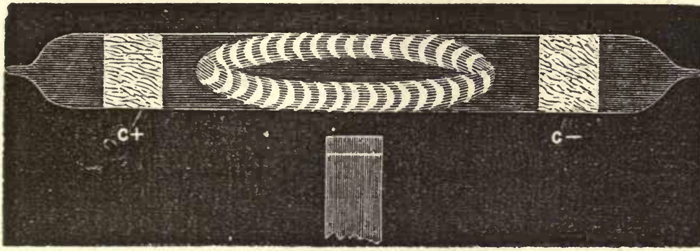
Fig. 1 represents the form which the stratified discharge assumes in a vacuum tube one inch diameter and 38 inches in length, + and − representing platinum wires attached to the terminals of a Ruhmkorff's induction coil.

When the tube, with its stratifications just described, was laid horizontally on the pole of a magnet, the stratified column showed a tendency to rotate as a whole round it. According to the theory of Ampère, the polarity of a magnet is owing to a superficial current of electricity perpetually circulating in a direction perpendicular to its axis; and he also showed that currents of electricity flowing in the same direction attract one another, while currents flowing in opposite directions repel each other. Hence, since the currents of electricity in the magnet and tube were flowing in the same direction on one side of the magnet, and in opposite directions on the other side, the stratified column was attracted at one end and repelled at the other, so as to take the form ∽, in consequence of its tendency to rotate as a whole round the pole of the magnet.

When narrow bands of tin foil wrapped round the glass tube near the platinum wires were put in communication with the poles of the induction battery, brilliant stratifications filled the whole tube between the tin coatings every time the electric circuit was broken or renewed; and when the tube was placed horizontally on the pole of a magnet, the stratifications no longer showed a tendency to rotate as a whole, they were divided into two parts tending to rotate in opposite directions; when the tube was placed between the poles of a powerful electro-magnet, one half of the stratifications were repelled and the other half attracted. When the tube was placed on the north pole, the divided stratifications arranged themselves on each side of the tube, changing their respective positions when placed on the south pole, but in every case each half was concave in opposite directions.

Fig. 2 (p. 81) represents the form which the induced stratified discharges assume when the vacuum tube is placed on or between the poles of a powerful electro-magnet—the tin foil coatings C + C − being attached by wires to the terminals of an induction coil.

Fig. 2.



If a vacuum tube with or without wires or tin coatings be laid upon the induction coil of a battery, or upon the prime conductor of an electrifying machine, stratifications are produced by induction which are divided by a magnet. Thus there are two distinct forms of the stratified discharge, one direct, the other induced.

When Professor Plücker of Bonn sent an induced current of electricity from Ruhmkorff's coil through a vacuum tube having a platinum wire fused into each extremity, and extending a little way into the interior of the tube, electric light radiated from every point of the negative wire, and when exposed to the action of an electro-magnet the whole tube was filled with a luminous atmosphere. But when all the negative platinum wire except its extreme point was insulated by a coating of glass, the rays of electric light which radiated from the point were united into one single and perfectly regular magnetic curve, upon the approach of an electro-magnet; when the negative platinum wire was partially insulated by glass coating, electric light emanated from every exposed part, and assumed the form of magnetic curves under electro-magnetic action. Whence Professor Plücker concluded that the luminous atmosphere in the first experiment was the locus of an infinite number of magnetic curves, and consequently that magnetic light emanates from the negative or warmth pole, and electric light from the positive or light pole. These magnetic curves of light are precisely similar to those assumed by iron filings from magnetic action.

The most remarkable of these experiments is the absolute extinction of a powerful electric discharge by magnetic action. Mr. Gassiot sent a discharge from a voltaic water battery, containing 3,520 insulated cells, into a tube filled with attenuated carbonic acid gas. The discharge was so strong that it was capable of passing through more than six inches of the gas, yet, on the approach of a very powerful electro-magnet, the stratifications were arrested as soon as they appeared, as if blown out, and finally extinguished. A stratified discharge, in vacuo, from 400 insulated cells of a nitric acid battery, was extinguished by the large electro-magnet of the Royal Institution; the luminous strata rushed from the positive pole of the battery, but under the magnetic force they retreated; cloud followed after cloud with deliberate motion, appearing as if swallowed up by the positive terminal. The amount of electricity that passed through the tube appeared to be materially increased by exciting the electro-magnet; the discharge was so intense on one occasion as to fuse half an inch of the positive terminal. A very powerful magnet is also capable of extinguishing a stratified discharge. In fact, according to the law of the reciprocal action of magnetism, the forces are equal in intensity and opposite in direction.

The electric discharge from an induction coil is discontinuous, or eruptive sparks of high tension are given out producing stratified discharges.

The discharge of the voltaic battery had hitherto been considered absolutely continuous; and so it is for chemical action, whether of analysis or combination;

nevertheless certain phenomena gave reason to doubt its continuity. Mr. Gassiot has proved that the tension of a single cell of a galvanic battery increases in force according to the chemical energy of the exciting liquid, and in all his experiments he found that 'the higher the chemical affinities of the elements used, the greater was the development of evidence of tension.' These observations induced him to institute a series of experiments with galvanic batteries of different chemical affinities, and to compare the resulting phenomena with those produced by the induction coil, whose sparks are of high tension. The same carbonic acid vacuum tubes were made use of in all the experiments; a copper wire formed the positive terminal, and a copper plate was fixed at the extremity of the negative terminal. In other tubes platinum terminals extended into the interior, coated with glass, except the points, to which charcoal balls were fixed. One end of the tubes was of small diameter and contained caustic potash.

When a discharge from an induction coil was sent through these tubes, there were either minute luminous spots, narrow stratifications, or a well defined cloud-like discharge at the positive pole, according to the size and structure of the terminal, but the characteristic phenomenon in all the tubes was a large cloud-like luminosity or circular glow on the brass plate or charcoal ball at the negative terminal.

With 512 insulated cells of copper and zinc of Daniell's constant battery, the exciting liquid being dilute sulphuric acid, a brilliant glow appeared round the charcoal ball of the negative terminal on the passage of the electric discharge through the tube, with very trifling luminosity of the positive pole.

Two copper plates that could be separated or closed by a screw, were placed between the poles of a nitric acid battery, so that the circuit could be made or broken gradually, and spark discharges were obtained between them. The vacuum tubes were placed between one of these plates and a pole of the battery; one of these tubes was 24 inches long, 18 in circumference, and had a circular copper disc 4 inches in diameter on its negative terminal. On completing the circuit, the discharge of the battery passed with a display of magnificent strata of dazzling brightness; on separating the plates by the screw, the luminous discharges presented the same appearance as when taken from an induction coil, but brighter. On the copper disc within the vacuum tube, there was a white layer, then a dark space about an inch broad, and then a bluish atmosphere curved like the disc, evidently three negative envelopes on a great scale. When the disc was made the positive pole, the effect was feeble.

In vacuum tubes 6 inches long and 1 inch diameter, with carbon balls on the terminals, the discharge of the nitric acid battery elicits extreme heat. In one of these the discharge presented a stream of light of intolerable brightness, but when viewed through a plate of green glass strata could be seen. This soon changed to a sphere of light on the positive ball, which became red hot, the negative being surrounded by magnificent envelopes; with a horse-shoe magnet the positive light was drawn out into strata. The needle of a galvanometer in circuit was violently deflected and the polarity reversed. When the caustic potash was heated, the discharge burst into a sunlike flame, subsequently subsiding into three or four large strata of a cloud-like shape, but intensely bright. This is called the arc discharge: it occurs in vacuum tubes with charcoal balls; when the potash is heated intensely, dazzling stratifications suddenly emanate from the positive ball, and powerful chemical action takes place in the battery, after which the discharge ceases.

This process facilitates the discharge and assists the disintegration of the carbon particles, and these in a minute state of division are subsequently found attached to the sides of the glass. It is these particles which produce the arc discharge with its intense vivid light so suddenly observed with far more brilliant effects than the usual stratified discharge. During its passage the conducting power of the vacuum tube is greatly enhanced.

It was already mentioned that a stratified discharge was obtained from 3,520 insulated cells of a water battery, which differs but little in intensity from 400 cells of the nitric acid battery. On one occasion the electricity seemed to pass through the vacuum tubes in a continuous stream, but when examined with Mr. Wheatstone's revolving mirror it was decidedly stratified. Mr. Gassiot never could obtain a continuous discharge in air, whether between the points or metallic plates of the water battery. The discharge was invariably in the form of minute clearly defined and separate sparks.

Thus it was proved by the preceding experiments that a spark discharge could be obtained in air from both the nitric acid and water battery; and that when these discharges were passed through the highly attenuated matter contained in carbonic acid vacua, the same luminous and stratified appearance was produced as by an induction coil; a proof that whatever may be the cause of the phenomena it could not arise from any peculiar action of that apparatus.

Mr. Gassiot finally concludes that the cause of the stratified discharge arising from the impulses of a force acting upon highly attenuated but resisting media is also applicable to the discharge of the voltaic battery in vacuo; while the fact of this discharge even in its full intensity having been now ascertained to be also stratified leads to the conclusion that the ordinary discharge of the voltaic battery, under every condition, is not continuous but intermittent, that it consists of a series of pulsations or vibrations of greater or less velocity, according to the resistance in the chemical or metallic elements of the battery or the conducting media through which the discharge passes.

Caustic potash absorbs the carbonic acid gas by degrees, and at last so completely exhausts a vacuum tube that electricity cannot be conducted. Air is a non-conductor, and an electric discharge that will not pass through an inch of air, will pass through more than 30 or 40 inches of attenuated gas.

It has already been mentioned that the stratified discharge can be obtained by a single discharge of the primary current of an inductive coil, however long may be the vacuum tube through which the discharge is passed. If no addition be made to the battery and no alteration be made in the arrangement of the coil so as to increase or diminish the intensity of the discharge, the stratifications will always present the same appearance and form, occupying the same spaces and positions in the vacuum tube; but if any change be made so as to alter the intensity, then a corresponding alteration will appear in the discharge, the striæ assuming a different shape, and the bright and dark divisions occupying different positions.

In order to try what effect a change of intensity would produce, three separate insulated voltaic batteries, in which the exciting liquid was brine, formed an electric circuit which was completed by two long wires. It was so arranged that the discharge of one, two, or all the three batteries could be separately employed. In order to vary the resistance at pleasure, two tubes 18 inches long containing distilled water and connected at their base were introduced into the circuit. By varying the depth to which the terminal wires of the circuit were plunged into the water, the resistance could be regulated at pleasure, and it was immaterial in what part of the circuit the vacuum tube was introduced provided the circuit was completed.

The first experiments were made with a carbonic acid vacuum tube 20 inches long and 4 inches in diameter. The negative terminal at one extremity of the tube was of aluminium, cup-shaped, about 3 inches in diameter; the positive terminal was a wire of the same metal fused into the other extremity of the tube; the point of the wire and cup were about four inches and a half apart. With this tube and 2,240 cells of the battery the discharge when the resistance was introduced had the appearance of a positive and negative discharge, impinging on and intermingling with each other, without any dark space intervening. Around the negative terminal the luminosity extends to the sides of the tube and tapers to the point of the positive wire. The light round the negative terminal becomes brighter, a dark space appears next to it when the resistance is diminished, and increases as the resistance decreases, by the rolling back of the light in bright clouds to the point of the positive terminal. These changes can be perfectly regulated by the resistance, and various luminous phenomena occur at each stage.

With 2,240 cells distinct sounds were heard in the tube; with the whole battery of 3,360 series the sounds were not heard till a magnet was applied to the striæ, when they again became audible and the striæ were spread over the surface of the tube.

A carbonic acid vacuum tube with platinum terminals fused into the same side far apart was now put into the circuit, the part of the wires that penetrated within the tube being coated with glass up to the carbon balls in which they terminated. When a discharge from all the three batteries passed through the tube, changes occurred in the form and number of the striæ corresponding to the greater or less amount of the resistance offered in the circuit.

At the commencement of the experiments there were 18 inches of water in each of the tubes, which formed the maximum resistance. The wires attached to the terminal wires of the battery were placed inside of these tubes, and as soon as they touched the surface of the water a faint luminous discharge was seen at each ball in the vacuum tube. As the wire attached to the negative end of the battery was slowly depressed, the two luminous discharges appeared to travel towards or attract each other, and at times a portion of the positive luminosity passed over and mingled with the negative; in this state the discharge was extinguished by a magnet.

When the wire was pressed farther into the water a dark space about an inch in length divided the light into two parts, the positive glow being sharply defined, the negative glow having an irregular edge. When the wire had been about three inches deep in the water, the positive and negative glows became more brilliant, and a single clearly defined luminous disc burst from the positive side and occupied the middle of the dark space. When the wire was pressed down till 13 inches of it were in the water, a second luminous disc travelled from the positive side, and then the two luminous discs or striæ occupied the dark space at a little distance from one another. As the wire was pressed more into the water, three parallel luminous striæ appeared, then four, then five, and so on till as many as thirteen or fourteen striped the dark central space. With the full power of the battery, the adjacent disc impinged on the glow that surrounded the negative ball. This disc was of a pale green, those adjacent were reddish, while the negative glow was of a bluish white; minute bright scintillations emanated from the negative ball, while distinct luminous flash discharges took place through the striæ. Thus by the amount of resistance introduced into the circuit, the number of striæ can be regulated, their position fixed, separating or closing up the dark space between the luminous glows round the balls.

In these experiments there is indication of a force emanating from the negative wire. The actual disruption of the particles from the negative terminal also indicates a force, and the disruption is as freely obtained by the continuous discharge of the battery as it is by the intermittent discharge of the induction coil. Besides, when Mr. Gassiot sent discharges from the induction coil through Torricellian vacua, he several times observed that while a cloud-like discharge issued from the positive terminal, a long tongue of the most brilliant blue phosphorescent light emanated from the upper part of the negative terminal, and a brilliant white tongue of light was also seen close to the negative wire: so there is reason to believe that force emanates from both terminals.

Some of the preceding striated discharges 'present an appearance somewhat analogous with the stationary undulations (or nodes) which exist in a column of air when isochronous progressive undulations meet one another from opposite directions, and on the surface of water by mechanical impulses similarly interfering with each other.'[2]

'May not the dark bands be the nodes of undulations arising from similar impulses proceeding from positive and negative discharges? or can the luminous stratifications which we obtain in a close circuit of the secondary coil of an induction apparatus, and in the circuit of a voltaic battery, be the representations of

[2] 'Connection of the Physical Sciences.'

pulsations which pass along the wire of the former, and through the battery of the latter, impulses probably generated by the action of the discharge along the wires?'

The action of magnetism and electricity on light is similarly illustrated by the rotation of the plane of polarization. Sir John Herschel was the first who tried to rotate the plane of polarization of a ray of light by surrounding it with a spiral wire electrized by the great battery of two enormous plates of copper and zinc at the London Institution, but he obtained no evidence of any such action. Long afterward Professor Faraday succeeded by sending a ray of light through a piece of silico-borate of lead, which formed the core of a magnetic helix. The silico-borate took on a quasi-crystallised state during the passage of the electric current round it, giving it for the moment the property of circular polarization, analogous to that of glass in a state of tension or compression.

Substances vary exceedingly in the facility with which they transmit electricity; even the same substance under another form differs remarkably in that property: charcoal, which next to the metals is the best conductor known, when under the form of diamond is quite impervious to electricity. In general, substances that are the best conductors of heat are also the best conductors of electricity, as for example the metals, which however, possess the transmissive property in very different degrees. Silver and copper are the best conductors, lead one of the worst; its resistance to the passage of electricity is twelve times greater than that of silver and copper, consequently it becomes twelve times as hot, for when a current of electricity is impeded it is changed into heat. So great is the resistance offered by a fine platinum wire, that the heat amounts to 3280° and the wire is melted, a striking instance of the correlation of electricity and heat, and of the power of the cohesive force.

When electricity is passing through conducting substances or when it is static, it induces an electric state in bodies at a distance by transmission through non-conducting substances or air, for it gives polarity and tension to the adjacent atoms, and these to the next, and the next in succession, throughout the whole intervening mass,—a strong proof of the individuality and polarity of the atoms of matter.

Motion, which is the result of all the physical powers, has itself a strong action upon the ultimate elements of matter; in cases of unstable equilibrium it accelerates and even determines their chemical union. Some substances will remain merely mixed as long as they are at rest, but no sooner is their inertia disturbed by a slight motion than they rush into permanent combination. In newly sublimed iodide of mercury the vibration impressed by the scratch of a pin is so rapidly transmitted through the mass that its colour is immediately changed from yellow to bright red. By a new arrangement of the molecules their action on light is altered.

Catalysis or the chemical decomposition and composition of substances by the contact of a foreign body, is well illustrated by the chloride of nitrogen, that explodes when touched by substances which at ordinary temperatures would neither combine with the chlorine nor with the nitrogen. The iodide of nitrogen explodes if touched by a feather, and M. Becquerel decomposed the iodide of nitrogen by the vibrations of sound. When substances only exist in consequence of the inertia of their atoms, the instability of their chemical attractions and repulsions is only increased by an external agent, so that a great effect is produced by a slight cause, as in an avalanche, the snowy mass is on the point of falling, and the smallest motion, a breath of wind, hurls it down. In such cases the potential energy of the unstable mass is in a moment changed into vis viva or impetus. Daguerreotype impression shows the power of the chemical rays on substances in unsteady equilibrium, and the length of time required to make the impression under the same circumstances is a measure of the instability.

Most of the fulminates are compounds of nitrogen; of that the fulminate of aniline is a recent instance, since it is formed by the slow action of nitrous acid on aniline. Explosion takes place on the sudden evolution of gas, or the sudden change of a solid into vapour. In these cases fire or percussion are the foreign causes of change. They are all particular instances of the general principle of catalysis, which is the chemical combination of heterogeneous atoms by the action of a substance that does not participate in the change. Thus it has long been known that when platinum is plunged into a mixture of oxygen and hydrogen it combines these gases into water. Acids in some cases seem to have the same effect; for when rags or starch are dissolved in an acid the starch is changed to dextrine and the liquid has acquired the power of turning the plane of polarised light to the right. The acid has undergone no alteration, but it has changed the properties of the starch though not its chemical composition. After a time, a second transformation takes place, the liquid ceases by degrees to turn the plane of polarisation to the right, and ends by turning it to the left. The acid is still unchanged, but the dextrine has now disappeared: it has combined with the water and is transformed into glucose or sugar of grapes.

The quantity of the physical powers, active and latent, is inappreciably great. The quantity of heat or potential energy generated by chemical combination alone is enormous.

SECTION III.

ATOMIC THEORY, ANALYSIS AND SYNTHESIS OF MATTER, UTILITY OF WASTE SUBSTANCES—COAL-TAR COLOURS, ETC.

THE chemical combination which forms the infinite variety of substances in the organic and inorganic creation consists in an intimate union of their ultimate atoms which produces substances differing from their constituent parts in every respect except gravitation, the sum of the weights of their constituent parts being invariably equal to the weight of the resulting substance. Thus the chemical union of oxygen and hydrogen forms water, and the weight of the water so formed is exactly equal to the sum of the weights of the two gases.

All chemical changes whether of analysis or composition are subject to definite unalterable laws of weight, measure and number; nothing is by chance or casual, the relative weights of the invisible atoms of matter, and their combination in definite proportions reveal the laws which prevailed in the primeval structure of created things. By the wonderful discovery of these laws Dr. Dalton has placed chemistry on a strictly numerical basis.

The chemical union of different kinds of atoms and volumes of matter in the definite proportions of whole numbers entirely changes their character and properties, as for example the chemical combination of one atom of hydrogen and one atom of oxygen into water. The condensation is often unexpected and wonderful; two different liquids are often condensed into a solid, and the result of the chemical combination of two different gases or vapours in quantitative proportions may be solid, liquid or aëriform, a fact which could only have been discovered by experiment. The powers of the atoms are changed and often highly exalted by chemical union as in ammonia, a chemical compound of three atoms of hydrogen and one of nitrogen, which absorbs 1,195 times more radiant heat than its constituents whether simple or mixed. During chemical combination light and electricity are often evolved, heat always. The quantity given out is exactly proportional to the energy of the chemical action, and is often so great and so rapidly evolved as to produce an explosion by the sudden expansion of the air around. Whatever the temperature may be, which is given out during the union of the atoms, the very same quantity of heat is requisite to dissolve their union, and the atoms are separated in the same definite proportions in which they were combined.

Voltaic electricity both combines and resolves substances into their component parts, strictly according to the law of definite proportions. It combines eight parts by weight of oxygen and one part by weight of hydrogen into water; and again when it decomposes water, one part by weight of hydrogen is given out at the negative pole of the battery, and eight parts by weight at the positive or zinc pole. For an electric current weakens or neutralizes the force of affinity in one direction and strengthens it in the other, so that the heterogeneous atoms of the substance under its influence have a tendency to go in different directions and appear at opposite poles. Mr. Faraday has established as a general law, that the quantity of electricity requisite to unite the atoms of matter, is precisely equal to the quantity requisite to separate the same atoms again.

Electro-chemical action, or the power of electricity to combine and separate the heterogeneous atoms of matter, is in direct proportion to the absolute quantity of electricity that passes in the current. Hence the superior analytical power of voltaic over static electricity, which has enormous intensity, but is very small in quantity. The electric current separates molecular combinations which yield to no other means: it is the most powerful instrument of analysis; light is the most delicate.

Two simple substances are only capable of a certain number of chemical combinations, which form a regular series of new substances; as for example oxygen and nitrogen. Two measures of nitrogen gas will unite with one measure of oxygen to form the protoxide of nitrogen; with two measures of oxygen it unites to form the binoxide of nitrogen; with three measures of oxygen it forms the hyponitrous acid; with four it forms nitrous oxide; and with five measures of oxygen it forms nitric acid. Thus there are five compounds of nitrogen and oxygen, no more. Affinity of *kind* is merely the attraction of one element or atom of matter for another; affinity of *degree* consists in the grades and limits of combination; the preceding series is of the fifth degree; the limit is the last term, for no further combination of these two gases can take place, and these are accomplished by art. All the five substances are deleterious, most of them deadly poisons, for the protoxide of nitrogen, which is the laughing gas, could not be long inhaled with impunity. For a long time the middle term of the preceding series was wanting, but Gay-Lussac formed it by attending to the laws of definite proportion and sequence.

The atoms of different kinds of matter possess an affinity, or attractive force, which binds them together chemically in different and very unequal degrees. Two substances may unite and form a third differing from both, as water does from oxygen and hydrogen; but if a new substance be added which has a greater attraction for one of the substances than for the other, it will dissolve their union, combine with that for which it has the strongest attraction, and set the other free. Thus the metal potassium, which has a greater attraction for oxygen than it has for hydrogen, decomposes water, combines with the oxygen, and sets the hydrogen free. Both chlorine and ozone have the property of liberating the iodine in a weak solution of the iodide of potassium; the liquid stains starch blue, a proof of the free iodine. The facility with which acids and alkalies combine affords the means of eliminating either the one or the other from a compound so as to liberate what remains.

The constituents of compound substances may be separated from one another by a variety of means depending upon their greater or less fusibility, volatility, and other properties. Water, acids, alcohols and other liquids hot or cold, different degrees of temperature, sublimation, solution, distillation, evaporation, together with static and voltaic electricity, are the most powerful means of analysis.

But the animal and vegetable creation rear their fabrics by a synthetic process. A plant after having absorbed carbonic acid and water, decomposes the carbonic acid, returns the oxygen to the atmosphere, and combines the carbon and water into wood, leaves, and a variety of organic substances. Now MM. Berthelot, Wöhler, and other distinguished chemists, by following this example of nature, have established a system of synthetic chemistry, by which they have produced from the chemical combination of the three elementary gases and carbon alone more than 1,000 complete organic substances, precisely the same with those formed within the living plants and animals. Yet we are as far as

* scarcely one, [probably not one] such as formed in vegetable or animal economy synthetically - but only those formed by decomposition of organic substances

ever from any explanation of the mystery of life, whether animal or vegetable.

Carbon and hydrogen will not combine at any artificial heat however great; but when the electric arc between highly purified charcoal terminals passes through hydrogen gas, acetylene, a new carburet of hydrogen, is formed, consisting of four equivalents of carbon and two of hydrogen. This substance, which no organized being is capable to form, was discovered by M. Berthelot, and being assumed as a base, yielded an extensive series of organic substances. Thus when two atoms of carbon are added to acetylene it becomes olefiant gas; when two equivalents of oxygen are added to olefiant gas, the result is alcohol, which is transformed into acetic acid by the addition of two atoms of oxygen, and from this by a similar process have been obtained the malic, tartaric, succinic, and the other acids; glycerine also, which is the sweet principle of the oils, wax, essential oils, the perfumes of fruit and flowers, the principle of the balms, the essential oil of mustard, and numerous other organic substances, simply from carbon, oxygen and hydrogen; but nitrogen was introduced by combining alcohol with ammonia, an inorganic substance consisting of three equivalents of hydrogen and one of nitrogen, from whence a vast * number of nitrogenized substances were derived, both animal and vegetable.

Chemical combination, which has from the beginning of created things, and still is, building up organic and inorganic matter in the earth, in the air, and the ocean, exerts forces of transcendent power, though silent, unperceived, and for the most part unknown. Professor Tyndall has given a striking instance of this in water, the most simple compound of oxygen and hydrogen, a constituent alike of organic and inorganic nature. 'In the combustion of the two gases to form a gallon of

* These substances are probably none of them formed synthetically in the vegetable – but by decomposition of strictly organic substances – by a descensive not an

water weighing ten pounds, an energy is expended, the atoms clash together with a force, equal to that of a ton weight let fall from a height of 23,757 feet; and in the change from the state of vapour to water, an energy is exerted equal to that of a ton weight falling from a height of 3,700 feet, or of a hundredweight falling from a height of 74,000 feet. The moving force of the stone avalanches of the Alps is but as that of snowflakes compared with the energy involved in the formation of a cloud. In passing finally from the liquid to the solid state,' that is from water to ice, 'the atoms of ten pounds exercise an energy equal to that of a ton weight falling down a precipice of 550 feet of perpendicular height.'

From Mr. Joule's investigation of the relation existing between chemical affinity and mechanical force, it appears that when affinity is feeble it can be overcome mechanically. He formed amalgams of different metals, that is he combined them with mercury, by electricity. The affinity of iron for mercury is so feeble that the amalgam is speedily decomposed when left undisturbed by the pressure of the atmosphere, and if a greater pressure be added, almost all the mercury is driven out. The efficacy of mechanical force to overcome feeble chemical affinities is strikingly illustrated by the amalgam of tin, out of which nearly the whole of the mercury is driven by long continued pressure. In these cases the force of affinity did not amount to chemical equivalency, otherwise the mercury could not have been driven out by so small a force. Instances from the weakest to the strongest affinity show that it is only when the power reaches a definite point that the law of chemical equivalents comes in. The intense energy which then begins to be exerted has just been shown.

It is vain to hope for a knowledge of the *absolute* weight of the ultimate atoms of matter, and nothing seems to be more beyond the power of man than to determine even their relative weights; yet the definite proportions in which they combine have enabled him to do so. Thus, an atom of oxygen unites with an atom of hydrogen to form water; but as every drop of water, however small, contains eight parts by weight of oxygen, and one part by weight of hydrogen, it follows that an atom of oxygen is eight times heavier than an atom of hydrogen. Now, since hydrogen gas is the lightest body known, its atom has been assumed as the unit of comparison. Hence, if the unit of hydrogen be represented by 1, that of oxygen may be represented by 8. Again, carbonic acid gas contains six parts by weight of carbon, and eight parts by weight of oxygen, and as an atom of oxygen is eight times heavier than an atom of hydrogen, therefore an atom of carbon is six times heavier than an atom of hydrogen, and consequently may be represented by 6. In this manner the relative weights of many substances have been determined. But the property of isomorphism also affords the means of ascertaining the atomic weights of certain substances with unerring certainty. It is exactly the contrary of dimorphism, for in the latter substances are chemically the same under different forms; whereas isomorphic bodies are chemically different under the same form. Now the peroxide of manganese contains one atom of oxygen for one atom of metal; but in 100 parts of the protoxide there are 21·94 parts of oxygen and 78·06 of manganese. Comparing these numbers with 8 the atomic weight of oxygen, the result is 28 the weight of an atom of manganese. The same number is obtained from two other isomorphic compounds of oxygen and manganese, which proves the accuracy of this result. The atomic weights of many bodies have been determined, of which the following are the most important.

Atomic Weights, an Atom of Hydrogen being the Unit.

Hydrogen	1	Bromine	80
Carbon	6	Copper, Zinc	32
Oxygen	8	Chlorine	35·5
Nitrogen	14	Potassium	39
Sulphur, Phosphorus	16	Rubidium	85
Sodium	23	Cæsium	123
Iron, Nickel, Manganese	28	Iodine	127
		Thallium	204

In the determination of atomic weights a few cases have occurred of fractional numbers, and although it cannot yet be affirmed that no such cases exist, yet it seems to be established by the new and more perfect analyses of MM. Dumas, Isidore, Williamson, and others, that the atomic weights of substances compared with an atom of hydrogen are in whole numbers.

This law leads to very important results. For example, the equivalent weights of the chemical elements of bodies derived from their specific gravities are either identical with, or simple multiples or sub-multiples of, their relative weights. Thus the specific gravity of hydrogen is 0·0693, and that of oxygen is 1·111; hence taking hydrogen as the unit of comparison, it is easy to see that 0·0693 : 1·111 :: 1 : 16, the simple multiple of 8, the relative atomic weight of oxygen. In fact since each substance has its own specific gravity or weight, that weight must depend upon the weight of its atoms, so that the weights of equal bulks of different substances are proportional to the weights of their atoms, and thus a relation is established between the atomic weights and specific gravities of bodies, so that one being given the other may be found.

Atoms like their substances have many different capacities for heat and electricity. It was proved by MM. Petit and Dulong, that specific heat, or the quantity of heat required to raise a simple substance to a given temperature, is inversely as the weight of its atoms, so that the specific heat or repulsive force of simple substances multiplied by their atomic weights is a constant quantity. Such is the condition requisite for the equilibrium or equality of force; or the law may be thus expressed: A given quantity of heat will raise to the same number of degrees a portion of every simple substance represented by its atomic weight. For instance, the atomic weight of sulphur is 16, that of zinc 32; hence it requires twice as much heat to raise a pound of sulphur ten degrees as it does a pound of zinc. It has also been proved that the atoms of compound bodies of analogous composition are endowed with the same capacity for heat, so that there is a perfect correspondence between the weight of atoms and their specific heat. The numbers representing the atomic weights derived from the specific heat of bodies are connected with their equivalent atomic weights by the simple ratios of equality, multiples or sub-multiples.

Mr. J. Croll has made experiments showing that the specific heat of compound gases and liquids is generally less, and those of solids more, than that of their component elements, which is contrary to the hitherto received opinion. Moreover it appears that the changes in the specific heat of bodies which occur during combination are not only due to chemical action, but also to molecular changes; the real specific heat of a simple atom probably remaining the same under all conditions.

Mr. Faraday has proved that the specific electricity of different substances is also in proportion to their atomic weights, that is to say, a given quantity of electricity will separate combined substances into parts represented by their atomic weights. For example, 32 parts of zinc will generate voltaic electricity enough to separate nine parts of water into eight parts of oxygen and one part of hydrogen gas. The weights thus derived from decomposition are exactly the same with those determined by composition, and thus the atomic weights derived from electro-decomposition accord exactly with those obtained from chemical composition. Moreover, Mr. Faraday, as already mentioned, proved that the very same quantity of electricity necessary to decompose a body into its elementary atoms, is requisite to unite them again. The analysis and synthesis of compound matter, solid or fluid, show a constant and definite proportion of the component elements expressed by number, and by an equivalent or multiple ratio of parts in every chemical change.

The atomic theory unites, by a common bond, specific gravity, chemical affinity, heat, and electricity. Taking atmospheric air at the temperature of 60° Fahr. and a barometric pressure at 30 inches as the standard unit of specific gravity; the quantity of heat required to raise a volume of water 1° Fahr. as the unit of specific heat; hydrogen gas as the unit of atomic weight; and atomic electro-chemical electricity as the unit of specific electricity, the following numbers have been established:

	Specific gravity	Equivalent atomic weight	Specific heat	Specific electricity
Hydrogen	0·0693	1	0·2936	1000
Oxygen	1·111	8	0·2361	125
Carbon	13·2	6	0·2631	
Nitrogen	0·978	14	0·2750	

The distances between the atoms of the gases are equal, hence the atomic weights of simple gases are proportional to their densities; and for the same reason, equal volumes of the same fluid contain an equal number of atoms, and the number of atoms in the same volume of different fluids is in the simple ratio of one to one, one to two, one to three, &c.

It follows from the atomic theory that the number of atoms in equal weights of any two solid substances, is in the inverse ratio to the weights of these atoms. Now since the bodies that have the greatest specific gravities are the heaviest, if the specific gravities and atomic weights of equal bulks of two simple substances be known, the relative number of atoms they contain may be found. For the density divided by the atomic weight of the one, is to the density divided by the atomic weight of the other, as the number of atoms in the first to the number of atoms in the second. By the preceding law it is found that in equal bulks of the three metals, sodium, platinum, and potassium, platinum contains five times as many atoms as sodium, and ten times as many as potassium. When substances which have strong analogous qualities are compared in this manner, the results are either equality, or a simple ratio.

It has already been mentioned that the protoxides of iron, copper, zinc, nickel and manganese, have the same form, and contain the same quantity of oxygen, but differ in the respective metals that are combined with it; and by the preceding law it appears that equal bulks of these isomorphous bodies contain also the same number of atoms.

Mr. Hermann Kopp has proved that the atomic weight of a substance divided by the specific gravity, that is to say, its atomic volume, is the same for all isomorphic bodies simple and compound, and as a general law that the atoms of isomorphous substances are not only the same in form, but equal in dimensions. It follows, therefore, that any one of the preceding metals might be substituted for any other in the respective protoxides, and on that account, according to the modern theory, they are the chemical equivalents of each other, for that expression is used now in a different sense from what it formerly had. Chemical equivalency between two or more substances consists in their capacity for being exchanged one for the other. Direct or indirect substitution forms the basis of the modern doctrine of chemical equivalents.

Substances which are capable of replacing one another in compounds, and which are endowed with qualities mutually analogous, are said to be isomeric. Many isomeric compounds are formed of the same materials, in the same proportions, and yet differ essentially both in their physical and chemical properties; whence M. Daniel observes, that a specific and definite arrangement of the constituent molecules in space appears to be no less essential to the individual constitution of bodies than a certain proportion between their heterogeneous ingredients.

Successive substitution in isomeric bodies does not alter the character of the chemical formulæ of these bodies; thus chlorine, bromine and iodine, are chemically equivalent with an atom of hydrogen, for they may be put for one or more atoms of hydrogen in various compounds without changing the character of the chemical formulæ of these compounds. The peroxide of hydrogen consists of one atom of hydrogen and two of oxygen; hence if 32·5 parts of zinc, 28 of manganese, and 29 of copper be successively put for the atom of hydrogen, the result will be the peroxides of zinc, manganese and copper respectively. Here the character of the chemical formula of the original compound remains the same, and the three metals are chemically equivalent to one another, and to the atom of hydrogen. In many compounds organic and inorganic, one or more atoms of hydrogen may be replaced by an equal number of atoms of sodium, potassium, zinc, &c., without altering the character of the chemical formula of the compound.

Olefiant gas, olefiant oil and paraffin, form an isomeric series of a gas, a liquid and a solid, consisting of carbon and hydrogen. The gas contains 86 parts in 100 of carbon, and forms the most luminous part of coal gas.

M. Dumas has proved it to be a general law, that when three isomeric bodies are arranged in the sequence of their chemical properties, there will also be a sequence in their respective atomic numbers, and that whenever this symmetry of chemical properties and atomic weights obtains, any one of these substances may be substituted for the other without changing the chemical character of the formula.

Sulphur, selenium, and tellurium, form an isomeric group; that is, they form a sequence, with analogous qualities, for sulphur is the most volatile; selenium, a simple substance found in iron pyrites in Sweden, is less volatile; and tellurium is the least volatile and with regard to their atomic sequence, the atomic weight of sulphur is 16, that of tellurium is 64, and half the sum of these numbers is 40, the atomic weight of selenium, the mean term. Hence selenium might be put in any compound for the sulphur, and the tellurium for the selenium, without changing the chemical character of its formula.

The metallic group of calcium, strontium, and barium, are endowed with analogous properties, perfect harmony in their chemical qualities, and in the numbers expressing their atomic weights. That of calcium is 20, that of barium is 68, and the half sum is 44, the atomic weight of strontium. So calcium might be put for strontium, and strontium for barium, in any compound without altering the character of its formula. Professors Johnson and Allen have shown that the new metalloids cæsium and rubidium form an isomeric triad with potassium, for the atomic weight of cæsium is 133, that of rubidium 86, and that of potassium 39.

Transmutations of one isomeric substance for another may also be made in organic bodies, but chlorine, bromine, and iodine form an exception to M. Dumas's law, because the arithmetical relation is wanting.

There are certain groups of substances, especially among the metals, whose atomic weights are in regular arithmetical series, as those of titanium, tin, and tantalum, which are 25, 59, and 92, the common difference being 34.

Certain groups of combined atoms called compound radicles are much more important than the preceding. They unite chemically with one another, and with other substances in definite proportions, precisely as if they were ultimate atoms. They are even capable of being substituted one for the other, forming groups of infinitely varied properties, and thus chemical equivalency extends to them.

Cyanogen, amidogen, and the peroxide of hydrogen are compound radicles which combine with other substances and with simple atoms as if they themselves were simple elements; though the first is a chemical compound of two atoms of carbon and one of nitrogen, the second a chemical compound of one atom of nitrogen and two of hydrogen, and the peroxide contains as before mentioned two atoms of oxygen and one of hydrogen. All three are capable of replacing hydrogen, chlorine, and metals by equivalent substitutions. For example, the chlorate of potash consists of one atom of potash, an atom of chlorine, and five atoms of oxygen; if then an atom of cyanogen whose weight is 26, be put for the atom of chlorine, the result would be the cyanate of potash.

Cyanogen, formed by passing nitrogen over red-hot carbon, consists of two equivalents of carbon and one of nitrogen. It is a frequent constituent of organic and inorganic compounds, and travels in the voltaic circuit as if it were a simple substance.

Ammonia consists of three equivalents of hydrogen and one of nitrogen; now, when the radical phenyle, which consists of twelve equivalents of carbon and five of hydrogen, is put in the ammonia for one equivalent of hydrogen, the result is aniline, whence most of the coal tar colours are obtained. In like manner carbazotic acid, a beautiful yellow dye from coal tar, is carbolic acid, three of whose equivalents of hydrogen have been replaced by three equivalents of an oxide of nitrogen.

Compound radicles, consisting of carbon and the three elementary gases, have been discovered which enter into combination in definite proportions as simple atoms, and all compound radicles travel in the galvanic circuit as equivalents to the elementary substances. Hitherto they have been regarded as representatives or equivalents of one atom of hydrogen. Now it is generally admitted that each has the property of replacing two, three, or more atoms of hydrogen by equivalent substitution. This multiple equivalency among compound radicals forms the basis of what is called the polyatomic theory, now so much employed by MM. Hofmann, Berthelot, and other great modern chemists.

Water is the most common radicle both in the inorganic and organic world. Though a compound of oxygen and hydrogen, it enters, according to the law of definite proportion, into the composition of various amorphous bodies in a dry state, that is in the form and proportion of its gases. It is an essential element in the greater number of crystals, and abounds in organic matter. In certain cases the same substance crystallizes at different temperatures, unites with different quantities of water under the form of oxygen and hydrogen, and assumes corresponding forms. For example, the seleniate of zinc unites with three different portions of water and takes three different forms, according as its temperature is hot, lukewarm, or cold. Thus each particle of water, containing one atom of oxygen and one of hydrogen, combines with one atom of zinc in three different proportions as if it were a simple atom.

The water of crystallization may be driven off from many substances by heat, as from the hydrates of lime, iron, copper, &c., but when combined with the oxides of certain metals, potassium for instance, it cannot be driven off by any means whatever. In general a heat of 212° Fahr. is sufficient, but some crystals lose their water of crystallization at the ordinary atmospheric temperature.

Crystals whose atoms are in unstable equilibrium, are readily altered both externally and internally by a very moderate degree of heat. Arragonite and calcareous spar are isomeric, that is, they are chemically the same but differ in form and hardness, which shows that their molecules are grouped differently. When the arragonite is heated, the inertia of its atoms is overcome, the crystal explodes with force, and becomes a mass of crystals of calcareous spar. The expansive force of the heat suddenly overcoming the force of cohesion causes the explosion, and at the same time disturbs the unstable repose of the atoms, which immediately obey their natural attractions and assume the stable form of calcareous spar.

Dialysis is a method of separating and analysing substances by means of their diffusion in alcohol or water. If a wide-mouthed vial nearly full of a solution of common salt be placed in a jar of water, after a few days it will be found that the particles of salt have come out of the vial and have diffused themselves through the superincumbent water, even to its surface. Now Professor Graham, Master of the Mint, with whom this subject originated, made three arrangements precisely like that described; the three vials were exactly similar and equal, the three jars exactly the same in size and form, and contained the same quantity of water; but the first vial contained a solution of gum arabic, the second a solution of Epsom salt, and the third a solution of common salt. After fourteen days the diffusion of the gum had risen through one half of the superincumbent water, while the particles of both the salts had risen to the surface. However the common salt would have risen much higher, for when the strata of water at the two surfaces were drawn off by a siphon and evaporated to dryness, there was fifteen times as much common salt as Epsom salt. The three solutions are heavier than water, yet they rise notwithstanding their gravitation, whence Mr. Graham thinks that there is probably an attraction between the particles of the dissolved substances and those of the water. The force of molecular attraction is more powerful than gravitation, hence the particles must rise by the difference of the two forces.

After many comparative experiments the professor concluded that most substances differ in diffusibility, and that crystalloids or crystalline substances such as salts, sugars, &c., are much more diffusible than colloids or amorphous sticky bodies, such as gum, caramel, jellies, and substances that combine with the hydrogen of the water to form gelatinous hydrates. *

The partial decomposition of definite chemical compounds may be effected by diffusion. Alum, which is a double sulphate of the two metals potassium and aluminium, furnishes an example; when allowed to diffuse itself from its aqueous solution, the diffusive tendency of potassium compounds is so much greater than the diffusive property of aluminium compounds, that a portion of the sulphate of potassium actually breaks away from the sulphate of aluminium with which it was combined, in order to diffuse itself in the super-

* absurd mistake – hydrates are not compounds of hydrogen but of water

incumbent external water more freely than the sulphate of alumina can do.

Common salt diffuses itself in a solid mass of jelly almost as easily and extensively as in the same bulk of free water. Thus colloid bodies do not interfere with the diffusion of crystalloids such as salts, but they almost entirely arrest the diffusion of one another. Solutions of salts, sugars, and other crystalloids pass freely through colloid substances, such as parchment-paper, vellum, and membrane into water, although they have no pores, because the particles of the crystals unite diffusively with the water combined in these substances, which solutions of gum, caramel, and other colloids cannot do. These colloid substances are permeable to solutions of crystalloids, impermeable to solutions of colloids. This constitutes Dialysis.

The instrument used by Mr. Graham was a little tray formed of vellum or membrane stretched tightly over a hoop of gutta-percha and capable of holding a liquid and floating on water. When a mixed solution of equal parts of salt and gum is put into the tray, after a time all the salt will have passed into the water below, leaving nothing in the tray but an aqueous solution of gum.

The following is one of the most extraordinary results of dialysis. Mr. Graham took a silicate of soda, a soluble crystalline salt formed by fusing quartz with carbonate of soda at a red heat, which diffuses readily. He acidulated the aqueous solution of the salt with hydrochloric acid, which changes the constituent silica from being a crystalloid substance into a colloid form. When the liquid was poured into the tray floating on water, after four days, the whole of the acid and the chloride of sodium had been diffused in the water and nothing remained in the tray but an aqueous solution of quartz. There remained in fact, a solution of sand in water, a substance so hard that no pure aqueous solution of it had ever been obtained. Many other crystalline substances besides quartz can exist both in the colloid and crystalloid states.

All colloid substances are characterized by non-crystalline habits, low diffusibility, chemical inertness, high atomic weight, and above all by their mutability. The aqueous solution of quartz is limpid and liquid, even if it contains 14 per cent. of silica, but after a time it becomes opalescent, viscous, and ultimately sets into a firm insoluble jelly, capable however of solution by chemical means. This jelly gradually shrinks, exudes pure water, and when perfectly dry it forms a glassy, transparent, but not anhydrous substance, and the residue left by ignition has a specific gravity of 2·2, that of crystallized silica being 2·6.

Mr. Graham has obtained many pure aqueous solutions of organic and inorganic matter, most of them being unstable. Ice near or at its melting point is believed to be a colloid body, consequently it is unstable and resembles a firm jelly, having a tendency to rend and recombine. 'The constant intervention of colloid septa in so many of the phenomena of animal and vegetable life gives to the subject of dialysis a high physiological interest, and it will doubtless exercise an important influence on the progress of physiological research.' [3]

Subsequently to these researches Mr. Graham published a memoir on a new method of analysing gases which he had called atmolysis. The memoir may be regarded as consisting of four parts, the first of which is preliminary, being on the reciprocal diffusion of gases through porous plates. The next three parts relate to effusion, or the passage of gases under constant pressure

[3] Lectures of much interest by Dr. William Odling in the *Chemical News* of 1862.

through a minute opening in a very thin plate into a vacuum; transpiration, or the passage of gases through capillary tubes into vacuo; and lastly atmolysis, which is the partial separation of a mixture of gases and vapours of different degrees of diffusibility by permitting them to diffuse themselves through a porous plate into a vacuum: a new kind of analysis, which possesses a practical character of extensive application.

The diffusing instrument employed by Mr. Graham was a cylindrical glass tube about an inch in diameter, ten inches long, with one end closed by a very thin porous disc of compressed artificial graphite fixed by a resinous cement. While the tube was being filled with hydrogen gas over a trough of mercury, the escape of the gas was prevented by covering the graphite very carefully with a thin sheet of gutta percha. As soon as the gutta percha was removed, the reciprocal diffusion of the gases began, and in from forty to sixty minutes the whole of the hydrogen had escaped from the tube, and a quantity of atmospheric air amounting to about one fourth of the volume of hydrogen had entered the tube and taken its place, according to the ordinary law of the diffusion of gases. During this time the mercury rises in the tube so as to form a column several inches high, a fact which is a striking demonstration of the intensity of the force with which the reciprocal penetration of different gases effected.

Natural plumbago or graphite has little or no porosity and cannot be used in these experiments, but the pores of artificial graphite of which pencils are made, appear to be so minute that only isolated molecules of gas are able to pass, without however being at all impeded by friction; for the smallest pores that we can suppose to exist in the graphite must be real tunnels compared with the minuteness of the ultimate atoms or molecules of a gaseous body. The cause of motion appears to reside solely in that internal movement of molecules which is now generally admitted as an essential condition of matter in a gaseous state. The molecules and atoms are assumed to be perfectly elastic and to move in all directions with different velocities according to the nature of the gas. Enclosed in a porous vessel the moving atoms constantly strike against its walls and against one another, but in consequence of their perfect elasticity, no loss of movement results from the collision. When the gases inside and outside of the tube are of the same density and molecular movement, an exchange takes place without any perceptible change of volume; but when the two gases are of different densities and molecular velocities, then the reciprocal penetration ceases to be equal on the two sides. Reciprocal diffusion of gases is accelerated by heat and retarded by cold; the tension of the gases is increased in the first case, and diminished in the second.

In Mr. Graham's experiments relating to effusion, a gas under a constant pressure was on one side of a minute opening in a very thin plate, and a vacuum on the other. The rapidity with which air or gases enter the vacuum depends upon their specific gravity. A gas rushes into a vacuum with the speed acquired by a heavy body in falling from the height of an atmosphere of the gas in question supposed to be everywhere of the same density. The height of this uniform atmosphere will be in an inverse ratio to the density of the gas. An atmosphere of hydrogen, for example, will be 16 times higher than one of oxygen. But the velocity acquired by a heavy body not being in direct proportion to the height, but to the square root of the height, it follows that the rate of flow of different gases into a vacuum will be in an inverse ratio to the square root of their respective densities. The rate of flow of oxygen being represented by 1, that of hydrogen will be represented by 4 the square root of 16. This law has been verified by experiment, and is quite analogous to that which regulates molecular diffusion, but the phenomena are essentially different. It is the gas *en masse* which partakes of the movements of effusion, whilst only the molecules or atoms of a gas are affected by the movements of diffusion. For that reason the swiftness of the effusion of a gas is many thousand times greater than that of diffusion. The swiftness of the efflux of atmospheric air is as rapid as the velocity of sound.

The rate of the flow of different gases under constant pressure through capillary tubes into a vacuum, constitutes the capillary transpiration of gases. These rates bear a constant proportion to one another, but they are singularly unlike the rates of effusion. They are independent of the material of the tube; they are not governed by specific gravity; and 'they appear to be in constant relation with no other known property of the same gases; and they form a class of phenomena remarkably isolated from all else at present known of gases.'

The pores of graphite are so fine that it is incapable either of effusion or transpiration, but it is readily penetrated by means of the molecular or diffusive movements of gases, as appears on comparing the time requisite for the passage of equal volumes of different gases under constant pressure into a vacuum. For oxygen, hydrogen and carbonic acid gas, the times are nearly as the square roots of their densities.

The atmolysis or partial separation of mixed gases and vapours of unequal diffusibility, can be effected by allowing the mixture to penetrate through a graphite plate into a vacuum. The amount of separation is in proportion to the pressure, and attains its maximum when the gases pass into a perfect vacuum. One of the results of atmolysis was the concentration of oxygen in atmospheric air. When a portion of air confined in a vessel was allowed to penetrate into a vacuum through graphite or unglazed earthenware, the nitrogen passed more rapidly than the oxygen in the ratio of 1·0668 to 1, and the portion of oxygen is proportionally increased in the air left behind in the vessel. The increase of oxygen actually observed when the air in the vessel was reduced from 1 volume to 0·5 was 0·48 per cent. The diffusion was continued till the air in the vessel was reduced to 0·0625 and the concentration of the oxygen in it amounted to 2·02 per cent. The molecular or diffusive mobility exercises a certain influence on the heating of gases by contact with heated liquid or solid substances. The more rapid the molecular movement of a gas is, the more frequent will be the contact of the molecules and the quicker will be the communication of heat. The greater cooling power of hydrogen compared with that of oxygen or air is probably owing to that cause. 'Oxygen and hydrogen gas have the same specific heat for equal volumes; but a hot object placed in hydrogen is really touched 3·8 times more frequently than it would be if placed in oxygen gas. Dalton had already ascribed this peculiarity of hydrogen to the high mobility of the gas.'[4]

It appears that isomorphic substances such as chloride, bromide, and iodide of sodium, have a similar diffusibility, another of the many analogies between these singular marine substances.

Modern chemistry is essentially experimental; the unprecedented magnitude to which British manufactures have risen is chiefly owing to experiments conducted with consummate skill and dexterity. In these investigations, accidental circumstances have sometimes occurred which led to other researches quite different

[4] M. H. Kopp.

from that originally in view, which have had unexpected and invaluable results. Although the simple elements are few, they are capable of an infinite variety of combinations, so that by analysis and new combinations, the most useful and valuable materials are now obtained from obnoxious or useless substances, formerly thrown away. The instances are numerous; but sawdust may be mentioned as one of the most remarkable. It was not even fit for fuel, but now oxalic acid, a bleaching principle most extensively used in the various processes of calico printing, is procured from it; the quantity required may be imagined, since the cotton cloth annually printed in Great Britain previous to the American war, would surround the earth's equator nineteen times. Oxalic acid, which is a vegetable substance, found combined with potash in wood sorrel or Oxalis acetosella, used to be made from sugar or starch, by the action of nitric acid. Now starch, sugar, and * woody fibre ~~or fibrine~~, all contain twelve parts of carbon and different portions of oxygen and hydrogen, always in the proportions that form water; hence the name of carbohydrates. Their composition is so similar that the one may be changed into the other by the addition or subtraction of one or two atoms of water under its atomic form; thus when fruits ripen, the starch they contain is changed into sugar by the addition of one atom of water under its dry form.

Now sawdust is woody fibre, and might be changed by nitric acid into oxalic acid like the others. But a less expensive method is actually employed.

When sawdust, mixed with two equivalents of the hydrate of soda and one equivalent of the hydrate of potash, is exposed to a heat of 400° for a few hours, the substances are fused, and when raised to a still higher temperature the hydrates are decomposed: hydrogen is evolved, and the carbon combines with the oxygen to

* woody fibre is cellulose or lignin, not fibrin. This latter is an entirely different substance

form the oxalate of soda and the oxalate of potash. In order to separate these oxalates they are put into a filter, a solution of carbonate of soda is passed through it; the oxalate of soda remains in the filter, the carbonate of potash passes through it; and when lime is added to the oxalate of soda, the soda is liberated, passes through the filter, and the oxalate of lime remains. Sulphuric acid is then added to the oxalate of lime, sulphate of lime is formed, and oxalic acid mixed with water remains, and by evaporation forms into beautiful crystals of oxalic acid. This is an instance of a complicated chemical process; nevertheless it is carried on to a vast extent in Manchester, nine tons a week being furnished by one manufactory alone. Two pounds of sawdust yield one pound of oxalic acid.

In ordinary distillation a volatile substance such as water, by absorbing the heat applied to it, becomes converted into vapour; by abstracting the absorbed heat from the vapour, it is reconverted into the original substance. Destructive distillation, on the contrary, consists of an entire destruction of the original substance and a simultaneous production of new substances. Of this the destructive distillation of coal furnishes the most interesting illustration, and shows at the same time the success of modern chemistry in utilizing waste substances.

Coal had been distilled for years to furnish gas for the illumination of our cities before it was discovered that the refuse contained principles of the greatest value. The products of the distillation are threefold: gas, coal water, and coal tar.

Coal gas is a combination of various gases, whose illuminating properties depend upon, and are exactly in proportion to, the quantity of carbon they contain. The particles of carbon raised to a white heat give the light, for the gaseous part has a feeble flame, and requires a higher temperature than solid matter, which becomes luminous at about 700° in the dark, and at from 1000° to 2000° in bright daylight. Coal gas consists of a combination of illuminants: olefiant gas, which contains 86 per cent. of carbon, carburetted hydrogen or marsh gas, which contains 75 per cent., carbonic oxide, carbonic acid gas, hydrogen, sulphuretted hydrogen, and a very small quantity of nitrogen, besides the bisulphide of carbon, and benzol, a pure hydro-carbon, consisting of 12 equivalents of carbon and 6 of hydrogen.

The poisonous quality of coal gas is owing to the carbonic oxide, which is fatal to life, and its explosive quality to carburetted hydrogen, which also is generated by decomposition of vegetable matter in stagnant pools and marshes; and in the firedamp of mines it still bears testimony to the vegetable origin of coal. That fatal gas increases in explosive force as it mixes with atmospheric air, and is at a maximum when it amounts to 12 per cent. Hydrogen, carburetted hydrogen, and carbonic oxide do not add much to the light, on account of the feeble flame of hydrogen and the small quantity of carbon they contain, but they force the chief illuminating gases out of the iron retorts in which the coal is distilled before the heat has had time to decompose them, and they also enable them to burn without smell or smoke.

Carbonic acid, bisulphide of carbon, and sulphuretted hydrogen are impurities from which coal gas is freed before it is fit for use. By passing the gas over lime, the lime absorbs both the carbonic acid and the sulphuretted hydrogen; one per cent. of carbonic acid diminishes the illuminating power six per cent., and the sulphuretted hydrogen has an abominable smell.

The bisulphide of carbon, consisting of one equivalent of carbon and two of sulphur, is got rid of by passing

* Olefiant gas is [illegible] more explosive than Carburetted hydrogen

the gas over hot lime. The water of the lime is decomposed, and carbonic oxide and sulphuretted hydrogen are produced; but the latter may be absorbed by passing the gas again over lime, or through a mixture of sawdust and the oxide of iron. The oxide of iron decomposes the sulphuretted hydrogen, forms water and sulphide of iron, then the air restores the sulphide to oxide, and the sulphur is deposited in the mixture. After passing the gas through it till none of that impurity remains, the gas is fit for use. The test is the nitro-prusside of sodium, which the gas stains purple if any of the impurity remains.

Paraffin, already mentioned as isomeric, is a pure hydrocarbon, colourless, transparent, and of crystalline texture. It melts at a heat of 120° or 130°, burns like wax without smell or smoke, and makes beautiful candles, which give a brilliant light on account of the 86 per cent. of carbon they contain. Paraffin oil is much used for lamps; the manufacture of these two substances at Bathgate is one of the largest chemical establishments in the world.

The black fœtid gas water resulting from the distillation of coals, formerly thrown away, is so rich in the salts of ammonia, that it has become the chief source from which these materials so important in the arts are obtained.

Ammonia is well known to be a colourless gas, with an acrid pungent smell, consisting of one equivalent of nitrogen and three of hydrogen. It has an alkaline character, combining with acids, and is extremely soluble in water.

Now the gas water contains carbonate of ammonia and sulphide of ammonium, and when any acid strong enough to decompose these substances is put into the liquid, the carbonic acid and sulphuretted hydrogen being volatile are driven off, and the acid combines with the ammonia to form a salt. For example, when muriatic acid is put into the liquid, it drives off the volatile gases and combines with the ammonia in solution to form muriate of ammonia, which is dissolved in water and evaporated till it crystallises; then it is vaporized and sublimed to free it from impurities.

When ammonia and muriatic acid are separately vaporized, the two colourless transparent vapours, when mixed, combine into solid muriate of ammonia, a result so unexpected that as Mr. Playfair justly observes, it could only have been taught by experiment. About 4,000 tons of muriate of ammonia are annually made from gas water in England for soldering, and for making alum.

Sulphate of ammonia to the extent of 5,000 tons is annually made by adding oil of vitriol to the liquid. It is also used for making alum, as well as for manure; it supplies our grain with nitrogen, an important article of vegetable food. To these may be added 2,000 tons of carbonate of ammonia, so that a substance that was considered to be good for nothing yields 11,000 tons of valuable materials, but even this quantity forms only part of the enormous amount annually consumed in the manufactures of Great Britain.

Coal tar is of complicated nature, containing a variety of substances, many of which are more or less volatile. When it is distilled by sending a current of steam through it, the steam collects the volatile parts, condenses them into naphtha; the first product is condensed steam or water with naphtha swimming on its surface, the next product is dead oil, and the remainder is pitch.

By the aid of the crude naphtha thus produced, Indian rubber is dissolved and waterproof clothes are made. When purified by sulphuric acid, it forms a substance like tar which is thrown away, and the remaining products when clarified are acid oils and neutral hydrocarbons. The carbolic and cressylic acids are the most important of these acid oils. The carbolic acid, which has the property of arresting the putrefaction and decay of organic matter, consists of 12 equivalents of carbon, 6 of hydrogen, and 2 of oxygen. The cressylic acid only differs from the preceding by having two more equivalents of hydrogen and two of oxygen in its chemical composition.

Creosote is a mixture of these two acids. Those vast beams of wood that are driven as piles into the sand or mud at the bottom of the sea, as well as the timbers that form marine superstructures, are saturated with it to a certain depth to preserve them from the attacks of marine insects, especially Limnoria terebrans, an isopod crustacean, which is so destructive in some of our harbours. The wood is deprived of its air by heat and the creosote easily enters.

Carbolic acid is liquid, but becomes solid when purified and dried; and as already mentioned the brilliant yellow dye, carbazotic acid, one of the coal tar colours, is a compound radical, in which the peroxide of nitrogen has replaced three equivalents of hydrogen. The other coal tar colours are obtained from the neutral hydrocarbons, that is to say, compounds of hydrogen and carbon, such as benzol, toluol, and other analogous substances.

Benzol, which consists of 12 equivalents of carbon and 6 of hydrogen, is very volatile, boiling at 117° Fahr., and when acted upon by nitric acid, it forms a compound radicle in which one equivalent of oxide of nitrogen takes the place of one of hydrogen. It smells strongly of bitter almonds, and may be used with safety instead of them. When water and iron are mixed with nitrobenzol, the iron combines with the oxygen and forms oxide of iron, and the result is rusted iron and aniline, which is the origin and foundation of the coal tar colours. Now aniline consists of 12 equivalents of carbon, 7 of hydrogen, and 1 of nitrogen. It is a compound radical: it is ammonia in which one equivalent of hydrogen has been replaced by the radical phenyle, consisting of 12 equivalents of carbon and 5 of hydrogen. It may be remarked that in all these chemical operations the quantity of carbon has remained the same.

Aniline is a colourless liquid, and, being an analogue of ammonia, it readily combines with the different acids to form the beautiful coal tar dyes, for which the world is indebted to the brilliant researches of Dr. Hofmann, professor of chemistry.

By combining a solution of the chloride of lime with the colourless liquid aniline, he obtained the beautiful colour mauve, but it could not be used as a dye till it was rendered permanent by his pupil, Mr. Perkins. His next discovery was the rich crimson crystalline dye magenta, which M. Verguin first introduced into trade at Lyons as a dyeing agent. It may be produced by mixing the anhydrous bichloride of tin with aniline and then driving off the excess of aniline by heat. Other metallic chlorides, nitrates, and many oxidizing agents, have the power of converting aniline into magenta; as for example when the two colourless liquids acetic acid and aniline are mixed and heated, a chemical combination takes place in which three atoms of ammonia have coalesced into one, a salt is formed which is the acetate of aniline or magenta. Here two liquids unite to form a solid and as in many other instances the resulting substance has the power of decomposing light which neither of its constituents can do. Magenta has a redder tint than mauve, and on that account it is sometimes called aniline red. Professor Hofmann has discovered quite recently that pure aniline has not the property of producing these colours, but that they originate in an impurity of the aniline called toluidine.

Rosaniline or roseine, a white substance, is the base of aniline. It is a powerful alkali, readily combining with acids to form highly coloured salts, many of which have a tendency to crystallize, like magenta. This base is most easily extracted from the acetate of aniline. The boiling solution of that salt decomposed by a large excess of ammonia, yields a crystalline precipitate of a reddish colour, and when the colourless liquid is separated by filtration from the precipitate, it deposits on cooling perfectly white needles and tablets of pure rosaniline. This substance unites to acids in three different proportions forming three kinds of salts. The salts that contain one equivalent of acid are extremely stable compounds; for the most part they have a green metallic reflection like some insects' wings; by transmitted light they are red, and their solutions in alcohol have the magnificent crimson colour of magenta.

A bright purple dye is furnished by mixing equal weights of magenta and aniline. When this mixture is kept at the temperature of 329° for some hours and then mixed with water and hydrochloric acid to remove any excess of magenta or aniline, the result is an insoluble purple residuum or precipitate, but which when well washed with water becomes soluble in alcohol and boiling water slightly acidulated with acetic acid. When the insoluble purple residue is boiled several times with dilute hydrochloric acid, a fine blue dye is formed; azuline, the most beautiful of the blue dyes, which resists the action of the strongest acids, and which is produced by oxidizing aniline under high pressure. It was first prepared at Lyons from phenic acid, a product of the distillation of coal; when pure it appears under the form of copper bronze-coloured crystals soluble in alcohol, to which they communicate a magnificent blue colour tinged with red; but most of the blue dyes are derived from carbolic acid and from creosote. A blood-red colour is the direct result of mixing the muriatic and phenic acids. Aniline, the great source of the coal tar colours, yields also a fine yellow. A vast deal of talent has been employed in the research of colouring dyes both at home and abroad, in which the manufacturers themselves have shown great scientific knowledge.

Attempts have been unsuccessfully made to obtain a green dye from chlorophyll, the green colouring matter of plants. The want was for a short time supplied by Lo-hao, a Chinese dye, but being unstable it was given up. However the very same substance has been procured from the Rhamnus cathartica (Buckthorn), one of the commonest European trees. M. Charwin of Lyons, who made the discovery, has utilized a waste substance, and rendered it permanent as a dye. It is the only known substance which with proper reagents is capable of producing all the seven colours of the spectrum.[5]

The coal tar colours have nearly superseded those from lichens which incrust rocks, walls and stems of aged trees with brilliant colours, which do not however furnish dyes directly; they yield a colourless crystalline substance which combines with alkalies to furnish very beautiful dyes; it is exactly the opposite of rosaniline, which is a base. The Variolaria dealbata yields litmus or orchil, from which the beautiful French purple is made. The Rocella tinctoria and fusiformis give blue and purple, and the pale yellow lichen, Parmelia parcolerina furnishes a bright yellow dye, which a little ammonia changes to a rich red, inclining to purple. Mauve was first made from orchil, but was not permanent. The fine dyes, alizarine blue, Turkey red and garancine, are still much in use. They are derived from madder, the dried roots of the Rubia tinctorum; the

[5] Lectures by Dr. Crace Calvert on improvement and progress of calico printing and dyeing since 1851.

madder dyes most extensively employed are alizarine and flower of madder. Mauve and other dyes are derived from guano, the offal of seabirds, which is imported in large quantities for manure.

The coal tar colours are manufactured on a highly scientific plan and most extensive scale in Great Britain, to supply the enormous quantity annually consumed in dyeing silk and printing cotton. In general, animal substances such as silk and wool can be permanently dyed at once, because they have a strong affinity or attraction for coloured dyes. If silk is destined to be a moiré, the silk before it is woven undergoes a chemical process in order to introduce fatty matter into it which gives a softness to the silk when woven and renders it fit to receive the moiré by intense pressure.

Cotton cloth has no affinity for dyes, which are washed out at once if not fixed by art, because cotton fibre consists of minute tubes generally open at the extremity, which imbibe the dye by capillary attraction, but cannot retain it unless fixed by a mordant, such as the white of a raw egg, which readily absorbs any dye that is mixed with it, and being then laid on the cloth in any pattern it is absorbed by the tubular fibres, and when coagulated by steam or any other application of heat it is immovably fixed. Both animal and vegetable substances afford a variety of mordants. Caseine or cheese, the curd of milk, which may also be obtained from pease and beans, is the mordant most used by calico printers; for if caseine be dissolved in twice the quantity of alkali necessary for its solution, it coagulates like white of egg and may be used in the same manner. Skimmed milk cheese from Scotland and Holland when purified is extensively used in calico printing. The quantity of mordants required is very great, for of all the cotton that was imported into Britain before the late American civil war, one seventh only was manufactured

+ This is not an accurate account of the action of mordants into muslin and printed calico, yet as already mentioned that was sufficient to envelope the earth's equator nineteen times, and twenty-seven millions of pieces were exported annually. Atmospheric electricity and ozone affect the process of dyeing, and east wind has a retarding and injurious effect. The Lyons manufacturers, not less celebrated for their scientific skill and taste than for the brilliancy of the colours, have an advantage in their fine climate and bright sun.

It is a singular circumstance that petroleum has existed in enormous quantities throughout the North American States and a great part of Canada, unnoticed and neglected till the year 1859, when its value was discovered, and it almost immediately formed a new and extensive branch of commerce, for during the succeeding year at least 1,000 wells were dug, some of which enriched the proprietors; others were a failure.

Petroleum from the fountains of Is, on the banks of the Euphrates about 120 miles from Babylon, furnished the asphaltic mortar for building Nineveh 2,000 years before the Christian era. There are many sources of naphtha, petroleum, and asphalt in Europe and Asia, which like those in Trinidad and Venezuela occur for the most part in rocks of the newer, secondary and tertiary formations, though sometimes in the lower. But in the northern part of the United States and Canada these substances occur in rocks of all ages from the lower silurian to the tertiary period inclusive; they are usually found in the limestones and more rarely in the sandstones and shales. Petroleum collects in the fissures of the rocks, chiefly in those that have a tendency downwards; in wells dug for it near one another, an abundant supply is furnished at all depths from 70 to 300 feet. In some parts of Ohio and Canada the ground is saturated with petroleum, so that it is believed there is enough in North America to supply the world for ages. In 1861 no less than 42,000,000 gallons of petroleum were sent to England. The wells are not without danger, for when they pass through the coal strata, the petroleum is accompanied by a * highly inflammable gas which on one occasion was accidentally set on fire; it ignited the petroleum, which was forced out as from the mouth of a volcano, and covered the ground with liquid fire far around; at the same time the burning gas formed an incandescent atmosphere which extended to a still greater distance.

The distillation of petroleum yields substances for the most part identical with those arising from the distillation of coal. The crude petroleum is put into an iron retort connected with a coil of iron pipes surrounded by cold water, called the condenser. Heat is applied to the retort, and from the open extremity of the condenser, a pale coloured liquid with a strong smell flows, which is very volatile and explosive naphtha. After the naphtha has passed over, an oil of excellent illuminating quality is distilled over. Steam is then forced into the retort, and a heavy oil is driven over, and there remains a black, oily, tarry matter, and a black cake used for fuel. After the naphtha has been repeatedly distilled, benzol is formed, and when the heavy oil is cooled to 30° Fahr., crystals of paraffin appear, which are separated from the oil by pressure, and when they are purified by alternate pressure and agitation in a melted state, they are moulded into candles. This paraffin is identical with that from coal. Among the products of the distillation of petroleum are naphthalin whence aniline is obtained, which yields mauve, magenta, and the other coal tar colours, also solferino which yields dianthine and other dyes and has been proposed as a substitute for chloroform and ether. Many other substances have been separated from petroleum which like some from coal have not yet been

* Coal strata have nothing to do with it. All petroleum is accompanied with inflammable gas

chemically examined. Most of the substances obtained from petroleum and the distillation of coal are common also to distilled peat, and now it is proposed to utilize sea weeds, in which the northern coasts of Scotland and Ireland are so rich. They were burnt for many years chiefly to furnish soda, but as that substance is obtained at a cheaper rate from salt, kelp or sea weed ashes has only been made lately to obtain iodine for medical purposes, and more than one half is wasted in the process. Besides iodine and six other substances generally procured from kelp, Mr. Stanford has discovered that it contains naphtha, paraffin oil and volatile oil rich in benzol, which yields aniline and magenta dyes and shows that marine vegetation as well as terrestrial abounds in colouring matter.

Every substance is now of use, no substance is without its value, but it would be a vain attempt to mention the innumerable discoveries made by experimental chemistry, which is daily extending its empire over the three kingdoms of organic and inorganic nature.

Composition of some of the preceding Substances.

Acetylene	C_2H_2	Aniline	$C_{12}H_7N_3$
Olefiant gas	C_2H_4	Rosaniline	$C_{40}H_9N_3$
Ammonia	H_3N	Carbolic acid	$C_{12}H_6O_2$
Benzol	$C_{12}H_6$	Cressylic acid	$C_{14}H\ O_2$
Phenyle	$C_{12}H_5N$		

× The coloring matter does not exist ~~[illegible]~~ in vegetation of any kind – it is formed by destructive distillation

xx In these symbols the writer sometimes uses the old notation + sometimes the new, confusion everywhere

SECTION IV.

THE SOLAR SPECTRUM, SPECTRUM ANALYSIS, SPECTRA OF GASES AND VOLATILIZED MATTER, INVERSION OF COLOURED LINES, CONSTITUTION OF SUN AND STARS.

To the unrivalled genius of Sir Isaac Newton we owe the solar spectrum, and the laws of coloured rings, by aid of which, Dr. Thomas Young proved and established the undulatory theory which forms the basis of the whole science of light. The visible part of the solar spectrum forming a band of seven colours was supposed to be continuous till the year 1802, when Dr. Wollaston looking with a prism whose axis was parallel to a narrow slit in a window shutter, at a sunbeam passing through it, discovered seven dark lines crossing the coloured band, at right angles to its length.

Twelve years afterwards, Fraunhofer of Munich, a celebrated optician, magnified the spectrum of a vertical line of light passing through an upright prism by receiving it upon the object glass of a telescope, and discovered 600 dark lines. Having ascertained that the position of the lines in the spectrum, and their distances from one another, are invariable under every circumstance, he determined their places accurately and drew the diagram known as Fraunhofer's lines, which is universally referred to as a standard of comparison. For that purpose, the principal lines are designated by letters; thus the dark line A is in the

-and their distances - but their relative distan red near the least refrangible end of the spectrum, B and C are in the orange, the very remarkable double line D is in the yellow, *b* and E are in the green, F is at the limit between the green and the blue, G is in the blue, and the double line H is in the violet.

The instrument used by MM. Bunsen and Kirchhoff, though more complicated, is constructed on the same principle as the preceding. A sunbeam transmitted by a very narrow vertical slit passes through four prisms, which disperse it so much, that if drawn on the scale seen with the magnifying telescope which receives it, the spectrum would extend over twenty feet. By means of a micrometer screw, the telescope can be turned round a vertical axis, and as the dark lines come successively under the cross wires in its eye-glass they are seen to pass over a graduated scale, so that the distances between two thousand of them have been measured in millimetres with unerring accuracy, but that is only a small part of the whole. When viewed through the telescope, the retina of the eye is the screen on which this wonderful spectrum falls, crossed by innumerable dark rayless lines of various breadths and intensities. Black bands given by the inferior refraction of one prism are here resolved into numerous dark lines as fine as a spider's thread.

Mr. Glaisher during his tenth scientific balloon ascent devoted his attention for a time almost entirely to the dark lines on the solar spectrum. At a height of about four miles and a half, they were almost innumerable; all he had seen on the earth were there, and many more. The nebulous lines H were both seen, the spectrum was a good deal lengthened at the violet end, and at the red end the line A was visible. The light from the sky near the sun gave a shorter spectrum; the lines were only visible from B to G.

Besides these cosmical or permanent lines, Sir David

Brewster observed that certain dark bands and lines in the red and green parts of the spectrum are only visible when the sun is near the horizon, whence he concluded that they are occasioned by the absorption of the solar light while traversing a thicker stratum of air than when the sun is in the zenith. Various groups of these absorption bands are to be seen at times on the solar spectrum, especially a remarkable one near Fraunhofer's line D, and Dr. Miller observed that temporary dark lines appeared during a heavy shower, which vanished when the rain ceased.

When the sun was high, M. Kirchhoff mentions that he had noticed traces of lines and nebulous bands in different parts of the spectrum, which he thinks might be resolved by a greater number of prisms than those in his apparatus.

Sir David Brewster was led to his discovery of atmospheric bands by observing that the brownish red vapour of nitrous oxide has the property of absorbing solar light, resolving the spectrum into a series of bright and dark bands, alternating. Professors Daniel and Miller found that bromine, iodine, and chlorous acid do the same, and Sir John Herschel observed a multitude of similar bands in the flame of cyanogen; but Dr. W. A. Miller, who has particularly studied the phenomena of absorption bands, has proved that the colour of a vapour does not necessarily determine the position or even the existence of dark bands. He has shown that some simple substances which do not occasion dark bands produce them abundantly by the absorptive power they acquire when in composition, while lines that are produced by a simple vapour, vanish when it is in combination. Dr. W. A. Miller has proved also that none of the preceding vapours exist in the atmosphere. He computed that if free bromine constituted only one in a thousand million parts of atmospheric air, it would betray its presence by absorptive bands; nevertheless he suspects that there may be some substance in the air that occasions certain unaccountable changes. Possibly ozone, so intimately connected with atmospheric electricity, may produce some unknown effect.

The spectra from glowing solids and liquids, such as Drummond's light, which is incandescent lime, the still more brilliant flame of the electric arc between charcoal points, glowing solid and fused metals, and coal-gas flame, are continuous; the spectra exhibit the seven colours, but they are not crossed by dark rayless lines, because such incandescent substances give off light of all refrangibility. But solids and liquids reduced to glowing vapours, and incandescent gases, only give out rays of certain refrangibilities, which cross their spectra at right angles, as bright lines of various colours and intensities. Each glowing vapour and gas has bright lines on its spectrum peculiar to itself.

In order to compare these bright lines with Fraunhofer's dark lines, solar light is transmitted through one half of the vertical slit in Kirchhoff's apparatus, and the light of the luminous vapour or gas through the other half. Then by prismatic refraction two spectra are seen in looking through the telescope, the gaseous one immediately below the solar one, and only divided from it by an almost imperceptible dark line. So that the bright lines appear to be continuations of the dark lines if they occupy the same position in the two spectra; if not, the deviation is at once visible. The coincidence or deviation of the bright lines on the spectra of two volatilized substances may be determined by the same method.

The coloured light that has so beautiful an effect in fire-works is owing to the combustion of the salts of different metals: as soda, or common salt, which gives a perfectly pure homogeneous yellow; potash gives a violet light, strontia red, baryta green. The colour is given out by the glowing atoms of the vaporized metals sodium, potassium, strontium, and barium in a state of violent ignition; for as the salt and its metal give the same colour and the same spectrum when ignited, it is evident that the colour is independent of the oxygen of the alkali.

Sir David Brewster appears to have been the first who analysed coloured light with a prism; and in 1822 Sir John Herschel, besides having made a series of observations on coloured flames, had determined the spectra of the muriates of strontia and lime, the chlorides and nitrate of copper and boracic acid; and observes that 'the colours thus communicated by different bases to flame afford, in many cases, a ready and neat way of detecting extremely minute quantities of them.'[6]

The same opinion was afterwards formed by Mr. Fox Talbot, who after many experiments on metallic salts, says in his paper,[7] that a glance at the prismatic spectrum of a flame may show it to contain substances which it would otherwise require a laborious chemical analysis to effect. In that paper this gentleman noticed that the glowing salts of lithium and strontium give a crimson or red colour to flame so exactly of the same tint that if these metals were in combination it would be impossible to decide to which metal the colour is due. But when he passed their respective lights through a prism, he found that the bright lines on their spectra are entirely different. 'The strontia flame,' he observes, 'exhibits a great number of red rays well separated from each other by dark intervals, not to mention an orange, and a very definite bright blue ray. The lithia

[6] This prediction, made in his Treatise on Light published in 1826, has been completely fulfilled by the discovery of four new metals by spectrum analysis.

[7] Phil. Mag. vol. iv. 1834, p. 114.

exhibits one single red ray.' Whence Mr. Fox Talbot observes, 'I hesitate not to say that optical analysis can distinguish the minutest portions of these two substances from each other with as much certainty, if not more, than any other known method.' Thus Sir John Herschel and Mr. Fox Talbot laid the foundation of a spectrum analysis of unrivalled delicacy and beauty, since carried to perfection by Messrs. Bunsen, Kirchhoff and other experimenters, presently to be mentioned.

M. Bunsen detected the characteristic crimson lithium line in the spectra of numerous substances; in granite, in the earliest geological strata, in meteoric stones, in the ashes of most land plants, in blood and other animal matter; so that instead of being one of the rarest metals, it exists in all the three kingdoms of nature. In the year 1857 Mr. Swan gave an instance of the extreme minuteness of spectrum analysis, by detecting the $\frac{1}{2,300,000}$th part of a grain of salt by its yellow light; but by the same reaction M. Bunsen not only recognised the 180 millionth part of a grain of sodium, but found that there is hardly any substance that does not contain it. It exists in the dust on our clothes and furniture, particles of it float in the air we breathe, so that while examining the spectra of other incandescent substances, flashes of yellow light appear as these atoms are volatilized and instantly burnt up, which shows that common salt is perhaps more universally diffused than any other kind of matter.

By spectrum analysis, M. Bunsen has discovered the two new metals, rubidium and cæsium. While examining with a prism the spectrum of the hundredth part of a grain of an alkaline substance separated from the residuum of the Durckheim mineral water, he saw coloured lines, which he had never seen before on the spectrum of any other alkali, and at once concluded that they belonged to a new metal; and having obtained about 200 grains of the substance by the evaporation of forty tons of the water, he found that they contained the chlorides of the two new metals in question. Moreover he perceived that these metallic chlorides resemble the chloride of potassium so nearly in spectrum and chemical character, that a refined prismatic analysis could alone determine the difference. He thus ascertained that the spectra of all the three have two red lines in the red part of their spectrum, and two violet lines in the indigo, while the middle part is occupied by a continuous diffused light. The only difference is that the two red lines in the rubidium spectrum are less refrangible than the red lines in the potassium spectrum, and that the cæsium spectrum is distinguished by two bright blue lines in the diffuse middle part. Rubidium received its name from rubidus, on account of the dark red of its lines, and cæsium from its sky-coloured blue lines.

M. Bunsen thinks that there can hardly be a doubt of rubidium having been mistaken for potassium, but he has shown that they may be distinguished by the difference in the solubility of the double salts which the chlorides of these two metals form with the chloride of platinum. An aqueous solution of the bichloride of platinum and potassium gives an insoluble yellow precipitate, consisting of the bichlorides of platinum and potassium. An aqueous solution of the bichlorides of platinum and rubidium gives an insoluble yellow precipitate of the bichlorides of platinum and rubidium. These two precipitates are undistinguishable to the eye. Now if a solution of platinum be added to the first, no further precipitate can take place, but if a solution of rubidium be added to it, a yellow precipitate is formed consisting of the bichloride of rubidium and potassium, because the chloride of rubidium resolves the precipitate, combines with the chloride of potassium, and sets the chloride of platinum free. Thus the precipitate of the bichloride of rubidium and potassium is the least soluble of the two. The yellow colour is evidently due to the potassium. Cæsium may be distinguished from potassium by the same process. The carbonates, hydrates, and other salts of the two metals were determined; their carbonates were shown to be readily separated, because the carbonate of cæsium is soluble in alcohol, which the carbonate of rubidium is not, and finally the metal rubidium was separated. It has an extreme avidity for oxygen, and burns in water like potassium, and possesses many other analogous qualities. It melts at the temperature of 38·5° Cent., and has a specific gravity of 1·516. Rubidium is abundant in the mineral lepidolite in many parts of Europe and North America, and M. Grandeau has detected it in the ashes of beetroot, tobacco, coffee, tea, and grapes by spectrum analysis. It exists in various mineral waters, and in fact is very general. Traces of various metals are met with in the same vegetable; thus the spectrum of tobacco gives lines characteristic of lithium, potassium, rubidium, and lime.

Mr. W. Crookes discovered the new metal thallium by means of its spectrum, which differs from every other in having one bright green line upon a dark ground. He obtained its various salts, and the metal itself, which he describes as being heavy, dense, and very like lead, but of greater specific gravity. Its fresh surface has a bright metallic lustre, not so blue as that of lead, but it tarnishes more easily. It is so soft that it can be indented by the nail, yet it can be drawn into wire, and in chemical properties it resembles mercury, lead, and bismuth. Altogether it is more like a metal than a metalloid, perhaps something between the two. Thallium is completely volatilized at a temperature below red heat, whether single or in composition. If the quantity be small, the green line appears in a sudden flash, lasting but the fraction of a second. If a larger quantity of the metal be gradually put into the flame, it lasts a little longer, appearing as a single green line of extraordinary purity and intensity, sharply defined on a black ground. With respect to volatility, thallium is analogous to the non-metallic element selenium, which is so volatile that its beautiful blue light only lasts a few seconds. The green light of thallium comes out more rapidly, and with less of the substance, than the blue light of selenium, a quantitative distinction which accords with Dr. Miller's observation that the rapidity with which a result is obtained, and the minuteness of the quantity required for the examination, gives this method a superiority over every other for the qualitative analysis of the alkalies and alkaline earths. Thallium has been detected in mineral waters, wine, treacle, tobacco, and chicory.

Drs. Reich and Richter discovered a fourth new metal in the zinc-blende at Freiberg in Saxony, which has been called indium, from two beautiful indigo-blue lines in its spectrum, which have a greater refrangibility than the blue lines in strontium. The chemical relations of indium resemble those of zinc, with which it is associated in nature. The metal can be reduced before the blowpipe into a bead, which marks paper and has the colour of tin.

The practical importance of spectrum science has been beautifully illustrated by Professor Roscoe by its application to overcome a difficulty in Bessemer's process for the manufacture of steel. According to that process, steel is made by sending a blast of air through a quantity of melted iron; the difficulty was when to stop the blast, for if stopped too soon, the metal retains so much carbon that it crumbles under the hammer; if continued a few minutes too long, the molten metal is so viscid that it cannot be poured into the moulds. Experience had hitherto enabled the manufacturer to judge of the right time from the appearance of the flame which issued from the mouth of the converting vessel, but now Professor Roscoe has determined the exact moment for cutting off the blast by a spectral examination of the flame, the light of which is most intense. The flame spectrum in its various phases revealed complicated masses of dark absorption bands and bright lines, showing that a variety of substances were present in the flame in a state of incandescent gas; and by a simultaneous comparison of these with well-known spectra of certain elementary bodies, Mr. Roscoe ascertained the presence of sodium, potassium, lithium, iron, carbon, phosphorus, hydrogen, and nitrogen in the flame.

Both Dr. Wollaston and Fraunhofer noticed that the spectrum of the electric spark was crossed by bright-coloured lines; and in the year 1835, Professor Wheatstone determined the spectra of the electric spark taken from fused zinc, cadmium, tin, bismuth, lead, and from mercury, and found that each is crossed by bright lines differing in number, position, and colour, but which are the same whether the electric spark be from a static, voltaic, or magneto-electric machine. Having given a plate showing the colours of these bright lines on the respective spectra, he proved that they are not owing to the electricity, but to the incandescent atoms of the metals, for by using different metals as terminals to the conducting wires, he determined the spectra of these metals in vacuo, which proved that they were due alone to the volatilization of the metallic terminals, and concluded that any one metal may be distinguished from another by the appearance of the spark.

Wheatstone discontinued his spectrum researches, for he had invented the electric telegraph, and was busy in extending the first telegraphic wire that ever carried the thought of man to man between London and Manchester. Soon after he laid the first aquatic line across the Thames, and he has lived to see his telegraphic lines spread over the surface of the earth and the bottom of the ocean.

Mr. Wheatstone had perceived that the bright lines on the spectra of the metals are different and more complicated when taken in air than in vacuo, and Professor Angström made the important remark that the electric spark gives two superposed spectra, one due to any metal that may be under examination, the other to the incandescence of the air through which the spark passes. Hence the importance of the spectrum analysis of gaseous substances, especially of those which constitute our atmosphere, a subject that has been ably and successfully investigated by Professor Plücker. For that purpose he made use of the Geissler or vacuum tubes, similar to those he used in his experiments on the stratification of electric light. When electricity was sent through a tube containing oxygen gas, the gas combined so rapidly with the platinum of the negative terminal of the battery that there was little time to examine the spectrum. The electral light in the tube was too red at first, but as the attenuated gas gradually disappeared it changed through flesh-colour to green, then through blue to reddish-violet, and at length there was too little gas to convey the electricity. However, the oxygen spectrum has a remarkably bright red band at its red extremity, two bright orange lines divided by a black one in the orange, and some bright bands in the green.

The electric light of attenuated hydrogen is red, and almost the whole light in its spectrum is concentrated into six bright bands of nearly equal breadths. There is a dazzling red band near the red end of the spectrum, which, however, does not coincide with the oxygen band; then comes a very beautiful yellow band, in which the whole of the yellow rays seem to be concentrated, followed by a grey interval which separates the yellow from three bright lines in the green, the first of which is yellowish green, the last a beautiful greenish blue; a black and a dark space separates the latter from the violet in which there is a bright line. The electric light in a tube containing highly rarefied aqueous vapour is red, the vapour is resolved into its simple elements by the electricity, the oxygen combines with the platinum of the negative or heat pole, and the spectrum is that of pure hydrogen with the three most prominent bands only.

The nitrogen spectrum is brilliant with all the seven colours; there are no broad dark spaces like those which divide the bright bands in the hydrogen spectrum, but it is crossed by numerous very fine black and grey lines. Fifteen of the latter stripe the red and orange; the green is separated from the yellow by a black narrow band; it is terminated by two bright blue lines, and very fine dark lines cross it and the rest of the spectrum. The tube light is yellowish red.

The spectrum of highly rarefied atmospheric air is chiefly that of nitrogen, for the oxygen combines with the platinum of the negative terminal, and is in too small a quantity to transmit the electricity through the tube.

The rarefied vapours of chlorine, bromine, and iodine are so rapidly combined with the platinum of the negative terminal, that it is difficult to determine their spectra; but they have peculiarities in common, which distinguish them from all other spectra. The bright lines that cross them are first at rest, but soon become flickering. In the iodine spectrum, five of those lines of flickering light of great beauty are in the green, two of them close together. The bromine spectrum shows a greater number, which extend across the colours of its middle part, accompanied by dark lines; and in the chlorine spectrum there are many lines, both of flickering light and darkness. New lines are brought out in the iodine spectrum by increase of temperature. At a low heat it is crossed by a number of dark lines, but with a higher temperature the vapour has a greenish hue, which is resolved by the prism into green lines at some distance from one another, and fainter blue light, crossed by groups of luminous bands.

Rarefied compound gases are resolved by the electricity into their component parts, and the result is superposed spectra, one belonging to each element. M. Seguin considers the aspect of the electric spark to be a sure indication of chemical action, for while the decomposition is in progress, the electric spark is encompassed by a halo, and the bright lines of the double spectrum are less distinct; but when the reaction is finished, the spark becomes slender, and the spectrum bands distinct. In the decomposition of highly carburetted and attenuated hydrogen gas, the spark resembles a flame, and the spectrum is like that of white light. When the gas is decomposed, the hydrogen is disengaged, and the carbon deposited on the extremities of the conducting wires; the spark becomes slender, and then the lines of the hydrogen, the lines belonging to the hydro-carbon and to carbon itself may be seen on the spectrum.[8]

The bright and coloured lines on the spectra of the gases, and the vapours of a great number of the metals and metallic salts, were known before MM. Bunsen and Kirchhoff began their systematic researches, during which they added many more, some so difficult and analogous, that it required all their skill and experience to make them out.

Of all the spectra that have been determined, those of sodium and iron are the most important and interesting. In that of sodium, the only light is of the purest yellow

[8] 'On the Spectrum of the Electric Spark in Compound Gases,' by Mr. J. M. Seguin. Comptes Rendus.

condensed into a double line of intense brilliancy on a dark ground. The iron spectrum on the contrary is crossed by bright lines of all intensities and colours in such multitudes, that their number has not been ascertained. The calcium spectrum has one very bright green band in the orange, a red line in the yellow, and a well-defined yellow line in the indigo. As already mentioned, the red and orange parts of the strontium are crossed by many red lines separated by dark intervals; there is a bright blue line between the orange and yellow, and an orange line in the blue. One intense crimson band in the orange characterises the lithium spectrum. Seven broad green bands stripe the yellow and a part of the green, in the barium spectrum, and that of magnesium has many green bands and lines.

All of these were determined by the heat of white coal gas flame, which amounts to 2350° Cent., and at the time MM. Bunsen and Kirchhoff were not aware that by an increase of temperature new bright lines were added to some of the spectra. That discovery was made by Professor Tyndall, while examining the spectrum of chloride of lithium, which with the low temperature has only one crimson band in the orange, but with the hotter flame of hydrogen gas, amounting to 3259° Cent., an orange line appeared in the yellow, and when Mr. Tyndall employed the electric lamp,[9] the spectrum acquired a broad brilliant blue band between the orange and yellow, while the crimson band remained unchanged. Professors Roscoe and Clifton confirmed Tyndall's discovery, and upon comparing the spectra of strontium and lithium, they found where only one prism was employed that the blue line of lithium appeared to coincide with the blue line, delta, of strontium; but with an

[9] The light of the electric lamp is produced by an apparatus which successively makes and breaks an electric current, whereby the terminal charcoal points become red-hot.

apparatus having several prisms like that of Kirchhoff, they saw that the two blue lines differed by one division of the measuring scale, the lithium line being the most refrangible. A great change was produced on the strontium spectrum by increased electric temperature: three of the red bands vanished, and new bright lines appeared, that were not coincident with those they replaced; the blue line was not affected, but four new violet lines were added. With the intense heat of the electric spark, the broad green band of the calcium spectrum is replaced by five green lines of less refrangibility, the well-defined yellow line vanishes, and instead of the red band three red or orange lines appear, of greater refrangibility than those that have vanished. Six of the bright green bands in the spectrum of barium entirely vanish, and bright new non-coincident lines appear. Thus, not only new lines appear at very high temperature, but the broad bands, characteristic of the metal or metallic compound at a low temperature of the flame or a weak spark, totally disappear at the higher temperature. The new bright lines, which supply the part of the broad bands, are generally not coincident with any part of the band, sometimes being less and sometimes being more refrangible. The gentlemen who made these experiments add, that possibly the cause of the disappearance of the broad bands and the production of the bright lines may be, that at the lower temperature of the flame or weak spark, the spectrum observed is produced by the glowing vapour of some compound, probably the oxide of the difficultly reducible metal, whereas, at the enormously high temperature of the intense electric spark, these compounds are split up, and the true spectrum is obtained, namely, the narrow bright lines. No such changes take place in the easily reducible metals, potassium, sodium, or lithium, which remain unaltered by change of temperature. In these experiments, a bead of the metallic salt on a platinum wire was placed between the platinum terminals, from which the spark of a powerful inductive coil could be passed, but in order to have a more intensely hot spark the coating of a Leyden jar was placed in communication with the terminals of the secondary current respectively. By this addition of static electricity, the intensity of the current was increased four-fold, and must have been beyond estimation.

By high temperature the cæsium spectrum has been so changed, that for number, colour and distinctness of its lines, it is the most beautiful of those of the alkaline and earthy metals, for besides its characteristic blue lines, it has six red and an orange-red line in the red part of its spectrum, a fine yellow line, and nine green lines, the last coinciding with Fraunhofer's E. The thallium spectrum also acquires more lines when evaporated by electricity, for besides the remarkable green line in the green, it acquires a faint one in the orange, two of nearly equal intensity in the green, a third fainter, and a fifth in the blue.

MM. Plücker and Hittorf, in recent experiments, proved that many non-metallic bodies, such as nitrogen and sulphur, give two distinctly different spectra on change of temperature, and that the transition from one spectrum to the other is sudden. The change is particularly striking in sulphur, for at the moment the first spectrum attains its maximum brightness, it disappears, and gives place to the second or high temperature spectrum, which is one of the richest in brilliant rays known. When the temperature is lowered the first spectrum reappears. These changes M. Plücker ascribes to the existence of the elements in two allotropic conditions. M. Plücker has also found that each metalloid possesses a peculiar and characteristic spectrum: as hydrogen, which has three bright lines, all of which are coincident with dark solar lines, and nitrogen, which exhibits a complicated series of bands.

The experiments of the Rev. Dr. Robinson on a variety of gases and vapours, inclosed in glass tubes, show that a greater change is produced by pressure than by heat. At the ordinary atmospheric pressure, the spectra show a number of bright lines on a coloured ground, the light of which is, in general, stronger towards the red than the violet end, and strongest in the green. In some the ground is so bright as to efface all but the most luminous lines. This is especially the case with hydrogen. On gradually exhausting the tube in which the vapour is contained, the spectra rather suddenly fade away, leaving only a suspicion of one or two lines, but upon exhausting the tube still more, these transition spectra become bright again, fresh lines appear, and they are changed into new spectra which are never so bright as those at ordinary pressure. Fewer lines are visible in the rarefied spectra, and of these four-tenths are not found in the spectra of atmospheric pressure. The difference between the common pressure spectra, the transition, and the rarefied spectra shows, that the character and even the existence of certain lines depend upon the mere density of the media, the chemical circumstances remaining unchanged. Dr. Robinson also observed that spectra are not superposed without a change; the spectrum of atmospheric air does not always exhibit all the lines of oxygen and nitrogen, and occasionally there are some lines not visible in either of them. It appears also that for certain lines the actions of bodies may be antagonistic.

Metals do not always give the same spectrum, whatever may be the combinations in which they are found. Among various instances M. Mitscherlich mentions that the spectra of copper and the chloride and iodide of copper present essential differences, and Mr. Roscoe has found that a similar difference prevails in the spectra of carbon compounds when in a state of incandescent gas, which have hitherto been supposed to yield the same spectrum. 'The spectrum obtained from the flame of olefiant gas is different from that obtained by the electric discharge through a vacuum of the same gas; while the spark passing through a cyanogen vacuum produces a spectrum identical with that of the olefiant gas flame, and through the carbonic oxide vacuum a spectrum coincident with that of the spark through olefiant gas vacuum.'

The chlorides, bromides, and iodides are the most easily vaporized of all the metallic salts, and give the most brilliant flames and the most intense spectra, especially the chlorides. A small piece of the chloride of barium volatilized by a colourless gas flame tinges the flame green, and the red and green lines on the spectrum stand out with extreme brilliancy. The scattered yellow light on the spectrum of the chloride of sodium is comparatively dark by contrast with the bright lines, and upon shading off the more luminous part of it, traces of lines are visible in the more refrangible portion.

Chloride of lithium gives the red and orange lines on its spectrum; the brilliant blue band discovered by Mr. Tyndall, and another more refrangible blue line is seen when the ignition is at its greatest intensity. Chloride of calcium gives a blue band very brightly, and several other lines. The light of the chloride of copper is very vivid, and its spectrum is remarkable for changing its appearance with the decomposition of the chloride. The chlorides of lead and cadmium, also, give very bright and definite spectra, and chloride of bismuth shows numerous brilliant red and blue rays which quickly disappear. Thus the chlorides give spectra with lines, such as the blue lithium and strontium lines, hitherto only brought out by an intense electric spark.[1]

M. Bunsen produced a beautiful effect by vaporizing a mixture of equal parts of the chlorides of sodium, potassium, lithium, calcium, strontium, and barium, and passing the light through the slit of his apparatus. For on looking through the telescope the spectrum of each substance with its characteristic coloured lines in all their brilliancy came successively into view, and gradually faded away as each substance was volatilized and driven off. The sequence showed the time required to vaporize each metal, and by spectrum analysis each metal could be recognized, although the mixture only contained the $\frac{1}{1000}$ part of a grain of each chloride.

The position, colour, and nature of the bright lines on the spectra of more than thirty metals have been determined, besides those of the elementary gases and that of the electric spark. To these M. Louis Grandeau has added the spectrum of lightning. By a particular arrangement the light passed at once through the slit in the instrument, and a glass tube containing nitrogen and the vapour of water. The general appearance of the lightning spectrum at first recalled that of the electric spark, but on a closer examination, M. Grandeau noticed in the spectrum of almost every flash the coincidence of a certain number of the rays of the lightning spectrum with those of the spectra of nitrogen and hydrogen. M. Grandeau remarks that this result is not surprising, since all admit the production of ammonia and nitric acid under the influence of electrical discharges. Besides the rays of nitrogen and hydrogen, the lightning spectrum contains the ubiquitous yellow ray of sodium.

Fraunhofer had noticed a coincidence between the

[1] 'On the Means of Increasing the Intensity of Metallic Spectra.' By Mr. W. Crookes.

double yellow sodium line and the double dark line D of the solar spectrum, though he was not aware to what it was due. This coincidence, observed by M. Kirchhoff many years afterwards, was fully appreciated by him, and became the foundation of one of the most brilliant discoveries of modern times. During a systematic comparison between the spectra of volatilized substances and the solar spectrum, he discovered a perfect coincidence between Fraunhofer's dark lines and all the bright and coloured lines on the spectra of the volatilized substances, sodium, calcium, magnesium, chromium, iron, and nickel. To these M. Angström has added aluminium and manganese, and M. Plücker has very recently found that all the three bright lines in the hydrogen spectrum are coincident with dark solar lines, and that none of the potassium lines correspond with any solar lines.

Drawings have been made of Fraunhofer's spectrum placed above the spectra of the principal metals and metallic salts, in which the coincidence of the bright and dark lines is shown from the line A in the extreme red to the line G in the indigo, and as the length of an undulation of the extreme violet light of the solar spectrum is the $\frac{17}{1,000,000}$ of an inch, and the length of an undulation of the extreme red is the $\frac{26}{1,000,000}$ of an inch, the length of the undulations of the intermediate rays can be computed by the undulatory theory of light. The length of the waves corresponding to Fraunhofer's seven principal lines and many of the intermediate ones have been computed, so that when a bright or coloured line is coincident with any of these, the length of its waves is at once known. There are other tables of Fraunhofer's lines, and the coincident bright ones in which each dark line is marked by its own number, as the two principal lines in the double line D, which are expressed by the numbers 1002·8 and 1006·8, and so with the others; thus the coincidence of the spectra of volatilized substances with the solar line forms a regular system.

Professor J. P. Cooke, junior, has recently constructed a spectroscope which shows that the lines of the solar spectrum are as innumerable as the stars of heaven, that at least ten times as many are distinctly seen as are given by Kirchhoff in his chart, besides an infinitude of nebulous bands just on the point of being resolved. Yet even with this greatly increased power, the coincidences between the bright lines of the metallic spectra and the dark lines of the solar spectrum remain perfect. M. Kirchhoff had seen a fine yellow line between the double lines D of the sodium spectrum. M. Merz of Munich found four additional lines, but Professor Cooke has discovered that there are in all seven intermediate lines and a nebulous band. Although the two members of the sodium line D could be spread so far apart that the $\frac{1}{2000}$ part of the intermediate space could be readily distinguished, yet the coincidence with the two dark Fraunhofer lines was absolute. The spectroscope 'shows that many of the bands of the metallic spectra are broad coloured spaces crossed themselves by bright lines. This is the case with the orange band of the strontium spectrum, and with the whole of the calcium and barium spectra to a remarkable extent.'[2]

As early as the year 1849, M. Foucault discovered that the sun's light when shining through the electric light gives black bands on that part of the spectrum where the electric light alone would have produced bright bands, so that the black and bright bands could be produced alternately by admitting or excluding the solar light; whence he concluded that the electric arc emits the same lines which it absorbs when they come from another luminous source. M. Angström also observed that the

[2] *The Chemical News and Journal of Physical Science* for July 4, 1863.

bright lines on the spectra of volatilized metals could be reversed by a stronger light shining through their flames. Neither of these gentlemen was aware of the importance of a discovery which enabled M. Kirchhoff to apply his delicate and refined analysis of terrestrial matter to the sun and stars.

He had already determined the coincidence of the double yellow sodium line with Fraunhofer's dark line D, but while looking with a prism at a bright solar beam passing through a yellow sodium flame, he was surprised to see a strong and well-defined double dark line instead of the double yellow sodium line which he expected. He obtained the very same result, more strongly, with Drummond's lime light, which is brighter than the flame of any volatilized metal, and as he found that he could produce the dark and yellow lines alternately, by admitting and shutting out the brighter light, he concluded that the sodium flame is subject to the law of exchange, in consequence of which it absorbs rays of the same refrangibility with those that it emits. In fact, the soda flame is pervious to all the rays in solar light and Drummond's flame, except those of the same refrangibility with its own; these it absorbs and it may be supposed changes them into heat. Hence M. Kirchhoff came finally to the conclusion, that the double dark line in the solar spectrum is the reverse or negative of the double yellow line seen on the spectrum of the sodium flame.

Quite recently, M. Fizeau has discovered that the spectrum of sodium burning in air is reversed during the combustion. At first it is black, with the usual double yellow line; at last, when the light is at its maximum, the double yellow line becomes black on a continuous spectrum with all the seven colours.

After M. Kirchhoff had ascertained that the bright lines in the spectra of calcium, chromium, magnesium, iron and nickel coincide with dark lines in the solar spectrum, he reversed them by sending Drummond's light through their respective flames, thus proving that the coloured flames of these six metals are subject, like the sodium light, to the law of exchanges.

M. Kirchhoff infers by analogy that the vapours of all these six metals exist in the luminous atmosphere of the sun, and that they absorb and change into heat such rays of the continuous light of the incandescent solar globe as have the same refrangibility with their own, so that the corresponding dark rayless lines on the solar spectrum are the reverses of the bright lines in the spectra which these vapours would give were it not for the brighter light of the sun shining through his luminous atmosphere.

The dazzling white light of the incandescent body of the sun containing rays of all refrangibilities would give a continuous spectrum shaded with all the seven colours, but for his luminous absorbent atmosphere, which comes like a veil between him and the earth, and crosses his spectrum with thousands of dark lines, which are the reverses or negatives of the bright lines in the spectra of the innumerable vapours it contains, all of which must doubtless be the gases of substances existing in the solar mass itself and vaporized by his intense heat.

Every metal, and almost every elementary substance in a state of gaseous combustion, gives its own peculiar luminous lines to its spectrum, but no volatilized matter can be proved to exist in the sun's atmosphere except such as have bright lines in their spectra coincident with some of its dark lines.

The bright lines in the spectrum of iron, coincident with the dark lines of the solar spectrum, are so numerous that many yet remain unknown. M. Kirchhoff counted seventy in the small space between Fraunhofer's lines D and F, in which the coincidence extends even to shade, the deepest dark lines corresponding to the most brilliant bright ones, and he computed that the chances are as 1 to the ninth power of 10, that the coincidence of these seventy lines is not fortuitous, but owing to a definite cause, whence he concluded that the presence of iron vapour in the solar atmosphere is proved with as much certainty as can be attained in any question of natural science.

In a later publication, M. Angström observes that, although the coincident iron lines between D and F are not so numerous as M. Kirchhoff affirmed, they are quite sufficient to establish beyond a doubt the presence of iron in the solar atmosphere. The iron lines are the most characteristic in the whole solar spectrum, and if a magnifying power be used, or if the light be refracted through several prisms, these lines, or at any rate the stronger ones among them, appear to be perfectly black. M. Angström noticed that on a careful examination of the solar spectrum, certain lines can be discovered, imbedded in a mass of fainter ones, which, with increased illumination, seem to withdraw themselves and disappear, while the first mentioned lines, on the contrary, only stand out in a stronger relief. These are metallic lines of high fusion temperature; the most remarkable among them almost invariably belong to iron.

The substances common on earth that have their vapours in the atmosphere of the sun, though they have fewer bright lines in their spectra than that of iron, are quite as characteristic, and quite as distinctly coincident with their reverses, whether they be single, in groups, or double, as the sodium line, which is brighter and its reverses darker than that of any other substance, because volatilized sodium gives out a greater quantity of light, and consequently absorbs a greater quantity.

M. Angström has added aluminium and manganese to the seven metals whose vapours M. Kirchhoff has shown to exist in the atmosphere of the sun, but he thinks it doubtful whether barium, zinc, or copper are solar metals, for although their brighter lines correspond with distinct dark solar lines, their weaker lines do not. Strontium is doubtful also, for one of its strongest bright lines is not coincident with any dark line. Though both iron and nickel are decidedly solar metals, yet as cobalt is doubtful, it cannot be presumed that meteorites are of solar origin.

The spectrum of luminous magnesium has many green lines perfectly coincident with those in the solar spectrum, so there is no doubt of that metal being a constituent of the sun's atmosphere. But there are magnesium rays as well as some of iron of such high refrangibility that in Mr. Stokes's long spectrum they are situated ten times as far from H as the whole length of the visible spectrum from A to H. These highly refrangible rays only become visible at the exalted temperature of the electric spark, and as they are not found in the solar spectrum, it is inferred that the heat of the sun is inferior to that of the electric spark.[3] Mr. Roscoe observes that this conclusion would only be legitimate if we knew that these rays of high refrangibility are not absorbed in passing through the atmosphere.

These are some of the most striking results of the numerous investigations that have been made since M. Kirchhoff published his discoveries, for the subject is anything but exhausted.

The intensely vivid light of a magnesium flame is rich in violet and extra-violet rays, partly due to the

[3] Dr. W. A. Miller has shown that these invisible highly refrangible rays exist in the vapours of all metals, and has obtained photographs of their spectra (see Phil. Trans. 1862, p. 876), which correspond to the spectra of fluorescence.

incandescent vapour of magnesium, and partly to the intensely heated magnesia formed by the combustion. The properties of this light having been examined and compared with those of the sun by Professors Roscoe and Bunsen, with a view to photographic purposes, they came to the conclusion that 'the steady and equable light evolved by magnesium wire, burning in the air, and the immense chemical action thus produced, render this source of light valuable as a simple means of obtaining a given amount of chemical illumination, and that the combustion of this metal constitutes a definite and simple source of light for the purpose of photochemical measurement.'

Bright lines of two different metals sometimes coincide with the same black line, that is, they appear to have the same reverse as an iron and a magnesian line, an iron and a nickel line, and some others; but it is not known whether the coincidence be real or apparent.

M. Kirchhoff has proved that neither gold, silver, tin, lead, antimony, arsenic, mercury, lithium, cadmium, and some others are constituents of the sun, because none of their bright lines are coincident with any of the dark lines of the solar spectrum. This negative discovery does no less honour to M. Kirchhoff than the proof of so many substances being common to the earth and sun.

Since all incandescent solid and liquid bodies give a continuous spectrum which exhibits no dark lines, M. Kirchhoff conceives that the sun consists of a solid or liquid nucleus, heated to the temperature of the most dazzling whiteness, and that it is surrounded by a luminous gaseous atmosphere of somewhat lower temperature, endowed with the law of exchanges. The spectra of Arcturus, Capella, and many other fixed stars are crossed by dark lines similar to, and often coincident with, the dark lines in the solar spectrum; therefore, it may be concluded that their structure is to a certain extent the same with that of the sun.

Numerous observations have been made on the spectra of the fixed stars, both in Britain and on the Continent. In England, Mr. Huggins and Professor W. A. Miller have published tables of the measures of about ninety dark lines in the spectrum of Aldebaran, nearly eighty in that of *α* Orionis or Betelgeux, and fifteen in that of *β* Pegasi, with diagrams of the two first which include the results of a comparison of the spectra of various terrestrial elements with those of the stars. Thus coloured lines of sodium, magnesium, calcium, hydrogen, iron, bismuth, tellurium, antimony and mercury were found to be coincident with some of the dark lines in the spectrum of Aldebaran, and besides these there are numerous lines in the spectrum of this star which are probably due to forms of matter unknown to us. Coloured lines of sodium, magnesium, calcium, iron and bismuth, coincided with dark lines in the spectrum of *α* Orionis; and *β* Pegasi had a spectrum closely resembling that of *α* Orionis, but much fainter.

Between forty and fifty stars were examined, and it was observed that the solar lines C and F corresponding to hydrogen, which are present in the spectra of nearly all the stars, are wanting in those of *α* Orionis and *β* Pegasi. With a few exceptions, the terrestrial elements hydrogen, sodium, magnesium, and iron, which appear to be most widely diffused through the stars, are precisely those which with the exception of magnesium are essential to life as it exists upon the earth. Besides, the elements hydrogen, sodium, and magnesium, represent the ocean, which is an essential part of a world similar to the earth. Should any planets revolve round *α* Orionis and *β* Pegasi, they probably would have no hydrogen, consequently, no ocean and no water: therefore, they could not be inhabited by beings constituted as we are.

Padre Secchi, the Roman astronomer, divides the stars into three types; the first and most dominant type includes Sirius, α Lyræ, and other white stars, which invariably contain hydrogen of high temperature, and are denoted by a black line in their spectra, which coincides with the solar line F; and there is another band also probably due to hydrogen in the violet half of the stars visible to the naked eye belonging to this group. A singular modification of this group, however, occurs in the stars of the constellation Orion, which so rarely show any deviation from one type, that, with the exception of α Orionis or Betelgeux, they may be said to form a family distinguished from all the other stars in the sky; their spectra are crossed by fine lines, faint in the violet, with a band more or less visible in F. γ Cassiopeiæ and β Lyræ differ from the stars of the first type in having a bright band near the solar line F, instead of a black one.[4]

Padre Secchi's second type includes α Orionis, α Tauri, Antares, β Pegasi, &c., which have coloured bands in the red and orange. According to M. Secchi, the most remarkable star in this section is α Herculis. It gives a spectrum which has the appearance of columns illuminated on one side; 'the stereoscopic effect of the convexity of these bands due to the shading is so surprising, that it cannot be beheld without astonishment.' The spectrum of the star δ^2 Lyræ has a similar appearance, only instead of convex it has concave bands.

The third type consists of stars whose spectra are crossed by fine lines, as Arcturus, Capella and our own sun.

4 In γ Cassiopeiæ, Mr. Huggins has detected a second *bright* line in the red part of the spectrum. He has also found that these two bright lines agree in position with the two brightest lines of the spectrum of hydrogen, and may therefore be considered due to luminous hydrogen.

The colours of the stars are produced by vapours existing in their atmospheres, one colour predominating over the others, which are absorbed by the number of dark lines.

Messrs. Huggins and Miller obtained extraordinary results from the examination of temporary and periodic stars. Temporary stars suddenly shine forth with great brilliancy and soon vanish or nearly vanish. A temporary star which suddenly appeared on the night of May 12, 1866, when examined with a spectroscope, had two spectra, showing that its light emanated from two distinct sources. One spectrum, analogous to that of the sun, was formed by the light of an incandescent solid or liquid photosphere, which suffered absorption by the vapours of an envelope cooler than itself. The second spectrum consisted of a few bright lines, indicating that the light by which it was formed was emitted by luminous gas: the position of some of the lines denoted hydrogen; whence the observers believed the phenomena to result from the burning of hydrogen with some other element, and that the photosphere was heated to incandescence by the resulting temperature.

The variation in the brightness of periodic stars has by some been supposed to be due to an opaque body periodically obscuring the light. Should that body be surrounded by an atmosphere like our planet's, its presence would be revealed by the absence or presence of additional lines of absorption in the spectrum of the star. Now three lines determined in the spectrum of Betelgeux were no longer found when the star arrived at its maximum of brightness, indicating it may be the presence of an atmosphere round the opaque body.

With regard to our own planets, Jupiter has lines in his spectrum which indicate the existence of an absorptive atmosphere; one band indicates the presence of vapours similar to those existing in our atmosphere, another band has no counterpart among the lines of absorption of the earth's atmosphere, and tells of some gas which it does not contain.

In the feeble spectrum of Saturn there are lines similar to those in the spectrum of Jupiter. These lines are less strongly marked in the ansæ of the rings, and show that the absorptive power of the atmosphere about the rings is less than that of the atmosphere which surrounds the ball.

M. Jansen has found lines denoting aqueous vapour in the atmospheres of both Jupiter and Saturn. Some very remarkable lines have been seen in the more refrangible part of the spectrum of Mars supposed to be connected with his red colour. Though the spectrum of Venus is brilliant, and the dark lines distinct, no additional lines indicate the existence of an atmosphere differing from our own.

The phenomena resulting from an examination of the nebulæ are most wonderful; their light is very feeble, even that of the brightest. 'The total light of the whole nebula in Orion, the largest and brightest of them, makes so small an impression on the naked eye, that you may look twenty times at its place and not perceive any nebulous light at all.'[5] Besides, the brightness of a surface cannot be increased by a telescope, however good. Notwithstanding difficulties which seem to be almost insurmountable, Mr. Huggins in England, and Padre Secchi at Rome, have been, and still are, engaged in these researches.

The planetary nebulæ are beautiful objects; they are like planets with a round or oval disc, equable, slightly mottled and of enormous magnitude; one near γ Aquarii is twenty seconds, and another is twelve

[5] Sir John Herschel, who is of the highest authority with regard to the nebulæ in both hemispheres.

seconds in diameter. Sir John Herschel computed that if these objects be as far from us as the nearest of the fixed stars, their magnitude, on the lowest estimation, would fill the orbit of Uranus. He discovered twenty-eight or twenty-nine of them, some of a beautiful blue tint, in the southern hemisphere; and from the uniformity of the discs in both hemispheres, and their apparent want of condensation, he presumed that they may be hollow shells emitting a feeble light from their surfaces only. The spectrum analysis of that light, by Mr. Huggins, in six of the planetary nebulæ, showed that their structure is utterly unlike anything else in creation,[6] for instead of an ordinary spectrum he found, to his infinite surprise, that the spectra of the feeble light of these bodies consist only of three bright lines, such as those which proceed from an intensely heated gas, and that the lines exhibited some of those of the hydrogen and nitrogen spectra and an unknown gaseous substance: whence he draws the astounding conclusion, that planetary nebulæ are probably composed of hydrogen, nitrogen, and some unknown gas, without any solid nucleus whatever.

The annular nebula in Lyra, which is probably nearest to the earth, and the dumb-bell nebula, gave a spectrum indicating matter in a gaseous form. The annular nebula appears to be a hollow elliptical ring of nebulous matter of enormous magnitude. The interior opening of the ring is not entirely dark, but filled with a faint hazy light, like fine gauze stretched over a hoop. The dumb-bell nebula in the constellation Vulpecula is like an hour-glass of bright matter surrounded by a thin hazy atmosphere, which gives the whole the form of an oblate spheroid. Both of these nebulæ when viewed with a very high telescopic power seem to consist of minute

[6] Since this observation, Mr. Huggins discovered that two small comets give an analogous spectrum.

clustering stars, but the spectra of these two nebulæ have one bright line, the structure of both being of the same gaseous constitution.

The great nebula on the sword handle of Orion was then examined. The spectrum of the light from the brightest parts of this nebula, near the trapezium, was crossed by three bright lines, in all respects similar to those on the spectra of the planetary and other nebulæ. Other portions of the great nebula were then brought successively under examination, but the spectra of the whole of those portions which still were sufficiently bright for this method of observation remained unchanged, and exhibited the three bright lines only. The whole of the great nebula, as far as it lay within the power of Mr. Huggins' instrument, emits light which is identical in its characters; the light from one part differs from the light from another part in intensity alone. The brighter portions of this nebula have been to a certain extent resolved into stars, by the powerful telescopes of Lord Rosse and Professor Bond, of the United States of America; the whole, or the greater part, of the light from that portion of the nebula must therefore be regarded as the united radiation of numerous stellar points. The spectrum of this radiation being crossed by the three bright lines reveals its gaseous source; Mr. Huggins therefore infers that at least some of these stellar points are merely denser parts of a gaseous matter, and that the nebulæ which he examined are enormous gaseous systems.

The spectrum of the great nebula in Orion was subsequently examined by Padre Secchi. He describes the light of the spectrum as of a uniform green, crossed by three bright lines; one tolerably wide and perfectly sharp, a very slender one close to it, and the third at a little distance from the latter. This spectrum afforded a striking contrast to the spectra of the small stars in the brighter parts of the nebula. As soon as the light from one of these stars entered the slit of the instrument, its continuous spectrum was seen to flash across the field of vision in a long coloured band. This shows that the mass of matter in this immense nebula is in a different state from that of the stars themselves, as Mr. Huggins had already observed. Padre Secchi does not draw any inference from his observations as to the structure of nebulæ in general, probably thinking it premature, but he expresses astonishment at their results.

Since the preceding lines were written, Mr. Huggins and Professor W. A. Miller have continued their researches on the constitution of the celestial bodies by a method of direct simultaneous comparison of the lines in their spectra with the lines in the spectra of many of the terrestrial elements. The spectra for comparison were obtained from the spark of the induction coil taken between points of various metals; and sometimes a platinum wire was used, surrounded with cotton, moistened with a solution of the substance required. The telescope of the instrument was mounted equatorially, and followed the star by clockwork. By this arrangement the spectrum of the star, and the spectrum of the metal compared with it, are seen in juxtaposition; and the coincidence or relative position of a dark line in the steliar spectrum with a bright line in the metallic spectrum can be determined with great precision.

It was found that Jupiter's atmosphere has a much greater absorptive power than the terrestrial atmosphere; that they have some gases or vapours in common, but that they are not identical.

Some of the lines seen in the atmosphere of Saturn appear to be identical with those seen in the spectrum of Jupiter.

'The lines characterizing the atmospheres of Jupiter and Saturn are not present in the spectrum of Mars.

Groups of lines appear in the blue portion of the spectrum; and these, by causing the predominance of the red rays, may be the cause of the red colour which distinguishes the light of this planet.'[7]

All the stronger lines of the solar spectrum were seen in the brilliant light of Venus; but no additional lines indicating an absorptive action of the planet's atmosphere.

The authors are of the opinion that in most of the planets the light is probably reflected from clouds floating at some distance from the surface, so that it is not subject to the strong absorptive action of the lower and denser strata of the planet's atmosphere, which, like our own, are most effective in producing atmospheric lines.

The results of the observations on the fixed stars are exceedingly interesting, for they show that their elementary constituents are similar, but not identical; and that although they contain many of the sixty-five terrestrial elements, there are probably new unknown substances also.

When seventy dark lines on the spectrum of the star Aldebaran, and eighty on that of *a* Orionis (Betelgeux) were compared with the bright lines on the spectra of the vapours of a variety of the terrestrial simple elements, it was found that Aldebaran contained nine terrestrial substances and *a* Orionis five: that is, there were only nine out of seventy of the dark lines of Aldebaran coincident with bright lines, and five out of eighty of those of *a* Orionis. Yet the seventy and eighty dark lines that were compared represented some of the strongest only of the numerous lines which were seen on the spectra of these stars. Some of those remaining were probably due to the vapours of other terrestrial elements

[7] From further observations Mr. Huggins is of opinion that the red colour of this planet is not due to its atmosphere, but is peculiar to certain parts of its surface.

which were not compared with these stars, but Mr. Huggins concludes that many of those dark lines are due to new unknown elements existing in these stars, and that we cannot assume that the sixty-five simple terrestrial elements constitute the entire primary material of the universe. A community of matter, however, exists throughout the visible creation; for the stars contain many of the elements common to the sun and earth. 'It is remarkable that the elements most widely diffused through the host of stars are some of those most closely connected with the living organism of our globe, including hydrogen, sodium, magnesium and iron. May it not be that, at least, the brighter stars are like our sun, the upholding and energizing centres of systems of worlds adapted to the abode of living beings?'

With regard to the nebulæ Mr. Huggins's observations show that nine are gaseous, the spectra of six exhibiting three bright lines, one shows an additional faint line also, while the spectra of the dumb-bell nebula and the annular nebula in Lyra show the brightness of three green lines only. The spectra of eight other nebulæ were continuous, showing that their light has not undergone any modification on its way to us.

Mr. Huggins has been able to discriminate between the light of the nucleus of a comet and that of its tail. The nucleus is self-luminous, and its substance is in the form of ignited gas. The coma shines by reflected light as clouds do, and observations of the spectra give reason to believe that comets chiefly consist of nitrogen and another elementary body different from nitrogen combined with it.

The terrestrial elements found in the fixed stars show that, like the sun, they have an intensely luminous nucleus: but if it be taken for granted that highly heated gases are non-luminous internally, the planetary nebula and the great nebula in Orion itself being thus considered to be gaseous, must emit their feeble light from their surfaces alone. All the true clusters of stars which are resolved by the telescope into distinct bright points of light, give a spectrum which does not consist of separate bright lines, but is apparently continuous in its light. The great nebula in Andromeda, which is visible to the naked eye, has an apparently continuous spectrum, but the whole of the red and orange part is wanting, and the brighter parts have a mottled appearance. The easily resolvable cluster in Hercules has a similar spectrum; Lord Rosse discovered dark streaks or lines in both.

There is a striking correspondence between the results of prismatic and telescopic observations; half of the nebulæ which have a continuous spectrum have been resolved into stars, while none of the gaseous nebulæ have been resolved even by Lord Rosse's telescope. Thus it appears probable that primordial nebulous matter does exist, according to the theories of Sir William Herschel and La Place.

The structure of the sun himself, which forms one amidst the multitude of stars which constitute the Milky Way; and the maintenance of his light and heat without apparent waste, are still in various respects involved in mystery.

The luminous gaseous atmosphere of the sun is of great extent and of lower temperature, at least in its upper regions, than the photosphere on which it rests. Mr. De la Rue's photographs of the sun show that the light from the border of the solar disc is less intense than that from the equator, on account of the greater depth of solar atmosphere it has to pass through before it reaches the earth, by which a larger portion of the light is absorbed.

The photosphere of the sun has a mottled appearance, exhibiting minute masses, which must be of enormous magnitude to be visible at such a distance. They have been examined with a very high telescopic power by Mr. Nasmyth, who describes them as lens-shaped bodies of wonderful uniformity, and likens them to willow leaves crossing each other in all directions, and moving irregularly among themselves. Mr. De la Rue and Padre Secchi say they have seen something similar, and others liken them to rice grains. Sir John Herschel [8] is of opinion that they consist of incandescent matter sustained at a level corresponding to their density in the solar atmosphere, an atmosphere which he considers as varying from a liquid state below to the highest tenuity of a rarefied gas above. In a memoir read at the Institute of Paris,[9] by M. Faye, something of the same kind is suggested.

There are comparatively brighter waves of the sun's disc, called faculæ, which are portions of the sun's photosphere thrown up into the higher regions of his atmosphere; for Mr. De la Rue took a stereoscopic impression of a solar spot and some faculæ, in which the spot appeared to be a hollow and the faculæ elevated ridges. Being elevated above the photosphere, their light is less absorbed by the sun's atmosphere, and by contrast they are brighter at the less luminous border of the solar disc than at the equator.

It appears that the red flames and protuberances seen round the edge of the sun during a total eclipse are gaseous or vaporous luminous bodies which certainly belong to the sun; for during the total eclipse in 1860 it was observed, that as the moon moved over the sun's disc, the red flames and part of the corona discovered themselves at the side which she had left, and were covered by her disc at the side towards which she was approaching. Besides, the illuminating effect of the red

[8] 'Quarterly Journal of Science,' April 1864. [9] Jan. 7, 1865.

light of these flames is so inferior to its photographic power, that Mr. De la Rue photographed one of the protuberances, although it was invisible to the naked eye.

The sun spots which are situated in that region of the sun which lies below the photosphere consist of a central darkness or umbra, surrounded by a penumbra which is less dark. Professor Wilson, of Glasgow, proved that the spots are cavities, of which the umbra or darkest part forms the bottom, and the penumbra the sloping sides, by observing that the umbra encroaches on that side of the penumbra which is next the visual centre of the sun. Hence the umbra of a spot is at a lower level than the penumbra; and since luminous ridges and sometimes detached portions of luminous matter cross over the spots, it is concluded that the whole phenomenon is below the surface. The spots have an apparent motion from east to west, due to the rotation of the sun; and Mr. Carrington discovered that they have a proper motion also from east to west, those nearest the solar equator moving fastest. They are confined to the equatorial regions.

No reason has yet been assigned for the periodicity of the spots, which go through a cycle of maxima and minima every ten years nearly. They are singularly connected with terrestrial magnetism; the maximum of the spots coincides with the period of the greatest disturbance of terrestrial magnetism. The spots seem to be influenced by the planet Venus in such a manner that when a spot comes round by rotation to the ecliptical neighbourhood of this planet, it has a tendency to dissolve; and, on the other hand, as the sun's surface recedes from the planet it has a tendency to break out into spots.[1]

[1] On the latest discoveries concerning the sun's surface, by Balfour Stewart, Esq., in the 'Chemical News and Journal of Physical Science' of April 1865.

PART II.

VEGETABLE ORGANISMS.

SECTION I.

MICROSCOPIC STRUCTURE OF THE VEGETABLE WORLD.

THE STUDY of the indefinitely small in the vegetable and animal creation, is as interesting as the relation between the powers of nature and the particles of matter.

The intimate organic structure of the vegetable world consists of a great variety of different textures indeterminable by the naked eye, and for the most part requiring a very high magnifying power to discriminate. But ultimate analysis has shown that vegetables are chemical combinations of a few very simple substances. Carbon and the three elementary gases constitute the bases of all. No part contains fewer than three of these universal elements, hence the great uniformity observed in the chemical structure of vegetables. The elements unite according to the same laws within the living plant as in the inorganic creation, and the chemical laws acting upon them are the same. For, as already mentioned, M. Berthelot having combined carbon and hydrogen into acetylene, which no plant is capable of doing, he assumed it as a base from which he deduced, by the common laws of synthetic chemistry, hundreds of substances precisely similar to those produced by vegetables. Although it may be inferred from this that chemical action is the same within the vegetable as it is in the inorganic world, yet it is accomplished within the plant under the control of the occult principle of plant-life. No mere physical powers are capable of forming directly out of inorganic elements, the living organism whose passage through the cycle of germination, growth, reproduction and decay, serves so pre-eminently to distinguish between it and inert matter. Plants, indeed, borrow materials from the inorganic, and powers from the physical world, to mould them into living structures, but both are returned at death to the great storehouse of nature.

All other circumstances being the same, the vigour and richness of vegetation are proportionate to the quantity of light and heat received. The functions of light and heat are different, but their combined and continued action is indispensable for the perfect development of vegetation. Light enables plants to decompose, change into living matter, and consolidate, the inorganic elements of carbonic acid gas, water, and ammonia, which are absorbed by the leaves and roots, from the atmosphere and the earth; the quantity of carbon consolidated being exactly in proportion to the intensity of the illumination, which accounts for the darker green tint of the tropical forests. Light acting in its chemical character is a deoxidizing principle, by which the numerous neutral compounds common to vegetables are formed. It is the principal agent in preparing the food of plants, and in all the combinations and decompositions the law of definite quantitative proportions is maintained. It is during these chemical changes that the specific heat of plants is slowly evolved, which, though generally feeble, is sometimes very sensible, especially when the flowers and fruit are forming, on account of the increase of chemical energy at that time. To the same cause, the phosphorescence of certain flowering plants and a few fungi, is supposed to be due.

The action of heat is manifested through the whole course of vegetable life, but its manifestations take various forms suited to the period and circumstances of growth. Upon it depends the formation of protein and nitrogenous substances, which abound in the seeds, buds, the points of the roots, and all those organs of plants which are either in a state of activity, or are destined to future development. The heat received, acting throughout the entire organism of a plant, may augment its structure to an indefinite extent, and thus supply new instruments for the chemical agency of light, and the production of new organic compounds. The whole energy of vegetable life is manifested in this production, and, in effecting it, each organ is not only drawing materials, but power, from the universe around it. The organizing power of plants bears a relation of equivalence to the light and heat which act upon them. The same annual plant from germination to the maturation of its seed receives about the same amount of light and heat, whatever be the latitude, its rate of growth being in an inverse ratio to the amount it receives in any given time. For one of the same species, the more rapid the growth, the shorter the life.

The living medium which possesses the marvellous property of being roused into energy by the action of light and heat, and which either forms the whole or the greatest part of every plant, is in its simplest form a minute globe consisting of two colourless transparent concentric cells in the closest contact, yet differing essentially in character and properties. The external one, which is the strongest, is formed of one or more concentric globular layers of cellulose, a substance nearly allied to starch, being a chemical compound of carbon, hydrogen, and oxygen in the proportions of 12, 10, and 10, respectively.[1] It forms the universal framework or skeleton of the vegetable world, but it has no share whatever in the vital functions of vegetation. It only serves as a protection to the globular cell within it, which is called the primordial cell because it is first formed, and because it pre-eminently constitutes the living part, since the whole phenomena of growth and reproduction depend upon it. In its earliest stage the primordial cell is a globular mass of an azotized colourless organizable liquid, called protoplasm, the life blood of vegetation, containing albuminous matter and dextrine or starch-gum. It is sufficiently viscid to maintain its globular form, but its surface becomes slightly consolidated into a delicate soft film. The viscid albuminous liquid within it is mixed with highly coloured semi-transparent particles containing starch; besides cavities or vacuoles full of a watery vegetable sap of highly refractive power are imbedded in it. By degrees the coloured particles become more and more condensed within a globule of mucus, which constitutes the nucleus of the primordial cell. The watery sap in the cavities increases so much as ultimately to fill nearly the whole of the cell at the expense of the viscid protoplasm, which then merely forms a lining to the cell either coloured or hyaline. The primordial cell then secretes and envelopes itself with the strong protecting coats of cellulose already described. On account of its high colour, which is chiefly green, the whole contents of the primordial cell are called the endochrome. The minute globular nucleus contains a liquid of high refractive power, and is coated with a delicate film. Its structure, which is best seen in the hairs and young parts of plants, is not always the same, nor is it always in the centre of the pri-

[1] According to Payen. * Like starch, it is stained blue by iodine.

* It is not affected by Iodine

mordial cell, being sometimes attached to the internal cell wall.[2] On the minute but complicated organ, the primordial cell, vegetable life depends.

It will be shown afterwards that the primordial cell sometimes constitutes the whole plant, with or without its cellular coat. By its continual bisection when so coated, linear plants, such as the confervæ, are formed and lengthened (fig. 3). When bisection is about to take place, the cell increases in length; the nucleus, which always plays an important part in cell formation, spontaneously divides into halves; at the same time the cell wall becomes constricted in the middle and gradually folds between them, and divides the original cell into two new ones, in which the nuclei become perfect and assume their normal position. The terminal cell may undergo the same process, so that the plant may be lengthened indefinitely.

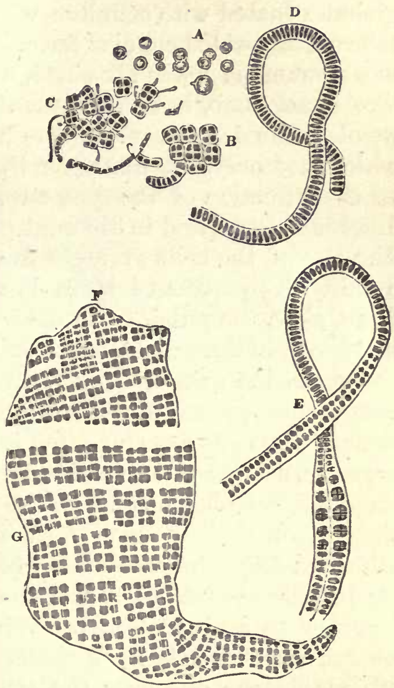


Fig. 3. Development of Ulva:—A, isolated cells; B, C, clustered subdivided cells; D, E, confervoid filaments; F, G, frond-like expansions.

Plants which spread in two directions are formed and

[2] 'On the Functions of the Nitrogenous Matter of Plants.' By M. L. Garreau, 'Annales des Sciences naturelles,' t. xiii. 1860.

increased by the successive division of the cells into four equal parts, as in some of the fuci, and the solid vegetable mass is formed and augmented upon the same principle, so that it consists of a congeries of primordial cells or globules coated with cellulose, which by mutual pressure take a many-sided cellular form. Six or eight sides are most common; when six-sided, a section of the solid is like honeycomb, but it frequently resembles a very irregular fine lace or network. The form of the cells, which not only depends upon the number of sides but on the direction of the pressure, varies exceedingly in different plants, and in different parts of the same plant. The size of the cells averages from the three to the five hundredth part of an inch in diameter. Some are very large, as in the pulp of the orange and lemon; but in the pollen of flowering plants, and other cases, they are not more than the thousandth part of an inch in diameter, consequently invisible to the naked eye. Occasionally the cells are elongated in the direction of least pressure, as in the stems and hairs of plants, or sometimes they have a stellar form. In the looser and fleshy parts they retain their globular form and only touch one another, leaving triangular spaces between them filled with air in water plants; but in general the cells are held together by a viscid liquid. When these intercellular spaces, whether left by globular or polyangular cells, are placed the one over the other for some distance, they constitute intercellular passages or channels, and sometimes they form lacunæ or large empty spaces.

Notwithstanding its great variety of forms, this solid congeries of cells, called cellular tissue, is the universal basis of vegetable structure; it forms the principal part of all plants, and the entire mass of many. Though often highly coloured, as in flowers, green leaves and young shoots, it is frequently hyaline and colourless. The dark cells in fig. 4 represent the green part of a leaf, the white ones are those of the colourless skin. Since the primordial cell is the medium in which light and heat act, cellular tissue is present wherever growth is in progress, for all the vital operations take place within its cells. All the organs of plants in their earliest stage consist entirely of cellular tissue, and even in full grown trees the bark and pith of the stem, as well as the soft parts of leaves and flowers, are generally composed of the cells of this tissue, which though assuming a great variety of forms never deviates far from the original type. Every important change in the structure of the cell diminishes or destroys its power of contributing to the nourishment of the plant, as appears in all the tissues derived from it, and which, according to M. von Mohl, is a necessary consequence of the disappearance of the vital part of the primordial cell from those parts of the cellular tissue destined to undergo the change.

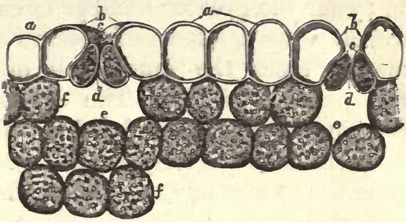


Fig. 4. Vertical section of the cuticle of Iris germanica :—*a*, cells of the cuticle ; *b*, cells at the sides of the stomata ; *c*, small green cells placed within these ; *d*, openings of the stomata ; *e*, lacunæ of the parenchyma ; *f*, cells of the parenchyma.

The fibro-vascular bundles which constitute the wood of trees, and form consecutive cylinders round the stem between the pith and the bark, consist of vascular ducts and woody fibre. The vascular ducts are formed of large wide cells each standing upon the other's flattened end, their cavities being thus separated from each other by septa or partitions directed at right angles to their longitudinal axis. This vascular tissue when young conveys the sap from the roots through the stem and branches to the leaves. It forms part of the stems of all climbing and quick-growing plants, in which the circulation of the sap is rapid, and the perspiration great. The sap in this crude state passes freely through the partitions, being probably a dialysable liquid; but in the autumn, when the sap ceases to rise, the septa are either absorbed or destroyed, as appears from the fragments of them that sometimes remain, and then the ducts become filled with air, which they convey to mature the sap in the leaves and all parts of the plant. Some of the vascular ducts have very narrow parallel fibres of a bluish colour twisted in a more or less elastic spiral from end to end of their internal surface, which in by far the greater number of cases turns in the same direction as a left-handed screw. In some ducts they merely cross the inner wall of the cell at regular distances as circles. The reticulated form from the crossing of right and left-handed spirals is still more frequent than the simple spiral; there is scarcely a plant, from the mosses upwards, in which that structure cannot be found.

In a vast majority of cases the secondary internal membrane of some of the ducts is perforated by orifices of numerous forms, sometimes irregularly, and sometimes in a regular pattern like a sieve, and on that account they are called the pitted tissue.

In the stem of a tree the vascular cylinders alternate with cylinders of woody fibre, as may be seen in a section perpendicular to the axis, in which the two tissues form a series of alternate rings. The woody or ligneous tissue, which gives strength and solidity to all vegetable structures, consists of bundles of nearly parallel spindle-shaped tubular fibres, having their attenuated extremities applied end to end to the extremities of those above and below them, so that they form groups of nearly straight lines; but although the ends of these tubular fibres overlap each other they do not prevent a free circulation of the sap. The different layers of these combined tissues which form the wood do not convey the rising sap in equal quantity. The outermost layers that are nearest the bark, which are always the last formed or youngest, convey it in greatest quantity, and on that account are called the sap-wood; the older the layers the less they convey, because the interior walls of the cells of both tissues are coated with successive layers of a mucilaginous substance which is the colouring matter of the wood (lignin), and is called sclerogen, which becomes hard, is ultimately united to the cell walls, and fills or nearly fills the tubular fibres and vascular ducts, so that those nearest the centre of the tree lose or nearly lose the power of conducting the sap, as in hard wood like the oak, though in softer wood, as the lime tree, it is not entirely lost. Ligneous tissue forms the chief part of the stems, branches, and shoots of trees and shrubs; it gives firmness to leaves, flowers, and all their parts, and strength to the stems and skins of herbaceous plants; it is found in the bark of all trees, and constitutes the strong fibre of hemp, flax, the agave, and many other plants, whence linen, canvas, and cordage are made. Cells lined with sclerogen form the shells of nuts, cocoa-nuts, and walnuts, as well as cherry, peach, and plum stones, the brown coat of apple and pear seeds, the gritty particles in the heart of the pear, the white coats of the pips of the orange and lemon, the husks of peas, &c.

All the tissues are represented in fig. 5, which is a longitudinal section of the Italian reed, much magnified. It consists of three parts: at *a* the cellular tissue of the pith is represented; *b* is a fibro-vascular bundle containing annular ducts (1), spiral ducts (2), a pitted duct (3), besides the long spindle-shaped threads of woody fibre; *c* is the exterior part of the reed, which consists of cellular tissue, the two surface rows being rather compressed and filled with coloured particles.

Besides the spiral vessels that are attached to the interior walls of the vascular ducts, there are groups of independent spiral vessels of great beauty and elasticity, of which the seeds of the wild clary afford a remarkable instance. They consist of cylindrical tubes with conical extremities twisted into a right or left-handed screw, which can be unrolled without breaking. They are found in the leaves of almost all plants, in the petals and stamens of flowers, in the stalks of all fruits, even in the minutest seeds; large parallel bundles of them imbedded in hexagonal cellular tissue may be seen in the veins of the kernel of the hazel nut, and they constitute the medullary sheath which surrounds the pith in trees. They are all hollow, and capable of conducting liquids.

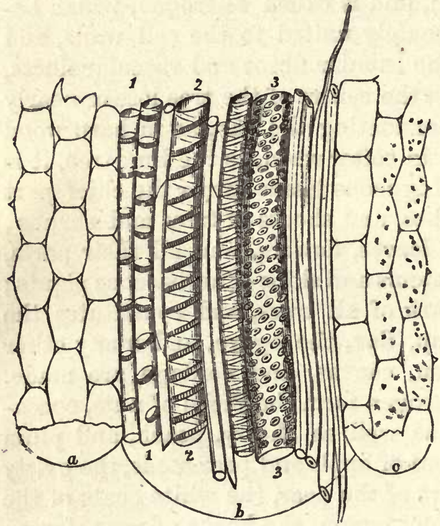


Fig. 5. Longitudinal section of stem of Italian reed:—*a*, pith; *b*, fibro-vascular bundles; *c*, cuticle.

The laticiferous vessels or vasa propria, those which contain the proper juices of plants whether milky or coloured, are exceedingly varied in their forms and arrangement in different plants, and in different parts of the same plant. In the leaves they generally form a delicate capillary network, in the bark they constitute a system of long vascular ducts forming an elongated irregular network pervious to the proper juices throughout; sometimes they are formed of cells joined end to end, and frequently they are thin branching flexuous tubes, meandering through the passages or interstices of the cellular tissue, and occasionally filling the lacunæ.[3]

Every one of the preceding tissues may be found in many of the highest class of vegetables—those which are distinguished by having seeds with two lobes or seed leaves, such as our common trees, shrubs, and most of the herbaceous plants. Palms, the cereals, grasses, canes, and all plants having seeds with but one lobe, which form the second class, consist of cellular tissue mixed with fibro-vascular bundles; whilst in the third or flowerless spore-bearing class, there is a general tendency to a more and more simple structure, from the tree fern to the lichens and algæ, which last consist of cellular tissue alone, and contain the lowest germs of vegetable life.

In seeds the miniature plant is enclosed between the two lobes, as in peas and beans, or in a cavity of a lobe, as in a grain of wheat or barley; and all the parts of the embryo are merely developed into the perfect plant during the progress of vegetation. A spore, on the contrary, which is the seed of a Cryptogam, or flowerless class of plants, is a most minute globular cell, full of granular matter, in which no embryo has yet been discovered, so that the parts of the future plant are supposed to be formed during the progress of vegetation, instead of being developed. Seeds, and spores also, sometimes produce new varieties, while buds and offsets only transmit the parent plant, with all its peculiarities. In the higher classes, the organs of nutrition and reproduction are always separate; in the lowest grades of vegetable life they are often the same. Seeds bear no proportion to spores either in size or num-

[3] 'Remarks on the Vessels of the Latex, the Vasa Propria, and the Receptacles of the elaborated Juices of Plants.' By M. Lestiboudois, 'Comptes rendus,' 1863.

ber; the latter are often so extremely small that they are invisible to the unaided eye, and are not to be counted even by thousands. It appears that beings, whether animal or vegetable, are prolific in the inverse ratio of their size. The incredible multitudes of the lowest grades of vegetable life, the rapidity of their growth, the shortness of their existence, and their enormous fruitfulness, make them powerful agents in preparing soil for the higher classes which are nourished by their decay. But no sooner do even the monarchs of the forest fall than the work of destruction begins; the light and heat which in their chemical form brought them to maturity, now in their physical character accelerate their decay; the moss and the lichen resume their empire, and live at the expense of the dying and the dead, a cycle which perpetuates the green mantle of the earth.

Notwithstanding the important part these inferior beings perform in the economy of nature, they were imperfectly known till they became a test for the power of the microscope. Then indeed not only were the most wonderful organisms discovered in the ostensible tribes of the Cryptogamia, but a new and unseen creation was brought under mortal eye, so varied, astonishing, and inexhaustible, that no limit can be assigned to it. This invisible creation teems in the earth, in the air, and in the waters, innumerable as the sand on the seashore. These beings have a beauty of their own, and are adorned and finished with as much care as the creatures of a higher order. The deeper the research, the more does the inexpressible perfection of God's works appear, whether in the majesty of the heavens, or in the infinitesimal beings on the earth.

SECTION II.

ALGÆ.

The principal objects in the study of plant-life are the organs by means of which they obtain and assimilate substances that are essential for their nourishment and growth, and those by which the perpetuity of their race is maintained and their type transmitted from age to age. In the lowest group of plants, represented by the Algæ, which come first into consideration, the two properties are combined; in the highest they are distinctly different, but the progress from one to the other may be traced through an ascending series of vegetable structure. In the simple grades of vegetables, the primordial cell frequently constitutes the whole plant; it appears first, and then envelopes itself with a coat either of cellulose or of a gelatinous substance.

Many instances of this are to be found amongst the Algæ, which are all aquatic plants, and are found growing either attached to other bodies, or floating in dependently, and live, some species in fresh water, and others in the sea and its estuaries. The Algæ absorb carbonic acid and give out oxygen, under the influence of sun-light, exactly as do the flowering plants; and the quantity of oxygen disengaged by them is said to be enormous.

Before proceeding to trace the structure and development of the Algæ, it may be desirable to indicate something of the classification of this curious group of plants. As already stated, they are without exception aquatic plants. They comprise three distinct orders, the Chlorospermeæ, having green spores; the Rhodospermeæ, having red spores; and the Melanospermeæ, having olive-coloured spores. These groups embrace all the varied plants known as sea-weeds, as well as the cellular plants which are developed in fresh water.

The Chlorospermeæ are separable into three groups, namely, those which are simply cellular, including the Palmelleæ, the green Desmidiaceæ, and the yellow-brown silicious-coated Diatomaceæ; those which are filamentous, called generally confervas, and including the true Confervaceæ, in which the threads have no compound axis, the Batrachospermeæ, in which the threads are partially incorporated with an axis, the Nostochineæ, in which the slender moniliform threads are invested with a mucous or gelatinous mass, the Oscillatoriæ, and some others; and those which are foliaceous, comprising the Ulvaceæ. All these are monœcious plants, whose reproductive bodies are zoospores provided with ciliary appendages, or motionless cysts filled with endochrome, true spermatozoids being rarely present.

The Rhodospermeæ divide primarily into two groups defined by the nature and position of their spores: one having the spores indefinite, produced within mother cells; the other having the spores single in the upper joints of the threads of the nucleus. The first group includes the Ceramiaceæ, which are filiform articulate plants, with the nucleus naked, and the Rhodymeniaceæ, which are compound inarticulate plants, with the spores generated within the cells of moniliform threads. The second group includes, amongst others, the Rhodomeliaceæ and the Laurenciaceæ, the former articulate, the latter inarticulate, and both bearing terminal spores, and having the nucleus conceptacular. To this group also belong the calcareous Corallinaceæ and the cartilaginous or membranaceous Sphærococcoideæ. The plants of this group are diœcious, with two kinds of fruit, spores and tetraspores, and they bear antheridia filled with active spermatozoids.

The Melanospermeæ divide into two series, the articulate and inarticulate. The former comprise the Ectocarpeæ, which are filiform plants with external cysts, and the Chordariæ, which are interlaced cylindrical plants with immersed cysts. The latter include the Laminariæ, flat, often strap-shaped, sometimes gigantic plants, having the spores superficial and indefinite, and the Fucaceæ, which constitute a large proportion of the shore-weeds of our seas and estuaries, and which bear their spores in elliptic or spherical conceptacles sunk in the frond. The Melanospermeæ are either monœcious or diœcious, and spermatozoids are general amongst them, though occasionally propagation is effected by means of zoospores resembling the spermatozoids.

Having thus indicated the several groups of the great Algal family, their structure and development will now be traced, commencing with the most simple forms, which occur among the CHLOROSPERMEÆ.

Spring water absorbs oxygen, nitrogen, and a large proportion of carbonic acid gas from the earth and the atmosphere, without losing its limpidity, but notwithstanding this apparent purity, if exposed for a time to the sun, green slime appears, and this the microscope shows to be full of globules or vesicles filled with green matter—the primordial cell in its earliest form. No green slime is formed in spring water if kept in darkness, so solar light is the principal agent in this growth, which is by no means a spontaneous birth; it is merely the development of one or more of the many kinds of germs, invisible to the naked eye, that exist in the earth, air, and water in myriads, waiting till favourable circumstances enable them to germinate.

The slime that covers damp walls or stones, and moist cliffs or rocks in the sea, also the slime or mucus that sometimes swims on the surface of water, are said by M. Bory de St. Vincent to be provisional creations waiting to be organized. Of this the conferva, Palmoglœa macrococca (fig. 6), is an example. It is a green slime covering damp places, consisting of microscopic primordial cells, each of which is surrounded by a gelatinous envelope, and filled with green granular matter occasionally con-

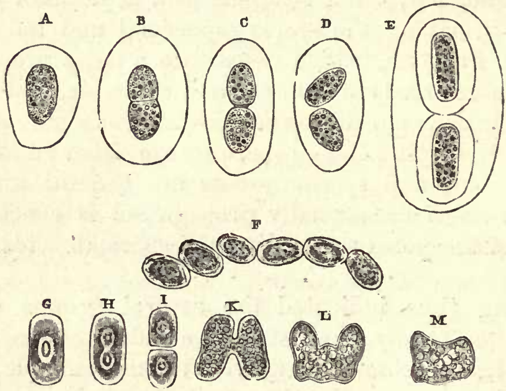


Fig. 6. Palmoglœa macrococca:—A, full grown cell; B—E, successive stages of binary division; F, row of cells produced by a succession of subdivisions; G—I, cells treated by iodine; K—M, cells in conjugation.

centrated into a nucleus. This singular plant is propagated in two different ways. The endochrome or green matter within the cell spontaneously divides into two equal parts, the thin coat of the cell bends round the two ends, separates them, then each half takes a globular or ovoid form, and secretes a gelatinous substance round itself which completes the separation, so that they form two distinct and independent plants, in every respect similar to that from whence they were derived. After a little time, each of these plants undergoes a similar bisection, so that four new plants are formed with their gelatinous envelopes; by the same process eight are produced and so on indefinitely, the organ of nutrition being the same with that of reproduction. Again, the membrane or film that covers each of these primordial cells is so thin and soft, that occasionally two adjacent cells of the series unite into one mass by a fusion of their sides and internal matter, which is then coated by a membrane, and after various internal changes becomes a spore which terminates a generation. By and by the spore germinates, produces a green primordial cell which secretes a gelatinous coat, and becomes by the process of bisection the parent of a new generation, which terminates by the union of two adjacent cells to produce a spore, a cycle of alternate modes of reproduction that may be continued till ended by some external circumstance, as the cold of winter.

When the matter in two adjacent cells joins to form a spore, it becomes granular, and mixed with minute particles of oil, which unite in a drop; and the spore, which is at first green, gradually assumes a yellow brown colour; conversely when the spore begins to grow, the oil disappears, and the green matter takes its place. This is a frequent occurrence during the formation of spores in this class of plants, for the endochrome or internal matter,—which consists of a small variety of elements probably in a state of unstable equilibrium or change,—is easily decomposed and recombined into new substances by chemical action, but the bisection of the cells of the Palmoglœa so as to form new individuals is probably owing to heat alone. There is no apparent difference between the cells selected to produce spores by their union, and the others. It seems that in every plant certain cells are reserved for certain purposes. Professor Karsten conceives the nucleated cells to be reserved for reproduction, while those destitute of nuclei are designed for secretion.

The Protococcus pluvialis (fig. 7), one of the unicellular Confervæ, is frequently met with in rain-water cisterns. The spore of the plant (fig. 7 A) is a globular primordial cell invested with a double coat of cellulose, sometimes separated by an aqueous fluid, sometimes not. The cell is filled with protoplasm, a colourless

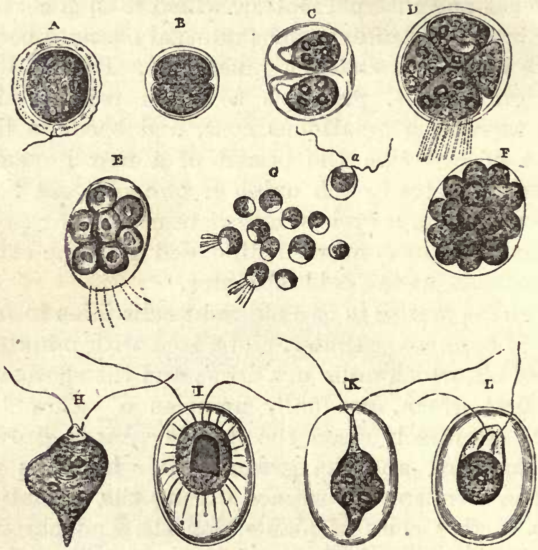


Fig. 7. Protococcus pluvialis:—A, encysted cell; B, C, cells divided into two; D, cell divided into four; E, cell divided into eight; F, cell divided into thirty-two; G, escaped motile gonidia; H—L, primordial utricles furnished with cilia.

watery liquid in which red and green particles are scattered. When this spore begins to grow, the endochrome, or solid matter in the primordial cell, divides spontaneously into two similar and equal parts, round at one end, and tapering to a point or beak at the other, each being coated by a very thin film of the transparent colourless protoplasm.

After various changes, the green matter with several red spots is condensed into the thick round half, while the tapering beaked part is left transparent, being only filled with the watery liquid. Both bodies are then coated with cellulose, and two vibratile filaments called cilia, from their resemblance to eye-lashes, proceed from a point near the beak. The whole of these changes take place while the two bodies are still within the common cellulose covering; the moment they come out of it, by a rupture in the cell-wall, they swim about with the greatest velocity by means of their cilia, which lash the water so rapidly that they are invisible even with a microscope. The activity of these zoospores, as they are called, continues for about an hour and a half; the motion then becomes gradually less rapid; the cilia may now be seen, and soon fall off; then the bodies acquire a firmer coat of cellulose, and sink to the bottom of the water, where they remain at rest as still, or winter spores. There is great variety in the Protococcus, for the matter in the primordial cell sometimes divides not only into two equal and similar parts, but into 4, 8, 16, 32 equal and similar parts consecutively; each brood is developed into zoospores, which ultimately become resting spores.

When a spore is to be formed in a primordial cell, the starch and green matter condense into a nucleus in its centre, and a membrane envelopes the liquid and the nucleus within it, so that a spore in its first stage is a free and independent cell containing azotized matter swimming in a formative liquid. If the spore is to be motile it remains of a green colour, and gets cilia; but if it is to be a winter spore, the internal matter forms into granules, mixed with particles of red oil, which coalesce into a drop, and it generally undergoes the same transformations as those which take place after the conjugation or union of two adjacent cells into one as already described. The zoospores may lose their cilia, fall to the bottom of the water as green spores, and reproduce a facsimile of the parent plant as buds do, or they may acquire a cellulose coat, undergo the transformations and change of colour mentioned, and sink to the bottom of the water as red winter spores.

Under certain circumstances which do not seem to be perfectly known, it happens that during the formation of some of the zoospores the green matter is gradually changed into a red oily substance; they lose their cilia, acquire by secretion their cell-walls and a mucous envelope, and float on the water as winter spores. Should they be left dry, they may remain in that state for an indefinite length of time without losing their vitality, and as they are extremely small, they are carried by currents of air into the atmosphere, from whence they are brought down in the rain, and having fallen occasionally in places where they were never seen before, have given rise to the idea of spontaneous generation.

Many cycles may be accomplished from the still cell to the zoospores, and back again, producing numerous generations from the same plant before it returns to the red thick-walled cell, which may again be dormant for an unlimited time. These cycles, however, do not finish the history of the plant, for there can be little doubt that, in some stage of its existence, a conjugation of two cells occurs, as in the Palmoglœa.

Sometimes when the division of the endochrome of the spore of the Protococcus is successively divided into sixteen parts, or even sooner, the new cells thus produced get two long cilia, as in fig. 7 H, and are liberated before they acquire their cellulose coat. This motile primordial cell soon acquires a bag-like investment (fig. 7 I, K, L,) of cellulose, through which the cilia pass, and thread-like extensions of the protoplasm are not unfrequently seen to radiate from the primordial cell to the surrounding bag, as in fig. 7 I, showing that the transparent space is only occupied by a watery liquid. The varieties of this plant are very numerous, and all related to one another. Sometimes the whole of the matter within the primordial cell of the spore divides at once into 4, 8, or 16 parts, giving rise to as many minute primordial cells.

The cilia are extensions of the colourless transparent film which covers the zoospores, and their vibrations are generally believed to be a consequence of the vital contractibility of that film, and intimately related to the changes taking place in the cell on which they are borne. The persistence of their motions after a cell is detached from a compound body covered with them, being like the persistence of the contractibility of muscle fibre after being detached from a living animal, proves that we must look to a contractile energy in the film of protoplasm for the maintenance of these curious operations.

It appears that a cell cannot perform two functions at the same time, and that one must either precede or follow the other. Thus, the zoospores have two distinct periods of action; the first is that of mechanical motion alone, which is followed by one of growth and multiplication, manifestations which, though very dissimilar, are really modes of action of the same vital energy that formed these bodies while they were yet in their parent cell. In fact, it seems to be a general law, that each cell is endowed, altogether or for a time, with its own mode of action, and is incapable of any other.

Of the Volvocineæ, by some regarded as fresh-water microscopic plants, the Stephanosphæra pluvialis may be taken as a type. This plant consists of a colourless transparent globe not more than the $\frac{48}{1000}$th of an inch in diameter, containing eight green primordial cells arranged in a circle in its equator. Each primordial cell is furnished with a pair of cilia; these 16 cilia pierce through the hyaline globe, and by their vibrations, they make it rotate about an axis perpendicular to the plane of its equator, and move actively through the water. Each of the primordial cells, which are green with a spot of red in the centre, secretes a cellular covering, and they swim about in the interior of the globe as free cells. Eventually they escape either by fissure of the globe, or by its gradual dissolution. After swimming about for a short time they become motionless, lose their cilia, and sink to the bottom as green still spores.

If, after being dried, water be poured on one of these green still spores, it takes up the water, its contents become closely granular, and fill the whole membrane of the spore. Then it divides, first into halves, then into quadrants or heart-shaped segments, meeting in a point in the centre of the membrane. These quadrants are ultimately divided into 8 wedge-shaped segments, whose contour lines, like the spokes of a wheel, meet in the centre, and each gets a pair of cilia. The coloured matter is driven back in each individual towards the thick end of the wedge as if by centrifugal force, and a colourless plasm remains in the points or beak. These disappear, a cavity is formed in the centre of the disc, the eight bodies assume the form of a wreath in close contact, and the original cilia, which continue to vibrate, cause the rotatory and progressive motion of the whole organism.

Sometimes the eight globular bodies have been seen to divide into a number of extremely minute motile cells, while yet within the parent globe. These gonidia, as they are called, are, with a few exceptions which may reproduce the plant, believed to perish when they come into the water.

The division of the primordial cell of this plant is confined to a certain time of day; it begins towards evening, and is completed the following morning, and according to Mr. F. Currey, the exact time is the same in Lapland, where there is no night, and at Berlin in spring when the day and night are almost equal. The fertility is enormous. It is calculated that in eight days, under favourable circumstances, 16,777,216 families of the Stephanosphæra pluvialis may be formed from one resting spore.

The transmutation of chlorophyll in the Protococcus and Volvocineæ, from green to red and vice versâ, which so frequently occurs in the lowest class of plants, shows that its molecules must be united by very feeble affinities, and easily converted into new combinations either by direct chemical action, or by other substances also in a state of change.

The Volvocineæ consist of various species according as the internal matter of the primordial cell divides into 2, 4, 8, 32, or a greater number of equal parts, forming respectively as many free cells which ultimately become ciliated spores, by means of which the globe either rotates on the spot, or in straight lines. The Volvox globator found in fresh-water pools is one of the most remarkable of these, both for its peculiarity and beauty of structure and for its comparatively large size, since in some lights it is visible to the naked eye while swimming in a drop of water. When viewed with a microscope, it is a pellucid sphere whose surface is studded with green spots, often connected by green threads; each of the spots has two cilia, so that the surface is bristled with these filaments, whose vibrations give the sphere either a rolling or smooth motion, or make it spin like a top in the same place.

Fig. 8. Volvox globator.

In the interior of the sphere there are from two to twenty dark green globes of different sizes; the smaller are attached to the internal surface, while the larger rotate freely by their cilia in the internal cavity. After a time the sphere bursts open and its inhabitants swim forth, and soon assume the form and character of that which gave them birth.

The growth and development of the Volvox globator are peculiar, for in the primordial cell the red and green endochrome breaks up into numerous angular masses, and a central globe rather larger than the rest. The angular masses are connected by green threads, the interstices between all the bodies are filled with a hyaline substance secreted from their surfaces, and the whole is enclosed in a distinctly membranous globular envelope.

As this young Volvox increases gradually in size, the hyaline matter is increased, the green threads lengthen, and the angular masses assume the form of a flask the $\frac{1}{3000}$th of an inch in diameter exactly as in the Protococcus; for the green matter with a few red spots is collected in the thick end, while the hyaline beak is turned towards the circumference of the sphere, which is pierced by their long cilia. Each of them is invested with a pellucid envelope of considerable thickness, the borders of which are flattened against those of similar envelopes. While these ciliated bodies are approaching maturity their endochrome exhibits vacuoles or apparently empty cavities of a spherical form about one-third of its own diameter. Mr. G. Busk discovered that these vacuoles expand and contract at regular intervals of about forty seconds. The contraction, which almost obliterates the cavity of the vacuole, is rapid and sudden; the dilatation is slow and gradual. This action ceases when the body comes to maturity.

When this mass of zoospores connected by green threads is immature and begins to expand into a hollow sphere, then the central globe is continually bisected so as to form 4, 8, 16, 32, 64, or a greater number of equal and similar parts, each of which is ultimately developed into a zoospore exactly the same with the matured green zoospores on the surface of the primary sphere, so that the 'Volvox globator is a composite fabric made up of a repetition of organisms in all respects similar to each other,' which Professor Ehrenberg the first to discover, though he did not investigate the development of the plant.

It appears that certain spheres of the Volvox are monœcious, that is, each sphere contains male and female cells, though the greater number of cells are neutral. The germ or female cells are larger and of a deeper green than the others; the male cells resemble them, but the endochrome within them breaks up symmetrically into a multitude of linear particles aggregated into discoid bundles beset with vibratile cilia, which move about within their cells and soon become decomposed into their component corpuscles. Each of these corpuscles has a linear body, thicker at its posterior end, and furnished with two long cilia. The female cell, when fertilized, gets a smooth envelope, and then a thicker one, beset with conical-pointed processes, and the contained chlorophyll gives place, as in Palmoglœa, to starch and a red or orange coloured oil. It appears that the Volvox stellatus and V. aureus are only phases of the Volvox globator.

The Desmidiaceæ are minute green algæ inhabiting fresh-water pools or slow running streams, never those that are muddy. They are free unicellular plants, sometimes triangular, sometimes cylindrical, crescent or bow-shaped, smooth or spined. So varied are their microscopic forms that a description would be tedious. In plants of such extreme minuteness, the only means of ascertaining the nature of their component materials is by chemical tests. A solution of iodine turns starch blue, and cellulose brown, and thus it is found that the interior of the Desmidiaceæ is occupied by a mass of starch granules, covered with chlorophyll, and mixed with a formative fluid. This mass, enclosed in a delicate membrane, constitutes the primordial cell; it has an exterior coat of firm cellulose, and the whole is more or less enveloped in a gelatinous substance. Like other plants, when in bright

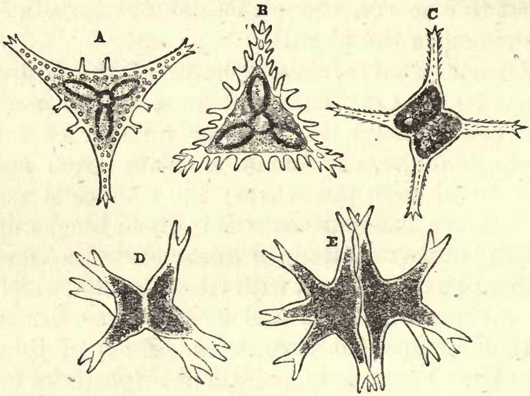


Fig. 9. Various species of Staurastrum:—A, vestitum; B, aculeatum; C, paradoxum; D, E, brachiatum.

sunshine, the Desmidiaceæ decompose carbonic acid gas, give off the oxygen, and assimilate the carbon into chlorophyll.

These plants are frequently distinguished by projections from their cellulose coat above their surface, these being sometimes short and conspicuous, but often projected in spines, which form a beautiful symmetrical hyaline border round the green internal cell, as shown in fig. 9. Another peculiarity of the Desmidiaceæ is the appearance of their being divided into two symmetrical parts by a satural line, as the name implies, though there is no real division.

Many of the Desmidiaceæ, but more especially the genus Closterium, are remarkable for having a double circulation of the internal fluid in opposite directions, maintained by a vital contractile energy. One current flows between the cellulose horny coat, and the thin film covering the chlorophyll, while the other spreads in a broad stream in the contrary direction between the thin film and the chlorophyll mass, carrying from the latter some of its coloured particles to the extremities of the frond, where there seems to be a connection between the two streams.

The type of the Desmidiaceæ is continued by various

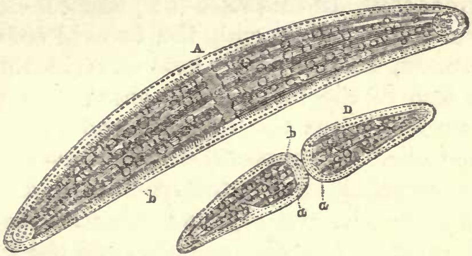


Fig. 10. Economy of Closterium Lunula:—A, frond showing central separation; D, frond in a state of self-division.

modes of bisection, depending upon the genus and species of the plant. In the Closterium Lunula, which has an elongated crescent shape, as in fig. 10 A, the endochrome or internal matter divides into two equal parts, which retreat from one another at the middle line; and a constriction of the cellulose coat takes place between them, which increases till it closes entirely round the extremities, as in fig. 10 D; then one of the halves remains at rest while the other moves from side to side, and finally detaches itself from the other with a jerk. In each of these halves a constriction of the endochrome may be seen, dividing it into an obtuse and an elongated part, and for some time the circulating fluid flows round the obtuse end, but the latter gradually assumes the form of the elongated end, the regular circulation of the fluid is established, and in five or six hours after the separation, two young desmids are formed precisely similar to their parent, the Closterium Lunula.

The Cosmarium, another Desmid, consists of a cell of two lobes united by a narrow isthmus. When about to multiply, the isthmus swells into two globular expansions, separated from each other and from the two lobes of the cell, by a narrow neck. These enlargements increase and assume the appearance of half segments of the original cell. In this state the plant consists of four segments lying end to end, the two old ones forming the extremes, with the two new ones in the middle. At last, each of the middle segments gets a new half, which soon acquires the full size and characteristics of the old one. This process, which is accomplished in twenty-four hours, is repeated ere long, and being continued indefinitely, the extreme lobes of the row are thrust farther and farther asunder, and the whole constricted thread or chain of Cosmaria is enclosed in a gelatinous sheath. The last two central lobes contain no portion of the original frond or plant, and may thus be considered to be entirely new individuals.

Many of the Desmidiaceæ multiply by the subdivision of their endochrome into a multitude of granular particles called gonidia, which are set free by the rupture of the cell wall, and of which every one may develop itself into a new cell. The gonidia may be zoospores with cilia and active locomotion, or they may be enclosed in a firm envelope, and become resting spores. The movement of the zoospores at first within the cavity of the cell which gave them their origin, and afterwards externally to it, has frequently been observed in the varied species of the genus Cosmarium, and has been described under the name of the 'swarming of the granules,' from the resemblance of the moving mass to a swarm of bees. Their subsequent history is unknown.

In the Pediastrum, a plant consisting of a cluster of cells, the zoospores are not emitted separately, but those formed by the subdivision of the endochrome of one cell into 4, 8, 16, 32, or 64 parts, escape from the parent plant still enclosed in the inner tunic of the cell, and it is within this that they develop themselves into a cluster resembling that in which they originated.

Mr. Thwaites discovered that the Desmidiaceæ are also propagated by conjugation, which would be impossible if the hard coat of the adjacent cells about to unite did not split open; then the whole endochrome in one cell passes into and blends with that in the other cell, so as to form one mass, which soon acquires a delicate membranaceous envelope. At first the mass consists of granular green matter, but when the membrane becomes thicker, it changes to brown or red. This body, which is called a sporangium, is sometimes smooth, sometimes granular, covered with tubercles or rough with spines, according to the nature of the original plants. The filamental species are propagated by conjugation, but the subsequent history of the produce is still obscure, though there is reason to believe that they give rise to plants of different forms, while all the other modes of increase only reproduce a facsimile of the parent.

Desmidiaceæ exist in America, but their distribution is little known. In Europe, their maximum seems to be in the south of England. They abound in small shallow pools that do not dry up in summer, and also on boggy moors. The larger kinds are spread out as a thin gelatinous stratum at the bottom of water, or collected in little tufts; others form a dirty cloud upon the stems and leaves of aquatic plants. They have been found in a fossil state in flint, their spores have been discovered in the grey chalk at Folkestone, and the cells of various species of Closterium and Euastrum are imbedded in the marls of the United States of North America.

The Diatomaceæ, or Brittleworts, are unicellular microscopic plants so numerous that there is hardly a spot on the face of the earth, from Spitzbergen to Victoria Land, where they may not be found. They abound in the ocean, in still and running fresh water, and even on the surface of the bare ground. They extend in latitude beyond the limits of all other plants, and can endure extremes of temperature, being able to exist in thermal springs, and in the pancake ice in the south polar latitudes. Though much too small to be visible to the naked eye, they occur in such countless myriads as to stain the berg and pancake ice wherever they are washed by the swell of the sea; and when enclosed in the congealing surface of the water they impart to the brash and pancake ice a pale ochreous colour.

Although the diatoms have a vast variety of forms, they all consist of a simple primordial cell whose external coat of cellulose is so deeply interpenetrated with silex that it is indestructible, a structure which constitutes the peculiar characteristic of the tribe. This primordial cell, as in other plants, contains organizable liquid or protoplasm, through which golden-brown granules are pretty regularly distributed, except in the centre, where they are collected into a nucleus. Round this nucleus they commonly form a ring from which radiating lines of granules diverge to the interior wall of the cell. In each of these there is a double current of granules, similar to the circulation in the Desmidiaceæ; it was discovered by Professor Smith in some of the comparatively large diatoms. At times oil globules are seen in the protoplasm. The golden-brown matter is supposed to be chlorophyll, whose green tint has been changed by the presence of iron, which is assimilated in this group. Such is the internal structure of a race of plants altogether invisible to the naked eye. Their external forms, reproduction and movements, are no less wonderful.

The silicious envelope of the simple cell of a Diatom or frustule, as a single plant is usually called, consists of two valves or plates, commonly of the most perfect symmetry, closely applied to each other along a line of junction like the two valves of a bivalve shell, and each valve being more or less concavo-convex, a cavity is left between the two which is occupied by the golden-brown cell described above. The form of the cavity differs greatly, for sometimes each valve is hemispherical, so that the cavity is globular; sometimes it is a small segment of a sphere, resembling a watch-glass, so that the cavity is lenticular; in short, the form of the cavity depends upon that of the valves, which may be heart-shaped, or much elongated, square, triangular, boat-shaped, or furnished with outgrowths, which, however, is rare.

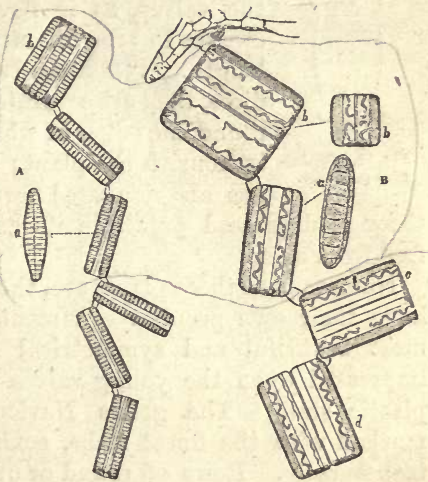


Fig. 11.—A, Diatoma vulgare:—*a*, side view of frustule; *b*, frustule undergoing self-division.
B. Grammatophora serpentina:—*a*, front and side view of single frustule; *b*, front and end view of divided frustule; *c*, frustule about to undergo division; *d*, frustule completely divided.

The diatom or frustule is considered to present its front view when the joint or suture of the valves is turned to the eye, as in fig. 11 B, *b*, whilst the side view is seen when the centre of either valve is directly beneath the eye, as in fig. 11 A, *a*. When the diatoms are young the valves are in close contact, but as they increase in size by a secretion round their edges, the valves separate from one another, and the cell membrane which is left exposed is immediately consolidated by silex, and forms a kind of hoop between the valves, as in fig. 12. This hoop increases in breadth as the cell increases in length. When the two valves are circular discs, they are separated by a circular hoop, round the edges of which water is admitted to nourish the plant; but when the diatom has an elongated form, the water enters through depressed points in its extremities which are free from silex.

Fig. 12. Biddulphia pulchella.

Numerous as these plants are, the valves of each genus have their own peculiar ornaments, consisting of the most beautiful and symmetrical designs, which are impressed upon the young valves when they are in a plastic state. The genus Navicula and others are marked with the finest striæ, some diagonally, others transversely. Rows of round or oval spots disposed in parallel lines are peculiar to some; the valves of others are covered with hexagonal forms of the most perfect structure, as those of the Pleurosigma angulatum, fig. 13, where A is the magnified diatom, and B and C its hexagonal areolations, seen under higher and higher microscopic powers; but the figures on the discoid genera are the most beautiful of all. There is generally a small ornamented circular space in the centre of the valves, from whence rays extend to the circumference, dividing the surface of the valves into eight, ten, or more equal parts, the alternate segments being differently and highly ornamented, as in the Actinocyclus undulatus (fig. 14), where A is the side view, and B is the front view. The Arachnoidiscus Ehrenbergii takes its name from the likeness of the figures on its circular valves to a spider's web. According to the observations of Mr. Shadbolt, each valve is formed of two superposed layers; on the uppermost of these, which is a thin horny transparent substance, the spider's web is engraven; and the undermost silicious layer, which forms the supporting frame-work, is like a circular Gothic window. The genus Triceratium, nearly allied to the preceding in general characters, though differing in having a triangular shape, has many species in a fossil state, while others are still existing in the ocean, and in tidal rivers. The Triceratium favus, one of the largest and most beautifully marked, occurs in the mud of the Thames, and that of the estuaries of other rivers on our coasts; it is also frequently found on the surface of uncleaned

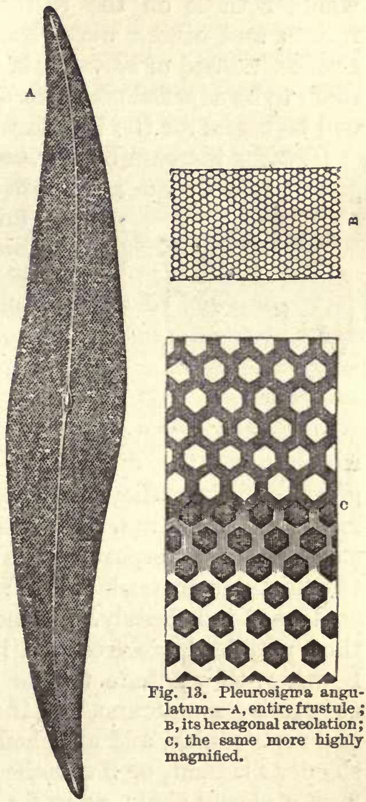


Fig. 13. Pleurosigma angulatum.—A, entire frustule; B, its hexagonal areolation; C, the same more highly magnified.

shells.[4] From the few examples given, a faint idea only can be formed of the variety and beauty of the engravings on the diatoms. It had long been doubted whether those on the valves of Coscinodiscus, Triceratium and others, were elevations or depressions, but Professor Rood of New York, United States, has proved them to be depressions by an optical arrangement which will be useful for the investigation of microscopic forms.

Diatoms increase by spontaneous bisection, by conjugation, and by the resolution of their endochrome into minute spores, called gonidia. When bisection is about to take place the cell elongates, the hoop increases in breadth, the endochrome divides into two equal parts, and the coating of the cell bends in between them, which gives the diatom the appearance of an hourglass. At last they separate, and upon each of the new surfaces a new silicious half is formed, usually the exact counterpart of the old one, so that there are two diatoms instead of one; and the process may be continued indefinitely. In most cases, the new diatoms thus produced are free and independent. Sometimes, however, they adhere to one another by a fragment or connecting membrane, and if they happen to be slender and rectangular, and attached side by side, they form a slender filament, or if attached by alternate angles they form a zigzag chain, as in fig. 11.

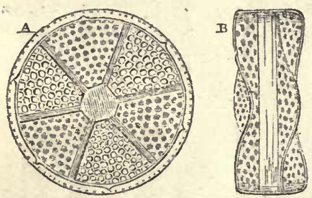


Fig. 14. Actinocyclus undulatus.

The Meridion circulare (fig. 15) is a diatom of exquisite beauty, millions and millions of which cover every submerged stone, twig, or blade of grass, and even form the

[4] The author is indebted throughout many parts of this section to the excellent work of Dr. Carpenter, and to the 'Cryptogamic Botany' of the Rev. M. J. Berkeley, from which also many of the cuts are derived.

mud at the bottom of the streams at West Point, in the United States of North America. Its frustule or single diatom is long, slender, and rectilinear, but being broader at one end than at the other, by continued bisection and adhering to one another they form a circular, spiral, or flattened helical screw of several turns. The individual frustules of some marine diatoms have a precisely similar form, being rectilinear and broader at one end than the other, but each frustule is attached by its narrow end to the extremity of branching cellulose stems fixed to sea-weeds or stones, and by a continuous subdivision of which the stem does not partake, they are spread out at their free ends like a fan.

By continual bisection a diatom is propagated through many generations, but at some stage or other, owing to an unknown cause, propagation by conjugation takes place. When two frustules are near to each other, two little swellings arise in one, which meet two little swellings in the other opposite to it. These soon unite and elongate, the septum or division between them is absorbed so that they form two tubes in which the endochrome of the two frustules becomes mixed, and a spore is formed in each of the two connecting tubes, which increase in size and change in form till they resemble in every respect the parent, except in being much larger. As these young diatoms swell, they split the two parent frustules, become free, and lay the foundation of a twin series of generations. In the Fragillaria only a single spore is formed.[5]

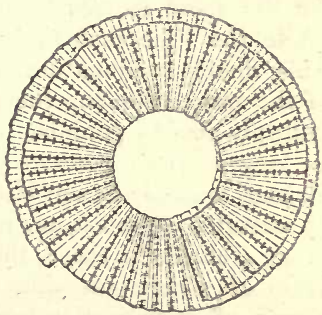


Fig. 15. Meridion circulare.

[5] Mr. Berkeley's 'Cryptogamic Botany.'

In Surirella and Epithemia the manner of conjugation is somewhat different. In the former the valves of two free adjacent frustules separate from each other at the suture or line of junction and the two endochromes are discharged; they coalesce and form a single mass, which becomes enclosed in a gelatinous envelope, and in time this mass shapes itself into a frustule resembling that of its parent, but larger. In Epithemia, however, the endochrome of each of the conjugating frustules divides at the time of its discharge into two halves; each half of the one coalesces with each half of the other, and two frustules are formed which become invested with a gelatinous envelope and gradually assume the form and markings of the parent frustules, but grow to a much larger size, for the spore masses have the power of self-increase up to the time that their envelopes are consolidated. This double conjugation seems to be the ordinary type of the process among the diatoms.[6] But these plants multiply also by gonidia. It is thought probable that as long as the vegetative processes are in full activity diatoms multiply by self-bisection, but when a deficiency of warmth, of moisture, or of some other condition, gives a check to these, that they increase by gonidia, some of which becoming encysted, possess a greater power of resisting unfavourable circumstances, and thus the species is maintained in a dormant state till a change enables them to germinate. It is even thought they may be the origin of distinct species.

A peculiar spontaneous locomotion is exhibited by some diatoms of a long narrow form, as the Naviculæ, which by a succession of jerks in the direction of their length, go to a certain distance, and then return nearly by the same path. The motion of the Bacillaria cur-

[6] 'Dr. Carpenter's 'Microscope.'

soria is still more unprecedented. The frustules, which are narrow, lanceolate, and acute, are joined end to end in a long line by some highly elastic invisible medium. One of the terminal frustules remains at rest while all the others slide over it till the line is so much stretched that they are nearly detached from one another; then they all slide back again in the same manner, and this alternate motion is continued indefinitely at regular intervals of time. The velocity of the diatoms at the free end of the row is very considerable; in the Bacillaria paradoxa it is $\frac{1}{200}$th of an inch in a second; the impetus of one has been observed to upset and even to push aside a plant as much as three times its size which obstructed its path. If the frustule at the free end gets

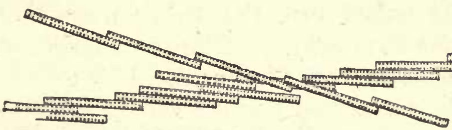


Fig. 16. Bacillaria paradoxa.

entangled, the fixed frustule takes the lead and continues the motion till the other is free. Minute particles in the vicinity are sometimes attracted and dragged after the frustules, sometimes they are repelled, possibly by some invisible organs; but the whole motion of the diatoms themselves may perhaps be attributed to the action of light and heat upon the highly contractile substance, whatever it may be, which connects their frustules, since their motion is exactly in proportion to the quantity of light and heat received, for it ceases during darkness, and is renewed on the return of light; ultimately it may disperse the individual frustules, which are not more than between the $\frac{28}{10,000}$th and the $\frac{84}{10,000}$th of an inch in length and the $\frac{4}{10,000}$th of an inch in breadth.

This Bacillaria paradoxa (fig. 16) differs from the preceding species in its motion; each half of the row of frustules moves in an opposite direction on each side of a central stationary frustule, and the alternate motion is so regular as to time, that if in advancing, the frustules meet with an impediment, they wait till the proper time comes for their retreat. The jerking motions of the Naviculæ are ascribed by Prof. W. Smith to forces acting within the plants, originating in the vital operations of growth, by which the surrounding water is drawn in at one end of the frustule, and expelled at the other.

Some species of diatoms are so universal that they are found in every region of the globe; others are local, but the same species does not inhabit both fresh and salt water, though some are found in brackish pools. The ocean teems with them. Though invisible as individuals to the naked eye, the living masses of the pelagic diatoms form coloured fringes on larger plants, and cover stones or rocks in cushion-like tufts; they spread over the surface as delicate velvet, in filamental strata on the sand, or mixed with the scum of living or decayed vegetable matter floating on the surface of the sea; and they exist in immense profusion in the open ocean as free forms. The numbers in which they exist in all latitudes, at all seasons, and at all depths—extending from an inch to the lowest limit to which the most attenuated ray of light can penetrate, or at which the pressure permits—are immeasurably in excess of what we have been in the habit of assuming. Temperature has little to do with the distribution of diatoms in the tropics; it decreases with the depth at a tolerably fixed rate till it becomes stationary. It increases in the polar regions with the depth, and approaches the standard, which is probably universal, near the bed of the ocean.

Nothing can exceed the vividness of colour or massiveness of the endochrome or soft internal matter of the floating diatoms, that matter which diminishes their specific gravity and makes the plant buoyant which otherwise would be weighed down by its silicious coat. At those periods in which the structural and reproductive phenomena proceed most vigorously, their position in depth must be fluctuating; hence they approach and vanish from the surface. Their growth is perfected by the heat and light which penetrates the sea in calm weather.

Diatoms are social plants crowded together in vast multitudes. Dr. Wallich met with an enormous assemblage of a filamental species of Rhizoselenia, which is from six to twenty times as long as it is broad, aggregated in tufted yellow masses, which covered the sea to the depth of some feet, and extended with little interruption throughout six degrees of longitude in the Indian Ocean. They were mixed with glistening yellow cylindrical species of such comparatively gigantic size as to be visible to the naked eye.

Other genera constitute the only vegetation in the high latitudes of the Antarctic Ocean. Dr. Hooker observes, that without the universal diffusion of diatoms in the South Polar Ocean, there would neither be food for the aquatic animals, nor would the water be purified from the carbonic acid which animal respiration, and the decomposition of matter, produce. These small plants afford an abundant supply of food to the herbivorous mollusca and other inhabitants of the sea, for they have been found in the stomachs of oysters, whelks, crabs, lobsters, scallops, &c. Even the Noctiluci, those luminous specks that make the wake of a boat shine like silver in a warm summer night, live on the floating pelagic diatoms, and countless myriads are devoured by the enormous shoals of salpi and other social marine animals.

The silicious shells of the diatoms form extensive fossil deposits in various parts of the globe, containing species which have long ceased to exist, and others that are identical with those still alive even in their most minute and delicate engravings. The polishing slate of Bilin in Bohemia, which occurs in beds 14 feet thick, and the Tripoli and Phonolite stones on the Rhine consist entirely of the silicious coats of diatoms, while the city of Richmond in Virginia stands upon a marine deposit of the debris of diatoms 13 feet thick, and of unknown extent. Near the Mediterranean, very extensive strata, consisting almost entirely of marine Diatomaceæ, alternate with calcareous strata chiefly formed of Foraminifera, the latter being a race of microscopic mollusca. The fossil Diatomaceæ at Oran in Algeria are particularly perfect and beautiful. In many of these deposits existing species are found.

The trade winds bring over large quantities of dust mixed with diatoms, which sinks through the upper into the lower current, blowing over America, and at last falls in Europe. Professor Ehrenberg found that this dust contained chiefly true American species, many of which were identical with forms existing at the bottom of the Antarctic Ocean, where an area of 4,800 square miles was discovered by Sir James Ross skirting the volcanic coast of Victoria Land, consisting of the remains of these microscopic plants, which have deposited their silicious valves at death for countless generations, producing geological changes of enormous magnitude; while a still greater area of sea-bed in the North Atlantic is the perpetual grave-yard of myriads of microscopic mollusca. Thus the Supreme Being, whose power is stupendously manifested in the motions of the celestial bodies, creates generations of infinitesimal creatures, adorns them with exquisite beauty, and makes them His agents to form future continents.

The Confervaceæ are a numerous tribe of pretty little plants, usually of a green colour, growing in fresh and salt water, on moist ground, wet rocks, and thermal springs. There is scarcely a gently running stream in which they may not be seen, like bunches of green threads, attached to stones and waving in the current; some are so soft as to become almost a mass of jelly when taken out of the water. They are sometimes branched, but more frequently simple, formed of cylindrical cells, joined in a single long row by their flat ends, and they increase in length by the bisection of their terminal cells.

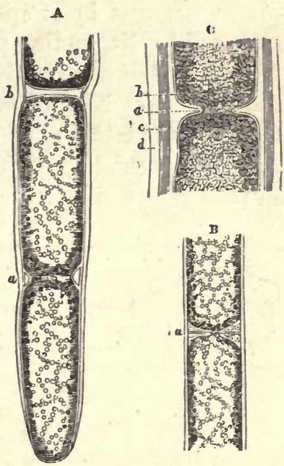


Fig. 17. Cell multiplication in Conferva glomerata:—A, portion of filament with incomplete separation at *a*, complete partition at *b*; B, the separation completed; C, formation of additional layers of cellulose wall.

In unicellular plants bisection is an act of reproduction; in the multicellular Confervæ it is an act of growth and extension which is accomplished as follows:—The terminal cell of the plant grows to twice its length, the matter within the primordial cell spontaneously divides into two equal parts, and both the film and cellulose coat which cover it, bend round, and form a double layer or cellulose division between them. This cellulose layer extends over the whole exterior of the primordial cell, so that the new cellulose division or septum becomes continuous with a new layer which is formed throughout the interior of the cellulose wall of the original cell. In this manner two perfect cells are formed out of one, and as the extreme cell may undergo the same process, the growth of the plant may be continued indefinitely. Branches are sometimes formed by buds springing from any part of the stem; though apparently so different, it results from the subdivision of the cell which produces the bud.

The Confervaceæ are generally reproduced by zoospores. In most cases the endochrome within a cell divides itself into numerous segments, each of which becomes a minute zoospore, and escapes into the water through a rupture in the cell wall. This is the case in a very graceful genus of Confervæ, of which the Chætophora elegans is a species. It consists of filamental strings of cells, ending in a capillary bristle, with lateral branches like narrow fronds. It is reproduced by zoospores. One half of each zoospore is round, opaque, and full of matter; the other half hyaline, and tapering to a beak furnished with four cilia. It frequently happens in this genus of Confervaceæ, where the filaments are divided at equal distances into little joints or compartments, that the zoospores issue from the terminal cell first, then from the next, and so on in succession till the upper part of the branch is left empty, while the lower part is still forming zoospores. After moving in water for a time, the zoospores retreat to a shady place, fix themselves to some substance, and begin to grow. These plants rapidly cover a large surface of water; for each individual cell may produce 100 zoospores, and as the development and dissemination of them continues during the whole summer, one plant may yield an enormous number.

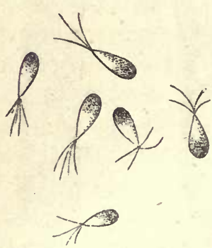


Fig. 18. Zoospores.

The Sphæroplea annulina is a rare and very remarkable Conferva, whose cinnabar-coloured spores make the surface of the water in which it floats, like a pool of blood. It has no root, being merely a filament with capillary extremities, formed of elongated cells joined end to end. The spores only grow on the filaments that are exposed to the sun and air; the filaments that are below the water are green and barren. The spores are filled with red matter, grains of starch, and red oil, the outer or cellulose coat being so plaited, that the spore looks like a red star with white rays.

When a spore germinates, it produces a minute cell ending in capillary fibres, which increases in length by the continual bisection of its central cells, while the other Confervæ grow by the bisection of those that are terminal. During this growth, the red contents of the spore are so changed by a remarkable succession of chemical processes, that the primordial cells in the filament of the young plant are filled with a colourless viscous matter, an aqueous liquid, granules of starch, and chlorophyll. In some of the cells the starch disappears, while the green matter and the other materials arrange themselves into a series of rings, alternating with empty spaces or vacuoles. After a time, the green changes to a yellowish red, and then each ring in succession resolves itself into a multitude of minute active particles, which move with incredible velocity in the void spaces of the cell, till at last the whole cell swarms with them. They are analogous to the pollen of flowering plants, and thence are called spermatozoids. Their form is cylindrical, thick, broad, and yellow at one end, sharp at the other, with a colourless beak, and long cilia. The parent cell is at last pierced by their united efforts, and out they rush in great confusion into the water; some whirl round their centres, others swim in a circle, many describe cycloidal curves by a series of leaps, and a few swim in straight lines.

During the preceding changes another process is in progress, within what may be called female cells. In these the starch, mixed with green matter and a plastic substance, arrange themselves also into green and vacant rings, and after various and complicated changes, each green ring forms itself into a kind of plastic primordial free cell, which, after being fertilized by the moving bodies, gets a stronger coat. The green matter becomes first of a red-brown colour, then red; and after leaving the parent cell it is invested with a plaited cellulose coat, and becomes a star-like resting spore which may produce a new plant. No cryptogamic plant exhibits a greater variety in the modes of action of the vital forces, none more activity in the motile powers. In some of these Confervæ, the moving male filaments, or spermatozoids, instead of escaping singly from their prison cell in confusion into the water, are discharged in a mass enclosed in a capsule furnished with cilia, which moves with its lively burden like a zoospore, till a lid falls off which sets them free.

Some pretty plants allied to the Confervæ are called Batrachospermeæ, from the resemblance which their beaded filaments bear to the spawn of a frog. They are all inhabitants of fresh water, chiefly of gently flowing streams, and are so flexible that they yield to every movement of the water, and when taken out of it are like a mass of jelly. Their colour is usually a brownish-green, but sometimes it is of a reddish or bluish purple. The central stem of the plant, though originally formed of a single row of large cylindrical cells placed end to end, gets an investment of cells, or rather branches, which ultimately becomes a thick cylindrical stem, bearing, at nearly regular intervals, whorls of short radiating branches, each composed of rounded cells, arranged in a bead-like row, and sometimes branching again. Some of the radiating branches grow out into transparent points, which may possibly be antheridia, and contain motile bodies; for within certain cells in other branches resting spores are found, which are agglomerated and form the large dark globular masses that are seen in the midst of the whorls.

The Hydrodictyon utriculatum is another allied plant of singular structure, which grows in fresh-water pools in the midland and southern counties of England. It resembles a regularly reticulated green purse, from four to six inches long, and is composed of a vast number of tubular cylindrical cells, which adhere to one another by their rounded extremities, the points of junction corresponding to the knots or intersections of the network. Each of these cells may form within itself from 7,000 to 20,000 gonidia, which at a certain stage of their development are observed to be in active motion in its interior; subsequently, by mutual adhesion, they form into groups which lay the foundation of new net-plants, when set free by the dissolution of their envelope. Besides these groups, there are certain cells which produce from 30,000 to 100,000 more minute bodies of a longer shape, each of which is furnished with four long cilia, and a red spot. These escape from their cell in a swarm, move freely in the water for a time, then come to rest, and sink to the bottom, where they remain, heaped together in green masses. Their future fate is unknown, but they are believed to be male filaments similar to those described, and are generally called spermatozoids.

The Nostochineæ are either an assemblage of cells loosely united into numerous green chaplets, or distinctly beaded filaments, generally twisted, and occasionally branched; they are imbedded in a firm gelatinous frond of different form, sometimes globular, sometimes spreading in branched masses, often of considerable size. They are frequently seen on damp shady walks in gardens: they shrink to a film in dry weather, and reappear so suddenly in rain that they have been called fallen stars. They are reproduced by spontaneous division of their filaments; the segments escape from the gelatinous mass, move slowly in the direction of their length, after a time come to rest, secrete a gelatinous envelope, and not only grow in length by transverse bisection, but split longitudinally into new filaments which are separated by their gelatinous secretions. These movements, discovered by M. Thuret, are evidently intended to disperse the plant.

Vesicular cells, destitute of endochrome, sometimes furnished with cilia, and of a larger size than the others, are occasionally seen at the end or middle of a filament of the Nostocs, sometimes situated at intervals along their length; and near to these are sporangial cells, a little larger than the ordinary cells. From analogy, it is believed that the vesicular cells are antheridia, and that the sporangial cells contain germs which, after being fertilized by the spermatozoids, are set free and become resting spores. In some species, the sporangial cells are oblong, and contain vividly green matter; in others, the cells are elliptical and brown.

The species are widely distributed. Hormosiphon arcticus, a species consisting of a modification of cellulose, abounds to such a degree in the herbless polar regions, that it affords a welcome variety of food. Each plant lies on a small depression of the snow, which covers the soft and almost boggy slopes bordering the arctic seas, but it is carried by the winds in every direction, rolling over the snow and ice to a distance of several miles. Two northern species of Nostoc were found by Dr. Hooker in Kerguelen's Land, growing on wet rocks near the sea; one of them was the common Nostoc commune. Other species occur in the warm springs in India, as well as in the arctic and antarctic regions, and an aquatic species is much used in China as a wholesome food. The genus Monormia forms floating masses of jelly on the surface of brackish water. The necklaces are of vast length, and, together with the jelly in which they are imbedded, wave with the slightest motion of the water. Floating masses grow on large ponds or lakes, which give the water a green tint.

The structure of the Oscillatoriæ is microscopic. They are minute filiform plants closely allied to the Nostocs; and consist of transparent colourless tubular filaments containing colour cells of various forms, more or less separated from each other, and visible through their transparent tubes; the colour is usually some shade of green, yellowish, or purple. In the genus Rivularia these tubular filaments have a globular transparent cell at the base, and are closely packed into little balls, either forming small groups, as in the Rivularia nitida, or singly attached to stones and rocks. In Rivularia nitida, the filaments radiate from a centre. Some Oscillatoriæ form velvety cushion-like patches upon rocks, others are attached in tufts as parasites to other sea weeds, while many are arranged in free or attached stratified bundles. Lingbya furnishes a beautiful specimen of the latter. The filaments in the stratified group are usually much twisted and interwoven, and some of them exhibit singular oscillating motions, as the Oscillatoria littoralis and spiralis, Spirulina tenuissima and others; one end of the filaments remains at rest, while the other extremity is in constant vibration. With a microscope the movement in some species is seen to be from side to side like a pendulum, in others it is spiral or twisting, and when a fragment of the plant is set free when vibrating the movement is progressive. If a fragment be put into a glass of water, its edge in a little time becomes fringed with short filaments radiating from central points with their tips outwards. They soon detach themselves from the fragment by their oscillations, and as their vibrations continue after they are free, they swim with a spiral motion to the edge of the water, and even ascend the glass till arrested by the dry part above.[7] During these motions there is a corresponding alteration in the form of the filamental tubes believed to arise from rhythmical periods of vital contractibility, which are affected by light and heat, because the motions are more rapid in sunshine than in shade; besides, they are checked by strong chemical agents. Some of the species have a tuft of delicate cilia at the extremities of their filaments.

The free stratified bundles contain the simplest form of the Oscillatoriæ. Each filament is a straight or slightly curved chain of cells, full of coloured matter, and enclosed in a common transparent colourless tube. Multiplication takes place in these by division; when about to multiply, two adjacent coloured cells, or the two halves of a divided cell, recede from one another, and the outer tube contracts at the point of division, and separates them into two distinctly new filaments. Sometimes the transparent outer tube does not yield, so that the divided parts retain their places in the tube, which dilates when these new parts are again divided. The manner of division varies with the species, and the generic characters of the Oscillatoriæ depend upon the different conditions of the external tube, and the form and arrangement of the coloured cells within it. The tube often contracts to the finest point during division, and frequently consists of distinct coats, the number of which increases upwards, sometimes with such regularity as to produce a beautiful streaked effect. Like their allies, the Oscillatoriæ are reproduced by zoospores. While these parts are growing, but especially during their dissolution, the endochrome undergoes various changes of colour, staining the water they die in, and rendering it putrid; some of the common kinds emit a strong odour of sulphuretted hydrogen.

[7] These motions were discovered, and are described by Dr. Harvey, in his 'Manual of British Marine Algæ.'

In the compound gelatinous Oscillatoriæ, the jelly is of very different degrees of tenacity. The mass of the Dasyglœa is so slippery that it can scarcely be taken hold of; Rivularia nitida (fig. 19) is equally so, its tubes being so thick and tender. Many species of the genus Rivularia have a peculiar mode of oblique alternate branching; species of that genus grow on the stems of aquatic plants, on rocks in rapid streams, on cliffs when washed by cataracts, or sometimes in calcareous water, in consequence of which crystals of carbonate of lime are deposited on their substance. The Rivularia nitida occurs among Algæ exposed at low tides, and a species of another genus floats on fresh-water lakes like green stars.

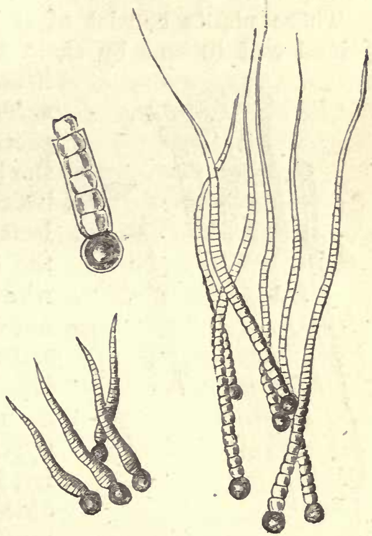


Fig. 19. Threads of Rivularia nitida.

The Oscillatoriæ are found in every part of the world, most abundantly in the temperate zones. They chiefly inhabit fresh water, but these minute plants attain their greatest size in the sea. Numerous species grow in warm springs, and one species, Trichodesmium erythræum (fig. 20), spreads for many square miles over the surface of the Indian seas in faggots of red-brown threads, like fragments of chopped hay; the same species is said to abound in the Red Sea also.[8]

[8] 'Cryptogamic Botany.' By the Rev. M. J. Berkeley.

The Conjugatæ are fresh-water plants of numerous species, which have almost the same structure as the Confervæ, but the green endochrome within the cells of their articulated threads is more highly organized, and the manner of reproduction is altogether different and very peculiar.

These plants consist of strings of cylindrical cells joined end to end by their flat ends, and generally float freely on or near the surface of still water, especially when buoyed up by the bubbles of gas which are liberated from them by the heat and light of the sun. In the early stage of their life, while as yet the cells are undergoing multiplication by self-division, the endochrome is diffused pretty uniformly in each cell; but as the plant approaches towards maturity, it undergoes various modifications, according to the species. In some it consists of large granules disposed in rows; in others it is formed into broad spiral bands with large granules in binary or stellar groups placed at intervals on it; and, in the Œdogonium capillare and others, the granules are united in spiral lines which cross one another and form a network.[9]

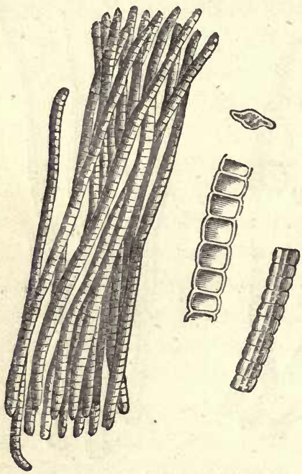


Fig. 20. Trichodesmium erythræum.

The act of conjugation by which spores are formed, usually takes place between the cells of two distinct parallel filaments which happen to be adjacent to each other, and all the cells of the two filaments generally

[9] 'Cryptogamic Botany.' By the Rev. M. J. Berkeley.

take part in it at once. The cells that are opposite to one another put out little protuberances, which come into contact with each other; the intervening partitions disappear, so that a tube is formed which establishes a free communication or passage between the cavities of the conjugating cells. In the genus Mesocarpus and others, the conjugating cells pour their endochromes into a dilatation of the passage that has been established between them, and it is there that the matter mingles to form a spore or embryo cell. But in the

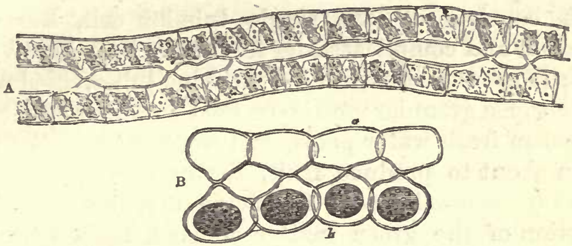


Fig. 21. Conjugation of Zygnema quininum:—A, two filaments in the first stage of conjugation; B, completion of the act of conjugation.

Zygnema (fig. 21), which is the commonest form of these plants, the endochrome of one cell passes entirely over into the cavity of the other, and within the latter the two endochromes coalesce into a single mass, round which a firm coat is developed, and it becomes a spore. All the cells of one filament are thus left empty, while spores are formed in all the cells of the other.[1] Sometimes cells in the same filament conjugate, and occasionally the endochrome in a cell divides into two parts, each of which becomes a spore.

Some of the spores are quiescent, others have cilia and are motile, but both after a time become attached at one end by two or three root-like fibres, and grow into

[1] 'The Microscope.' By Dr. Carpenter.

filaments by repeated bisection. According to the observations of M. Itzigsohn, the endochrome in certain filaments of Spirogyra breaks up before conjugation into little spherical aggregations, which are gradually converted into nearly colourless spiral filaments, having an active spontaneous motion, and therefore corresponding precisely to antherozoids. With the exception of South America, the Conjugatæ are widely dispersed in warm and temperate climates.

The genus Vaucheria may be assumed as a type of the Siphoneæ, whose essential character is, that the plant consists of one single tubular cell, however branched and complicated its form may be. The Vaucherias form tufted masses of branching tubes, filled with bright green granular matter, on mud and damp soil; they abound in fresh-water pools, and some grow in the sea. When about to produce fruit, the extremities of some of the tubes swell out in the shape of a club, in which a portion of the green matter collects, takes a darker hue, and is separated from the rest by a transparent space and a new envelope. After various changes, the darker green matter forms itself into a zoospore, which is so active that it breaks open the top of its club-shaped cell, and comes into the water; sometimes several come, one after another. They are egg-shaped, with a colourless beak, and as their whole body is bristled with cilia, they leave a long current in their wake when they swim, which they do with such impetus that they are flattened against any obstacle they meet with, even to the discharge of their green endochrome. They escape from their cell about eight in the morning, move for two hours, then come to rest, and begin to grow into a new plant.

M. Pringsheim discovered another mode of reproduction in the Vaucherias, which are monœcious plants, that is to say, the same plant produces snake-like fertilizing spermatozoids and female germ cells. For example, the Vaucheria sessilis consists of one long branched cell; on the same side of it two swellings appear near to each other, one of which elongates, curls round like a horn, and is soon filled with snake-shaped filaments having long cilia at their thin end, with which they move rapidly both within the horn, and after they come out of it into the water. They are perfectly colourless, and correspond to the pollen of flowering plants. The other protrusion which swells into a globose germ cell, and which corresponds to the pistil of a flower, contains a mass of green endochrome, which, after being fertilized by the snake-like filaments, becomes a primordial cell which has no motion, but after having secreted a strong coating of cellulose, it sinks to the bottom of the water, becomes a winter or resting spore, and lays the foundation for a new generation of plants. The resting spores produce new forms, while the zoospores, like buds, only multiply the type of the individual plant with all its peculiarities.

The marine genus Bryopsis grows in New Zealand, the Falkland Islands, and the seas about Cape Horn. The species are mostly parasites on other Algæ, and produce innumerable zoospores. The genus Codium is found in high latitudes, and appears under four different forms on the British coasts; one of these inhabits turfy banks exposed to the spray of the sea, the others grow in deep water, or on rocks never uncovered but at spring tides. Species of this genus are found as far south as Kerguelen's Land, and in most of the intervening latitudes. The Caulerpas inhabit the warmer districts in the northern hemisphere, and furnish five species in New Zealand. The numerous species afford almost the whole food of turtles on many coasts, and other genera furnish nutriment to a host of smaller animals.[2]

[2] 'Cryptogamic Botany.' By the Rev. M. J. Berkeley.

The Achlya prolifera is also a unicellular plant, much smaller than the Vaucheria, but whether an Alga or a Fungus is not very clearly settled. To the naked eye it appears as a cluster of colourless threads on dead flies floating in water, on the gills of fishes, and sometimes on frogs. With a microscope the tufts are seen to consist of tubes extending in all directions, filled with a nearly colourless granular matter, the particles of which are seen to move slowly in streams along the walls of the tubes, the currents sometimes anastomosing with each other. When the plant is about thirty-six hours old, the endochrome begins to accumulate in the dilated ends of the tubes, and is cut off from the remainder by a transverse division, the motion of the particles being still visible in the part cut off. The endochrome breaks up into a number of long masses, each of which acquires a cell wall and two cilia, and begins to move about within the parent cell; when mature they are set free by the rupture in its wall, and germinate, and produce a facsimile of the parent. It appears that, in some species, the transverse dividing film becomes convex as soon as the motile bodies are discharged, a new fertile articulation is formed and new motile spores are set free, and this process is continued till the vital powers of the plant are exhausted. The Achlya has resting spores, which may remain long in the water without change, but if a dead insect be put into it, they fix on it and germinate immediately. It is supposed that these resting spores are fertilized by filamental bodies. The Achlya prolifera goes through all its changes in an hour and a half or two hours. It is found in the thermal springs at Vichy, Nevis, and Vaux, where it contains an alkaline iodide.

The whole of the plants which have been described in the preceding pages belong to the group of green Algæ, although many are inhabitants of fresh water.

The structure of the marine Algæ is entirely cellular. Deprived of vascular tubes, they can have no circulation of sap, consequently they derive their nourishment by absorption throughout their whole surface from the medium in which they live, for their root, or rather fulcrum, only serves to fix them to the rocks and stones to prevent them from being buffeted by the waves. Since solar light and heat decrease rapidly with the depth, each family of Algæ has a zone peculiar to itself. The first zone extends from high to low water mark, and is inhabited by plants periodically exposed to the atmosphere, to the direct light and heat of the sun, and occasionally to rain. Some of the Algæ that are long left dry are believed to derive some nourishment from the substances to which they are fixed. The second zone, which extends from low water mark to a depth of fifteen fathoms, is the region of the great marine forests which encircle the globe in both hemispheres. Other two zones follow at greater and greater depths, but all are divided into various minor regions, below the last of which the Algæ decrease as the depth increases, till, as far as we know, vegetation ceases altogether; that depth, however, must be very great, as diatoms are sometimes found, and in great quantities, three hundred fathoms deep.

The marine Confervas, like those growing in fresh water, are slender-jointed filaments formed of one series of cells joined end to end. The cells become more or less flattened on the surface of contact, while the side walls retain their natural curvature, which may be cylindrical or oval. The filament may, therefore, be cylindrical or beaded. The cells are almost always longer than they are broad, and for the most part equal and similar in the same plant, although there are exceptions to uniformity of size. The cells contain a transparent liquid through which minute solid particles of various shades of green are pretty evenly scattered. The conversion of these particles into zoospores has already been described. Since these Algæ have no roots, and the cell wall no opening, each cell of a Conferva elaborates independently the nutriment it absorbs from the water. Some species form a fleecy layer over rocks, and on the bottoms of salt-water pools and estuaries, others extend in bundles in salt-water ditches, and some are found on rocks, between tide marks, rising in long, straight, stiff, and wiry tufts, from three to eight or twelve inches high.

The genus Hormotrichum, which forms tufts several inches long, of bright grass green, differs from the Confervas in being soft and gelatinous, and even more by its mode of increase, which, however, is still by zoospores. The H. collabens may be taken as the type of this genus. It forms a long and large tuft of soft gelatinous and slippery filaments of glossy green. The joints of the filaments are once, or once and a half, longer than they are broad, and the green granular matter within them is collected into a round sac or sporidium in the centre of each, and after being converted into zoospores, the sac comes through a rupture in the joint into the water, opens, and sets the zoospores free.

The genus Cladophora, which has twenty-five species in the British seas alone, forms tufts of jointed filaments from four to eight, ten, or even twenty inches high. In some species the filaments are rigid, bristly, and wiry; in others they are soft and silky; but they are always richly, variously, and sometimes densely, branched and rebranched. In some the branches and branchlets are forked, in others tripartite; the Cladophora pellucida, which is a rigid, wiry plant, combines both these forms.

The genus Bangia consists of purple filamentous jointed and unbranched Algæ, which are distinguished from all others by the microscopic arrangement of their endochrome, which is enclosed in little cells placed according to a definite plan within the transparent and tubular joints of the filaments. In the Bangia fuscopurpurea, whose blackish purple tufts, several inches long, cling closely to the rocks near high-water mark, the tubular joints contain rows of minute colour cells radiating from a centre. In the narrow filaments there is but one colour cell in a joint, but in the broader filaments there are from three to five, forming a tesselated line across it. In this plant one spore is produced in each joint. The Bangia ciliaris forms a scarcely perceptible rosy pink fringe of hair-like jointed filaments on the Zostera marina, and also on other Algæ. The filaments are not more than the tenth or fifth of an inch long, consequently their joints are most minute, yet the microscope shows that they contain from two to three colour cells set as if radiating from a centre, and that the granular endochrome in each cell is converted into two zoospores. The Bangia ceramicola, which forms purplish pink tufts on small Algæ in rock pools, differs from both of the preceding. The joints of its filaments are once or twice as long as they are broad, and contain colour cells like long upright lines. By aided vision zoospores are seen to be formed within the linear colour cells, then the cells run together into a globular mass, which bursts through the cell wall, leaving the joint empty. The whole genus is soft and sometimes gelatinous.

The Enteromorpha genus is characterized by a cylindrical and tubular stem and branches. These plants form two groups, one whose filaments and branches swell from a narrow base upwards and terminate in a blunt extremity, while in the other group the tips of the branches are pointed. The Enteromorpha intestinalis, which is an inhabitant of many seas, has a thin membranous, tubular, cylindrical, and unbranched stem, inflated upwards into a broad round head, being more or less wrinkled and curled throughout. Downwards it tapers to a fine thread, and although attached at first, at last it becomes floating. Several of these plants rise from the same root, sometimes to the height of two feet, at others not more than an inch, and they are of every width, from the tenth of an inch to three inches, their colour being grass green. The typical form of the other group is much branched, and all the branchlets are finely pointed.

The three genera Codium, Bryopsis, and the marine Vaucherias are all soft plants characterized by their filaments being tubular, however much they may be branched. They agree also in being reproduced by zoospores developed from the green matter within little sacs attached to the exterior of their filaments. The species of the genus Codium differ much, although formed of similar elements. In the C. tomentosum, which is from three to twelve inches long, the dark green stem is thicker than a crow's quill and much branched; while Codium Bursa, on the contrary, is a dark green round spongy lump of tubular filaments, densely interwoven and matted together. These masses, which are from one to eight inches in diameter, become hollow when old, and different sizes and ages grow together in a group.

The Bryopsis is a yellowish green tubular plant, from two to four inches high, plumed like a feather, and sometimes replumed. It is a rare plant in England, and grows on the larger Algæ in deep water.

The Vaucheria marina forms soft limp tufts of hair-like filament filled with bright green matter, which often runs partially out. It is from one to three inches high, and has a few long upright branches, to which are attached small stalked pear-shaped sacs containing zoospores. Both this plant and the Vaucheria velutina, grow on muddy shores.

The Ulvas, which are the grass green lavers seen on all our coasts, originate in the simple vegetable cell, whatever form their foliaceous fronds may ultimately assume. When the cell is divided in one direction only, a confervoid filament is the result; and if the filament should increase in breadth as well as length, according to a determinate law, a ribbon-shaped frond may be produced; but when the original cell is divided into four cells, and each of these four and all their successors

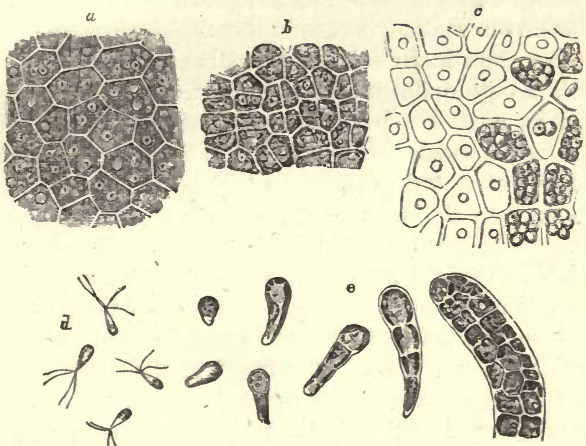


Fig. 22. Ulva latissima: *a*, portion of ordinary frond; *b*, cells in which the endochrome is beginning to break up; *c*, cells from the boundary between the coloured and colourless portion, some containing zoospores; *d*, ciliated zoospores; *e*, development of zoospores.

undergo similar division, the increase being as the series 1, 4, 16, 64, &c., a membranous expansion is formed, in which all the cells are firmly attached to one another, and every portion is the exact counterpart of another. The cells of the Ulvas frequently exhibit an imperfect separation of the granular endochrome into four parts preparatory to multiplication by double division, and the entire frond or leaf shows the groups of cells arranged in clusters containing some multiple form of four, as in fig. 3, page 171.

The frond membrane of the true Ulvas, as that of the Ulva lactuca, is formed of but one layer of cells; the frond itself is thin as cambric paper, almost transparent, and of a pretty light green. When young it is a puckered inflated bag, which afterwards bursts and opens into a flat, ribless, wavy, more or less rounded expansion, three to six inches long, and as many broad. This plant, which is attached to the rocks between the tide marks on our shores, is rare in the Mediterranean; nor is it so common in Britain as the Ulva latissima (fig. 22), which is cosmopolite, and abundant everywhere. It is found as a ribless irregular expansion of a full bright green in deep water, and of a yellow apple green when in shallow water, and exposed to the light. The base and stem are very short, and the frond, which the microscope shows to be formed of two layers of cell membrane, spreads so rapidly into crisp wide-lobed foliations, that the parts often overlap each other in stiff bulging folds. It is from six inches to a foot in height, and from three to twelve inches wide. The frond of the Ulva Linza is also formed of two layers of cells, but so small and so closely pressed together that the two layers can only be detected by the microscope. This plant, which is from six inches to two feet long, is a ribless, narrow, ribbon-shaped expansion with curled wavy edges tapering to a base, and either blunt or pointed at the top. Its colour is the same as that of the Ulva lactuca.

In the Ulvas, which are multilocular plants, some cells are selected to bear fruit, and others not. The granular endochrome of these chosen cells divides into several parts, which are at first in close contact and at rest; then they become restless, acquire four or a greater number of cilia, and pass through a fracture in the cell wall into the water, in which they swim freely as zoospores. After a time they come to rest, attach themselves to some object, and begin to grow. The walls of the cells which have thus discharged their endochrome in the form of zoospores, remain as colourless spots on the frond. The whole colouring matter of a portion of the frond may escape as zoospores, leaving behind it nothing but a white membrane. With a microscope, this process may sometimes be observed in all the different stages of its progress.

Every full-grown Ulva has its own precise and definite form, but whatever that may be, the young plants on their first appearance from the shore are in all respects similar to Confervas; the top cells soon divide, and a plane or sac-like frond is formed.

Certain Ulvas, which have a yellow tint, produce small zoospores with only two cilia, but in the Ulva bullosa and the Ulva latissima four zoospores are produced in the same cell, each having four cilia. The same fructification prevails also in the purple Ulvas—Porphyra laciniata and vulgaris. The latter is seen in winter and the early spring, covering the rocks near high water mark, with its tiny bright purple lanceolate leaves. Later in the season it grows into a flat narrow ribless frond with a pointed end, and about two feet long, the margin of the frond becoming waved and plaited as the plant increases in growth. At a later period, it is seen mixed with the Porphyra laciniata, which is a ribless flat frond of a dull purple; sometimes it is very thin, divided or torn, and occasionally growing in a circle round its root. Both forms are sold as laver.[3]

The RHODOSPERMEÆ, Florideæ, or Rosetangles, are the most beautiful of the marine vegetation. No sea plant surpasses them in delicacy and grace of form or richness

[3] 'British Seaweeds.' By Mrs. Alfred Gatty.

of colouring, but the most beautiful are seldom seen, because they grow below the line of ebb tides, or under the shelter of other sea weeds in the rock pools left at low water, their crimson tints being deepest when sheltered from strong light. The Rhodosperms, which have representatives in every sea, are much more numerous than the green Algæ both in genera and species. Thirteen orders, comprising sixty-seven genera, inhabit the British coasts. Many are exceedingly minute, forming patches and velvety cushions on rocks and other Algæ; a vast number have jointed filamentous fronds, while others consist of tubular filaments, and many exhibit a shrub-like collection of firm branches; some are flat and foliaceous expansions without a midrib, either thin and delicate, or thick and strong, while a very brilliant group of both narrow and spreading fronds possess a midrib as a distinguishing character. The structure of the frond varies from a simple membranous to a cartilaginous or even horny substance, caused by a greater development of the cellular tissue, which in the higher kinds of Florideæ divides the epidermal layer or skin from the parenchyme or spongy matter within.

The mode of reproduction by tetraspores, as well as by simple spores, distinguishes the Rhodosperms from the other two great divisions of the marine Algæ. These bodies are produced by the division of the red or crimson endochrome into four parts, which remain in the cells till they acquire an envelope; their form, which is much varied, depends upon that of the endochrome. Some are produced by the breaking up of a globe of endochrome from the centre into four pyramidal segments; or should the endochrome be elliptical, by dividing it into four by three parallel segments, or a mass may be divided into four by horizontal and vertical sections. Some of these are represented, greatly magnified, in fig. 23. The tetraspores are lodged in wart-like excrescences, immersed either partially or wholly in some part of the frond.

The simple spores are produced within colourless tubercules called nuclei, variously situated upon the plant, as at fig. 23 *a, c.* These nuclei contain many microscopic spores. Sometimes the nuclei are enclosed in conceptacles or ovate sacs, which are either perforate or not at the apex. These contain many microscopic strings of cells like jointed threads, and the endochrome

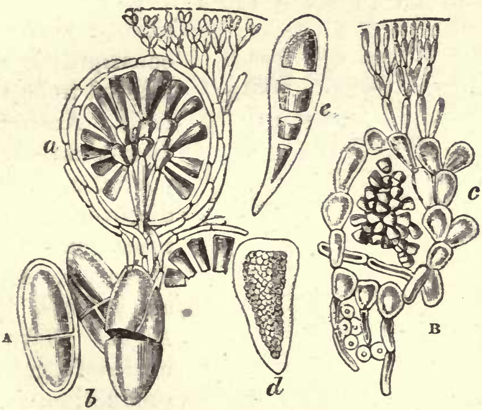


Fig. 23. A, Polyides rotundus:—*a*, thin slice showing the wedge-shaped spores; *b*, tetraspores.
B. Furcellaria fastigiata:—*c*, thin slice showing a nucleus with the dividing spores; *d*, one of the large cells; *e*, a tetraspore.

in each joint of these threads is converted into a spore successively from the summit downward. Sometimes the endochrome in one or two joints only, becomes a spore whether terminal or central, and when the spores break through the joint wall and fall off from the threads, they are collected without any definite order into a mass within the nuclei. Sometimes new joints or cells are produced on the threads when the old ones have yielded their fruit. Occasionally a globose nucleus contains several secondary nucleoli full of spores. In every instance, the perfect spore is a dense grumous mass surrounded by a hyaline sub-gelatinous coat consisting of at least two membranes. The situation, mode of growth, and structure of the nuclei vary almost infinitely, and together with the structure of the frond afford the distinctive marks by which the genera are separated from each other.

The spores and tetraspores are equally capable, like buds, of reproducing their species; but the spores are believed to be in some cases fertilized by spindle-shaped particles, and consequently are considered to be the true fruit. Antheridia, or sacs containing these particles, have been discovered in various genera of Rhodosperms. Although, as a rule, the red Algæ have two modes of vegetative reproduction, yet there are various species in which tetraspores only have hitherto been met with.

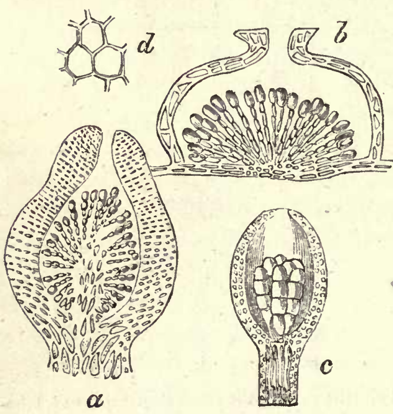


Fig. 24. Vertical sections of conceptacles:—*a*, Gracilaria armata; *b*, Grinnelia americana; *c*, Corallina officinalis, the membrane of which, more highly magnified, is shown at *d*.

A large proportion of the higher Rhodosperms is distinguished from those possessing the preceding mode of fructification by the internal structure of their reproductive nuclei. In some of these Algæ the nuclei are divided into two equal chambers by a fibro-cellular substance to which the spores are attached; in others, pear-shaped spores radiate from a fibro-cellular substance at the base of the nucleus. There are, moreover, Algæ which have nuclei containing conical spores whose broad bases radiate from the centre, and other arrangements occur.

The Rhodosperms are comparatively small plants. Some which form velvety cushions on stones, or minute tufts on small Algæ, are only the fraction of an inch high, but the larger kinds range from one to four, six, ten, or twenty inches; probably none exceed two feet. In thickness, some fronds are fine, like jointed and branched hairs, while others are thick, like hog's bristles or crow quills. Numerous as the forms are, the simple jointed filamentous frond is connected by a series of forms with the highest order of the class.

A great portion of the Rhodosperms on the British coasts is composed of the exquisitely beautiful order of the Ceramiaceæ. They abound in every rocky pool, on every piece of wood that has been long exposed to the waves, on rocks and stones, and, above all, they fringe the Zostera marina, or sea wrack, as well as the firmer Algæ, with every shade of red from bright crimson to purple. They are articulated filiform plants, approaching in simplicity of form to the Confervas. The genus Callithamnion, which has thirty species in the British seas, consists of cylindrical jointed threads more or less profusely branched, and distinguished by having the divisions between the joints opaque and of various shades of red and purple, while the joints themselves are transparent and colourless, so that the stem and branches appear to be striped across by alternately white and coloured bands which are often visible to the naked eye, notwithstanding the smallness of the plants and the delicacy of their filaments, as the C. sparsum,—which is a soft purple tuft of jointed threads scarcely one-tenth of an inch high.

The Callithamnion corymbosum has a soft jointed filamentous stem, hair-like below, fine as a cobweb above, and excessively branched, with dichotomous branches. In fig. 25 *a* represents a thread of this plant with tetraspores, much magnified; *b*, a portion of the same, more highly magnified; *c*, a thread with naked nuclei, gongylospermous, that is, filled with a mass of spores, magnified; and *d*, a spore, magnified more highly. The nuclei are naked in all the Ceramiaceæ.

The genus Ceramium, some species of which have spinulose branchlets, is characterized by the tips of the

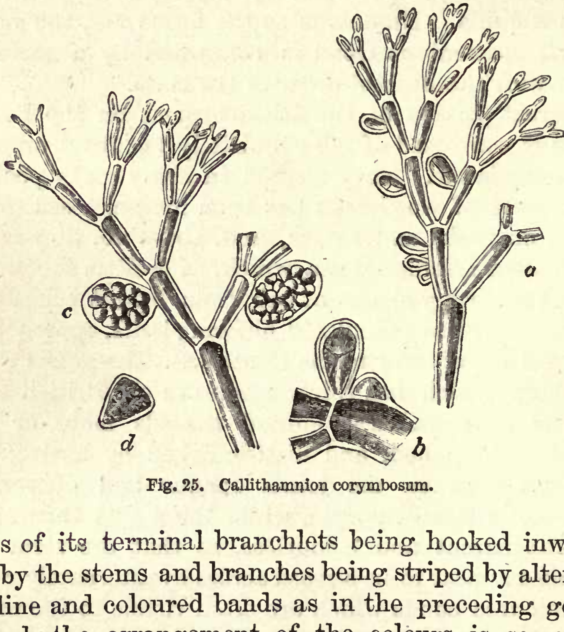


Fig. 25. Callithamnion corymbosum.

forks of its terminal branchlets being hooked inwards, and by the stems and branches being striped by alternate hyaline and coloured bands as in the preceding genus, though the arrangement of the colours is somewhat different. The Ceramium ciliatum, which is a dense tuft of capillary jointed filaments, from two to six inches long, repeatedly and regularly forked, has the tips of the last forks so much hooked inwards, that the extremities of the branchlets look as if they were heart-shaped. It has minute spores in globular nuclei, sessile on the branches with two or three branch-like hairs beneath them, and tetraspores set in the coloured parts of the joints with a thorn between each, for in this plant the centre of the joint is hyaline, the rest coloured.

The genus Griffithsia contains various species of bright rose-coloured plants, which become bleached when put into fresh water, and form a circle when spread out. Soft, tender, and gelatinous, they form dense tufts of jointed and branched filaments on rocks at low water mark. The filaments are slender below, capillary and forked above, and the joints contain one linear upright rose-coloured tube, which is seen throughout their transparent walls: a distinguished mark of the genus. Tetraspores are borne on the hair-like jointed ramuli, and spores are amassed in coated roundish sessile nuclei, surrounded by minute hair-like fibres. Several species once called Griffithsia differ so much from the others, that they are by some referred to Halurus, which has the stems and branches thickened by overlapping whorls of tiny forked jointed and curved ramuli. They are propagated by spores, enclosed in clusters of nuclei borne on the tips of short branches, with a mass of curved ramuli folding over them, and by tetraspores attached to the inside of another set of curved ramuli. Antheridia have been discovered in several genera of the group Ceramiaceæ, especially in Ceramium, Callithamnion, Griffithsia, and Halurus. They consist of little clusters of cells variously arranged, in which the active particles known as spermatozoids are generated.

The Polysiphonia are Algæ, seen in tufts from ten to twelve inches long, of usually much branched jointed filaments, on rocks, corallines, and the smaller Algæ at low water mark. The joints of the filaments contain upright tubes, full of purple or reddish brown matter, which is seen through their transparent walls. The number of these colour tubes vary from four to ten, eighteen, or even twenty, and form the characteristic of the genus. Thus there is a similarity of structure between the Polysiphonia, a genus of the highest order amongst Rhodosperms, and the Griffithsia, which is one of the lowest. The Polysiphonia elongata, which is from six to twelve inches high, has four primary and several secondary colour tubes in the transparent joints of its filaments. Like many of its congeners, this plant does not come to perfection or bear fruit till the second spring. In its youth, it resembles the full grown plant but is smaller, and the colour tubes are not formed in the capillary threads of the tufts, which with many of its branchlets are deciduous, leaving the plant in its naked winter state. With returning warmth, it assumes its perfect form, and in March and April bears fruit, which consists of nuclei in conceptacles, sessile on the branches, either clustered or scattered. The spores are at the top of jointed threads rising from a substance at the base of the nuclei. In some species of this genus, tetraspores only have been found.

The Cryptonemiaceæ are the most numerous and diversified of all the orders of the Rhodosperms. Thirty-five genera are widely dispersed throughout the world, chiefly in the northern hemisphere; twenty-four genera at least occur on the east coast of North America; and fifteen genera have representatives in the British seas. This multitude of generic forms is divided into two groups of gelatinous structure, the one having inarticulate fronds composed of articulate threads closely incorporated, the other membranaceous, formed of cells closely incorporated into a foliaceous expansion. Most of these plants have a stratum of cellular tissue, interposed between a spongy matter in the interior of the frond, and the epiderm or external skin, which for the most part consists of a simple layer of minute cells firmly united by their sides, generally forming a mere film; but it may be thin and flexible, thick, tough, or leathery, according to circumstances.

The Furcellaria fastigiata (fig. 23 B) has an intermediate layer of cellular tissue between its skin, and a pulpy interior. The frond is cylindrical, smooth, strong, and opaque, repeatedly forked with long narrow forkings. The root is fibrous, and the stem short and tapering. Masses of spores nestle under the skin and swell out the upper forkings, and oblong tetraspores are deeply imbedded in the same.

In the Dumontia filiformis the simple undivided stem and branches are filled with a watery jelly.

The stem of the Chylocladia kaliformis is a cylindrical tube, from four to eighteen inches high, constricted at intervals of half an inch or more into long hollow joints; branches of the very same construction but smaller spring from each constriction either opposite to one another or in whorls; these again have lesser branches, all tapering more or less to each end. The plant, which is of a pink colour fading to greenish yellow, is propagated by tetraspores imbedded in the branches, and by transparent conceptacles sessile on the branchlets, enclosing nuclei containing pyramidal spores. We neither possess the Constantinea rosa marina, nor the C. sitchensis, some of the largest and finest plants of the group, both being inhabitants of high latitudes, but there are some very pretty species on the British coasts. They are supposed to be annuals.

The red dulses belong to the foliaceous and gelatinous part of this order. The Chondrus crispus, or Irish moss, sold as Carrigeen, is very common on rocky coasts in the northern seas. It is from three to eight inches high, and exceedingly varied in form. The frond is thickish, firm, and elastic, with a stratum of cellular tissue under the skin, which is probably much developed, as the plant becomes horny when dried. It is reproduced by tetraspores, in large oval groups scattered all over the surface, often prominent on one side only, and, in some rare instances, spores in prominent oval conceptacles are immersed in the lesser frond divisions. Besides these are warts composed of radiating threads, possibly antheridia, but not made out.

The Rhodymeniaceæ are sometimes filiform, but for the most part they are compressed flat cellular fronds, spreading widely from a short delicate stem. They are

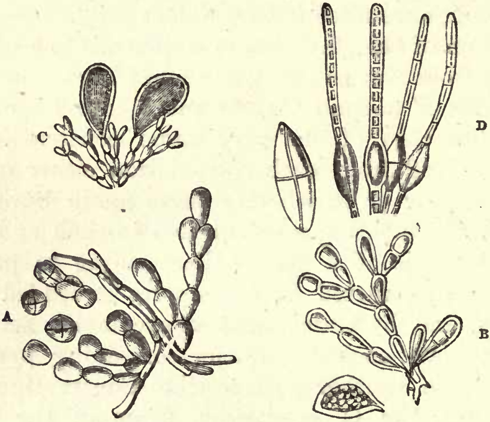


Fig. 26.—A, Rhabdonia Coulteri, portion of nucleus. B, Sphærococcus coronopifolius; portion of nucleus and single spore. C, Wrangelia penicillata, spore threads. D, Cruoria pellita, tetraspores.

usually of a blood red, but Rhodymenia palmata, or common Scotch dulse, is of a dark purple. The tetraspores are variously disposed, and simple or compound globular conceptacles containing nuclei are either attached externally to the filiform fronds, or partly immersed in those that are foliaceous. The spores are produced in the joints of moniliform threads within the nuclei, which are sometimes divided into two chambers by threads running from wall to wall. Rhabdonia (fig. 26 A) belongs to this group.

The Wrangeliaceæ are filiform, many species consisting of a central thread coated more or less with smaller ones, sometimes so disposed as to form a most elegant lacework. Each joint of the stem, branches, and branchlets is beset with whorls of short slender forked and jointed ramuli. They have clusters of spores in stalked capsules. The spore threads of Wrangelia penicillata (fig. 26 C) are surrounded by a whorl of ramuli composed of radiating pyriform spores arising from the endochrome of terminal cells.

The Squamariæ resemble lichens in spreading themselves in a red crust over stones and rocks. They have roots below, and warts, on their upper surface, in which there are tufts of moniliform spore-bearing threads. The tetraspores of Cruoria pellita are shown in fig. 26 D; its repeatedly forked filaments taper upwards, and the tetraspores are formed in the swollen centre cell of the filaments. The Peyssonnelia grows on shells and other marine objects, and extends from the Mediterranean to Ireland, and the east coast of North America.

The Polyides rotundus (fig. 23 A), representing the only genus of the Spongiocarpeæ, has a dark purple solid gristly cylindrical stem, repeatedly and regularly forked, all being of the same thickness. The tips of the last forkings, which are small and equal, give the top of the plant a rounded form. The microscope shows that the stem and branches are composed of a central column of interlaced threads and radiating cells; it shows, moreover, that hyaline nuclei containing a cluster of conical spores whose broad bases radiate in all directions from a centre, as in fig. 23 *a*, are scattered among the articulated threads of oblong irregular spongy warts which clasp or embrace the stem and branches. The tetraspores are buried in the ends of the last forks.

This plant is so like the Furcellaria fastigiata (fig. 23 B), that it affords a remarkable instance of similarity of form and total diversity of fructification, not only in the spores and their arrangements, but in the form of the tetraspores; for in the Polyides they are formed by two sections, one vertical and the other horizontal, while in the Furcellaria the endochrome is divided by three annular sections, as in fig. 23 E.

The Gelidium corneum, common in Britain and almost everywhere, representing the group Gelidiaceæ, is opaque, firm, and of a dark purple. The axis with its alternate and repeated branches lying all in one plane, is composed of confervoid threads. This plant is distinguished by having its spore-cases or nuclei divided into two chambers by a fibro-cellular substance; the spores are either attached to this or to a network of threads; these bodies and the tetraspores are lodged in the tips of the branchlets. It is one of the most variable of all Algæ.

The Sphærococcoideæ comprise some of the most common and beautiful Algæ, remarkable for their brilliant rose and purple tints. This section consists of those red Algæ which have their nuclei lodged in an external subglobose conceptacle, the spores being formed at the tips of jointed threads rising from a substance at the base of the nucleus. A portion of a nucleus of Sphærococcus coronopifolius, and a single spore magnified, is shown at fig. 26 *b*. The tetraspores are variously disposed. The fronds in this family are either gristly or membranaceous, and totally different from those which follow. They often assume a leafy aspect from the regularity of the nerves, which sometimes perform the functions of a stem when the membraneous border has decayed, and then they give rise in turn to new fronds. That happens in some species of Nitophyllum: a very short stem rises from a minute disc, and spreads widely into a flat ribless expansion, more or less deeply slit into broad rounded divisions. Wavy nerves from the top of the stem spread through the fronds, which are left bare in winter, and give rise to new fronds in spring. The leaves of the Delesseria sanguinea, from two to eight inches long and from one to six inches broad, are of the richest colour and most delicate structure, with evenly curled edges, and a firm solid stem, with prominent midrib and nerves. In winter globose stalked spore conceptacles are borne on the skeleton midribs of the summer's leaves from which the margin has decayed, which thus become the stems of the next year's plant. In this plant tetraspores in small special stalked leaflets fringe the skeleton midribs; in the Nitophyllums they are either scattered in dots over the frond, confined to the centre, or in lines round the margin. As regards the internal structure of this order, nothing can be more various, but they never acquire a truly articulate form. The genera and species of this group are widely distributed; they have many representatives in the Mediterranean.[4] The genus Sphærococcus is confined to Europe, while numerous genera are exclusively tenants of the southern hemisphere. The Gracilaria lichenoides, the Ceylon moss, is celebrated for its gelatinous qualities; and the Gracilaria compressa on our own shores is excellent as a pickle or preserve, and very ornamental. One of the most beautiful Algæ known is the Grinnelia americana, which abounds on the eastern coast of North America; fig. 24 *b*, is a vertical section of its conceptacle, showing the rudimentary placenta and spore threads. It differs singularly from the Delesseria sanguinea, of which it is an exact analogue, in the capsules being scattered over the surface of the frond instead of being situated on

[4] 'Flora Italica Crypta.'

the midrib.[5] The Delesseria sanguinea is now known as the Wormskioldia sanguinea.

The Corallines are florid Algæ, which absorb such a quantity of carbonate of lime from the surrounding water, that they become rigid, hard, and often stony. They are purple or pink when fresh, white and sometimes brittle when dry, and are propagated by strings of spore threads rising from the base of the nuclei which are enclosed in conceptacles or spore cases, open at the top. Some are articulate, composed of closely compacted threads, as the Corallina officinalis, a pretty little branched and bushy plant, most luxuriant in deep water, and particularly abundant in the rocky pools. Its urn-shaped spore sacs are attached to the tips or sides of the branches; fig. 24 *c* is a vertical section of one of them magnified, and *d* is a membrane of the same, more highly magnified, with impressions of the external cells. The joints of the articulate corallines, which are flexible and vary much in length, are either free from carbonate of lime, or ornamented with calcareous plates; it is through these open spaces that the plant is believed to obtain nourishment. The forms of the corallines are varied beyond description; many are mere amorphous crusts on stones and sea weeds, increasing from the centre outwards as in the lichens, others are lobed and branched like real corals. Corallines ascend to very high latitudes, but abound most in warm and tropical seas: either free, or coating pebbles at vast depths, they form the last zone of vegetable life.

The Laurenciaceæ have fronds which are soft and thread-like, or solid, fleshy, and inarticulate; both are repeatedly branched. The colour of these plants is purple or a dullish red, but they are extremely sensitive to the influence of light and air, changing through every shade of orange, yellow, or green, according to the

[5] Mr. Berkeley's 'Cryptogamic Botany.'

exposure, and like many other florid Algæ they lose their colour in fresh water. They are amongst our commonest sea weeds. The Laurencia pinnatifida is the pepper dulse of Scotland, and is also native on the eastern and western coasts of North America. Species have been found at the Cape of Good Hope, Australia, and New Zealand. The fructification in this section is quite peculiar. They have tetraspores lodged in the branchlets; and egg-shaped conceptacles with a terminal pore, enclosing nuclei with pear-shaped spores radiating from a fibro-cellular mass at their base. The antheridia, which differ in the different species, attain a greater degree of complication than in other tribes. In Laurencia tenuissima they form curious lateral twisted plates of a greyish tint, bordered with large cells. The plate is occupied by the productive cells of a much smaller size, evidently springing from a cellular branched axis. In Laurencia pinnatifida instead of a plate there is a somewhat hollow cup-shaped disc, formed of dart-like vertical groups of pale cells surmounted by two or three larger oily-looking sacs filled with yellow pigment. These bodies are sometimes forked, and appear to shoot out from the mass. L. dasyphylla presents a third modification, the antheridium being a sac, and the dart-like groups of cells being ejected from the minute terminal orifice. The moving particles produced in the cells of these three forms, differ a little in shape, and as they do not germinate they are believed to be spermatozoids, though no cilia have been found on them.

The Rhodomelaceæ, the last and highest family of florid Algæ, are, as the name implies, of a rich red brown colour. None of the other Rhodosperms can vie with them in peculiarity or variety of structure. The fronds may be areolate or reticulate, filiform or variously leafy, articulate or inarticulate.

Some genera, as for example Dasya, have slender, often elegantly branched threads, while such genera as Amansia and Odonthalia have instead a flat and pinnatifid frond. The latter, which has a very conspicuous cellular reticulation, is a genus of high latitudes, but is common on some parts of the Scotch and North American coasts. The British seas are rich in many genera of this order, and analogous forms occur in the southern hemisphere, where there are at least twenty-three genera. Many are remarkable for their singularity of structure: the Claudea for example, which is one of the most elegant of the Algæ, has a cancellated frond and is the ornament of warm seas; the Amansia and Leveillea which are distinguished by the beautiful reticulation of their fronds caused by large hexagonal cells; and the Dictyurus, in which the net forms a spiral web round the principal stem. Fig. 27 shows a portion of the network of Dictyurus purpurascens magnified. All the genera of this order possess free areolate hollow conceptacles perforated above, and containing nuclei, from the base of which short tufts of threads arise, each bearing a large obovate spore at its apex. The tetraspores are arranged in series either within the frond, or in distinct pod-like receptacles called stichidia. Fig. 28 shows the Polyzonia cuneifolia with its tetraspores arranged in rows in their pod-like stichidia, together with the areolated conceptacle and spores, all highly magnified. The antheridia differ in form in the different genera. In the Dasya they assume that of pods full of cells, in which the motile particles are generated; in the Rytiphlæa tinctoria the antheridia resemble those of the Dasya except

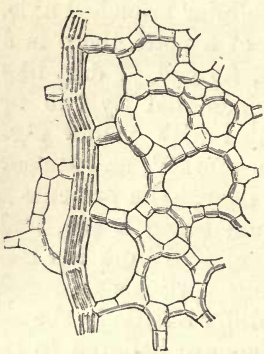


Fig. 27. Dictyurus purpurascens.

in being elliptical, and in the Rytiphlæa pinastroides they are cellular bodies, without any investing membranes, clothed with delicate hairs.

The form of the Rhodosperms, as well as the limits of the species, like those of other Algæ, are affected by many circumstances known and unknown, such as the depth, temperature, saltness, and currents in the water. The Gelidium corneum varies to such an extent that its forms may not only be considered as distinct species, but even as belonging to different genera. The Delesseria alata is sometimes destitute of its margin, and then its midribs alone being left, it has the form of the Delesseria angustissima. Several species of the florid Algæ, which in their natural state have the tips of their fronds even and straight, occasionally produce hooked and clasping tips.

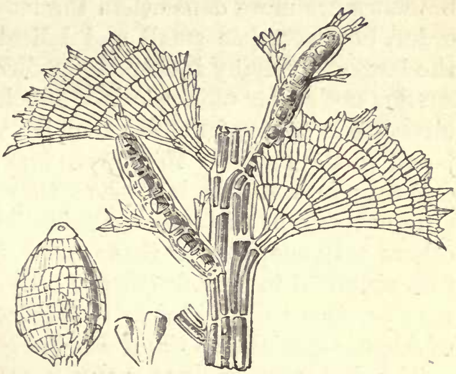


Fig. 28. Polyzonia cuneifolia.

Brackish water is often a cause of change. The Irish moss, Chondrus crispus, when exposed to the fresh water of an estuary acquires great breadth and thickness, while at low water mark it is thin and has narrow forked branches, and there are many intermediate forms. The fruit rarely varies with these changes; its disposition and intimate structure, as well as that of the frond, are the points of prime importance for the determination of genera and species in the Algæ.

The Melanospermeæ, or Melanosperms, are olive-green Algæ, sometimes inclining to brown. They have fewer species than the Rhodosperms, but the individuals exceed in abundance and in magnitude all the other Algæ.

These large Melanospermous Algæ, which form marine forests in both hemispheres, are excessively strong and tough on the exterior but of a looser texture within, so that the cells of their tissue are of different sizes and forms, according to the degree of pressure. The stems and branches are more dense than the leaves. This highest order, however, has small and delicate Algæ united to the largest by many intermediate forms. The Melanosperms are either monœcious or diœcious, and bear their olive-green spores in cases, that is cysts, variously disposed on the plants. Many have two kinds of zoospores differing in nothing but size; they are produced in different organs; in some species both are fertile, in others only one, and, in these cases, the other is therefore supposed to be a fertilizing body, but however that may be, there are certainly antherozoids in this group of Algæ, especially in the order Fucaceæ.

The Ectocarpeæ have many representatives on our coasts, all of which are tufts of articulated threads from one to eighteen inches long, branched or simple. They are generally soft, some so flaccid that they cling together, but sometimes they are firm and stiff. The cysts which are attached to these threads have various forms; they are spherical, siliquose (that is, like long pods), or of other shapes, according to the species; but whatever form they may assume, they are filled with a dense endochrome. Besides these they have active granules contained in other distinct organs. M. Thuret has decided beyond a doubt that the latter are small zoospores, and it is presumed that the endochrome in the cysts is resolved into zoospores, but of a different order, as in the Ulvas. These two organs are for the most part situated on different individuals; in Ectocarpus pusillus (fig. 29 *b*) they are on the same. The different forms of fruit carpels are represented magnified in fig. 29.

The Ectocarpeæ contain little or no gelatine, whereas the genera of the group Chordariæ have soft gelatinous fronds of many forms, either incrustations, convex lumps, or tubers, like the Leathesia so common on our coasts; small plants as the Mesogloias, which have soft slippery filiform stems beset with myriads of moniliferous worm-like branches; or lastly the Chorda filum, a simple unbranched slimy cylindrical cord, varying from a quarter of an inch to the thickness of a pencil, and from one to twenty or even forty feet in length in deep water. The cord is tubular, divided into chambers by transverse partitions, formed of interlaced vertical and horizontal articulated threads. It tapers at each extremity, and the exterior, which is brown, is clothed with pellucid hairs. Vertical spores are immersed throughout the whole surface of the cord, and Dr. Harvey says that, mixed with these, there are numerous narrow, elliptical, transversely striated cells, which according to M. Thuret produce zoospores. Each plant rises solitary from its own little disc, but as the Chorda filum is a social plant, vast assemblies of it cover extensive areas of sand and mud, and form dense thickets in our northern seas. There are bands of it in the North

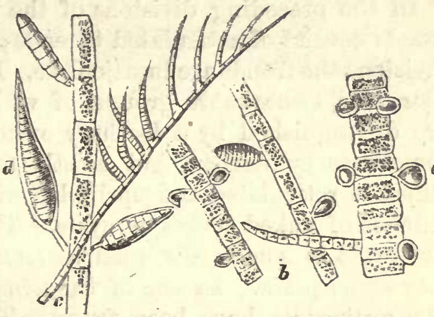


Fig. 29. Fruit of Ectocarpus:—*a*, E. sphærosporus; *b*, E. pusillus; *c*, E. fenestratus; *d*, E. fasciculatus.

Sea 15 to 20 miles long, and more than 600 feet wide; there is a submarine forest of it in Skapta Bay, Orkney; and in passing through the sounds of the western islands, as between Kerrera and the mainland, there are others. The long cords always lean in the direction of the tide, and must oscillate between two zones of rest, one at the turn of the flood, and another at the turn of the ebb. When dried the people use them for fishing lines. In the Chordaria divaricata both kinds of spore cysts are external, and give rise to zoospores.

In the preceding divisions of the Melanosperms the fronds consist of articulated threads; in the succeeding divisions the fronds are inarticulate. The latter comprise four very remarkable groups, of which the Dictyoteæ are distinguished by a leathery or membranous frond, sometimes cylindrical, but mostly flat, the surface of which is reticulated and sprinkled with groups or little patches of naked spores or cysts. The endochrome in the cysts is sometimes quadripartite, or even divided into eight parts. In one of the genera only, anything like antheridia have been found. The zoospores produced from the quadripartite endochrome are large, of a dark colour, and have two lateral cilia, while the bodies in the filiform much divided antheridia seated variously in the tufted threads are far more minute and pale, but with similar cilia. This order obtains its maximum of development in the tropical and subtropical regions; several species are found in the Mediterranean, while a few occur on our coasts, and on those of North America.[6]

The genus Dictyota begins the zonarioid group, whose structure is very curious. Every band (lacinia) of the frond terminates in a single cell, by the constant

[6] Berkeley's 'Cryptogamic Botany.'

division of which at the lower side, the other cells of the frond are formed, the terminal cell of the frond being thus continually pushed onwards. Hence it results that the longitudinal lines of superficial cells converge, thus affording a ready method of ascertaining the genus in default of fructification. When a new centre of growth is to be made, that is, when the frond is to become forked, the terminal cell divides longitudinally and then each half-cell grows according to its own law. Fig. 30 shows the tip of the frond of the Dictyota dichotoma magnified; the cells on its surface are square, and the interior of each has a spiral structure.

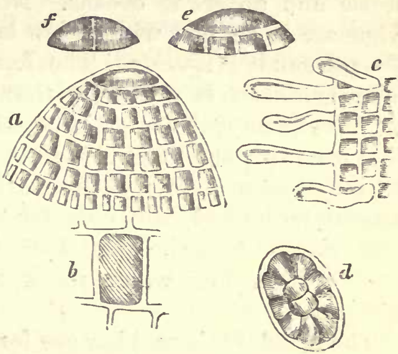


Fig. 30. Dictyota dichotoma:—*a*, tip of young frond; *b*, cell showing spiral structure; *c*, threads from marginal cells; *d*, sorus of spores; *e*, *f*, terminal cells dividing into new centres of growth.

The Padina Pavonia, or Peacock's-tail laver of our southern coast, and those of North America and the Mediterranean, is sometimes included in the genus Zonaria. The species is remarkable for its wedge-shaped fronds, which are olive green shaded with rust colour, and, when in fruit, they are striped across with dark concentric zones, which are merely lines of spores immersed in the frond and seen through its transparent superficial membrane. Each zone is ornamented with a fringe of orange-coloured hairs. Parallel to, or rather concentric with, the spores, is a row of articulated threads, which bear so strong a resemblance to the antheridia of the Cutleria that a similarity of function is suspected by Mr. Berkeley. Species of Zonaria, Padina, and Haliseris, which is the most highly developed of the Dictyoteæ, are most abundant in tropical and low latitudes.

The Cutleria multifida is a small plant not exceeding eight inches in length, of an olive green varied with rusty tints. The frond is a flat ribless expansion many times variously slit in the upper part. It is beautifully marked by prominent dot-like tufts of fructification scattered over both sides of the frond, and grows on rocks and shells in from four to fifteen fathoms water.[7]

The great Laminariæ form the principal part of those vast submarine forests which encircle the globe in the arctic and antarctic oceans. None of these gigantic Algæ are to be met with in low latitudes, but there are several smaller species. The Laminaria debilis of the Mediterranean is not more than five inches high, and we have some ribbon-shaped species also of small size. Besides, many small individuals of the large species grow on our coasts at low water mark or below it; but the largest individuals are only found at depths suited to their size, so that the great Laminaria, or tangle forests, extend from low water mark to a depth of fifteen fathoms.

The fronds of these Algæ are for the most part leathery and of a fibro-cellular consistence. The Laminaria bulbosa is the largest of our sea weeds. Mr. Berkeley says that individuals are sometimes found which are a sufficient load for a man to carry. A flat stem, often more than a foot long, rises with a twist from a round hollow bulb a foot in diameter, throwing out numerous stout fibrous roots below; the stem is bordered by a thin wavy membrane, whence these plants are commonly called sea furbelows. At the top of the stalk there is a broad leafy expansion cut into straps or segments, twelve or more feet long, and from one to two feet wide.

[7] Mrs. Gatty's 'British Sea Weeds.'

The Laminaria digitata, commonly called the great tangle, oar weed, or sea girdle, has a fibrous root, a stem six or more feet long, with a wide expansion at its top cut into very long narrow segments. The fronds of some Laminariæ are deciduous; the stem increases in size year by year, a new frond springing from the apex and replacing the old one, which at last separates from the point of junction with the new frond, to which it is attached till the latter has attained its natural form and dimensions.

The Laminaria saccharina, called the devil's apron on our northern coasts, is of a greenish olive when young, brownish when old. It has a fibrous root, a stem several feet long, ending in a flat ribless ribbon-like expansion, always very much longer than the stem, and terminating in a point. The margin of the frond is even, but wavy or puckered.

'The fruit of these three great Laminariæ is imbedded here and there in the surface of the frond, thickening it and forming cloudy patches.'[8] It consists of thick club-shaped perpendicular cells in which the endochrome is ultimately divided into four parts. This is certainly the case in the Laminaria bulbosa, and also in the Alaria Pylaii, a species of which latter genus, the Alaria esculenta of our own coasts, is a much esteemed British dulse.

Abundance of colossal Algæ are found in the North Pacific, about the Kurile and Aleutian Islands, and along the deeply indented and channel-furrowed north-western coast of America. The Nereocystis Lutkeana forms dense forests in Norfolk Bay, and all about Sitka. Its stem resembles whipcord, and is sometimes 300 feet long. It is exceedingly slender at the top, where it terminates in an enormous air-bladder six or seven feet long, and about four feet and a half in diameter at its widest

[8] Berkeley's 'Cryptogamic Botany.'

part, the lower extremity passing into the stem. This huge air-vessel, which is the usual seat of the sea otter, is crowned with a tuft of twin leaves mostly rising on five stalks. These leaves, which are membranous and lanceolate when young, and from one to two feet long and two inches broad at the centre, are only marked with a few faint nerves, but they ultimately split lengthwise, cover a large space, and attain a length of twenty-seven or thirty feet, or even more. The growth of the Nereocystis must be enormously rapid, since it is an annual, and must therefore develop its whole gigantic proportions in one summer.[9] Boats cannot pass through the floating masses of this plant, whose stem is used for fishing lines, and whose cylindrical air-vessel serves as a siphon for pumping water out of boats.

The Thalassiophyllum Clathrus is also an inhabitant of the Russian coast of North America. It is about six feet high, very bushy and branched, each branch bearing a broad leaf at its extremity which unfolds spirally, and by this gradual development produces the stem with its branches and lateral divisions. A spiral border wound round the stem indicates the growth of the frond, which presents a large convex bent lamina without nerves, or a leaf of which one-half is wanting. Numerous long narrow perforations, arranged in a radiating form, give it the appearance of a cut fan.

The Macrocystis pyrifera and the Laminaria radiata are the most remarkable of marine plants, for their gigantic size and the extent of their range. They are met with on the antarctic coasts two degrees nearer the pole than any other vegetable, except the Diatomaceæ. The stem of the Macrocystis is slender, smooth, round, and slimy, rising from a fibrous root, like other Laminariæ, and bearing at its tip a lanceolate

[9] Berkeley's 'Cryptogamic Botany.'

or oblong lanceolate frond. This frond divides at the base; the fissures extend upwards so as to form two petioles, each of which swells into an oblong or pyriform air-vessel. Another fissure is formed in a similar way a little above, and so on, till a single frond may at the same time have eight or ten fissures, each of which will ultimately gain the common apex. The margins of the fissures are at first perfectly smooth, but they soon become ciliated like the outer edge. The continuity with the fibrous base is at last broken, and the divisions of the leaves going on indefinitely, the whole reaches the length of some hundred feet, forming enormous floating masses which are wafted by the waves hundreds of miles from their origin. Fructification only takes place in young plants; consequently in such as are still attached to their native rocks. Even in that youthful state, Mr. Darwin mentions that such is the buoyancy of this powerful weed, that there is scarcely a loose block of stone on the coasts of Cape Horn that is not buoyed up by it.[1] The Macrocystis is native on the shores of the Atlantic, from Cape Horn to 43° S. latitude; but on the Pacific coast, according to Dr. Hooker, it extends to the river San Francisco in California, and perhaps to Kamschatka. The plant isr eproduced by pyriform cells, full of endochrome, in nearly parallel rows imbedded in the fronds.

The rocky coasts of the Falkland Islands are covered with a vast growth of the gigantic Macrocystis mixed with forests of the arborescent Lessonia, which forms large dichotomous trees with a stem from eight to ten feet high and a foot in diameter. The leaves are two or three feet long, drooping from the forked branches like weeping willows. In the Lessonia nigrescens the quadripartite endochrome, ultimately resolved into

[1] 'Voyage of the Adventurer and Beagle,' by Mr. Darwin.

spores, is contained in thickened club-shaped cells springing vertically between the surfaces of the frond.

A transverse section of the stem of many of the larger sea weeds presents zones, formed period by period, corresponding with the development of the laminæ, roots, and branches. The stem of the Lessonia bears a strong analogy to that of dicotyledons in having rings of growth, though there is a great difference. As increase in Lessonia takes place by the constant division of a flat leaf, the basilar portion of which becomes the petiole and ultimately swells into a branch, the stems have always a more or less elliptical form, and their section exhibits an elliptical core. This form of the core is not however peculiar, but exists in other Algæ. It is probable that the Lessoniæ, although attaining so large a size, are really of rapid growth.[2]

The Ecklonia is essentially a southern genus, though one species ascends to Spain and the Canaries. The frond is pinnatifid, the segments arising from the evolution of marginal teeth. The stem of the Ecklonia buccinalis, which is three or four inches thick and strongly inflated above, exhibits rings of growth with an orbicular central pith.

The group of the Fucaceæ exhibits the highest structure of all the olive-green Algæ, and forms a large portion of the sea weeds on our coasts, but they abound more in individuals than in the number of genera and species. A few have cylindrical stems and branches swelling out at intervals into large oblong inflated air-vessels, which gives them buoyancy in the water. The rest have a flat, ribbon-like stem, and for the most part dichotomous branches with a decided midrib, but no air-vessels, because they chiefly grow at half-tide level, and are exposed twice every twenty-four hours. The most common of our fuci, the Fucus vesiculosus, or bladder-wrack, has

[2] Berkeley's 'Cryptogamic Botany.'

a midrib with air-vessels, generally in pairs on each side of it, formed by the inflation of the frond; these vessels, however, are frequently wanting, for it is the most variable in form and most widely spread of the Fuci. The fructification of this group is contained in large clavate receptacles or expansions of an orange or greenish yellow colour situated at the extremities or borders of the branches.

MM. Thuret and Decaisne discovered, by microscopic investigation, that the fuci have a truly sexual fructification, consisting of male and female cells inclosed in these receptacles. In the common Fucus vesiculosus it was found that the male and female cells are either in different individuals, or in different conceptacles on the same individual; whilst in the Fucus platycarpus, both the male and female cells were found to be contained in a globular cavity enclosed in the flattened receptacles which grow at the extremities of the branches. The cavity is lined with jointed hair-like filaments formed of cells, some of which are so long as to project through a pore on the surface of the receptacle in a spreading brush (see fig. 31, where the whole is highly magnified). Towards maturity, the cells of some of these filaments assume an ovoid form; the white viscous, granular matter in their interior acquires an orange hue, and is divided into a multitude of hyaline particles, each having an orange spot and two cilia of unequal lengths, which enable these spermatozoids to swim with great vivacity in the water as soon as they are set free by the rupture of the cell in which they are inclosed. Besides these, dark olive-green female cells, of a large pyriform shape, are fixed to the walls of the same cavity by very short stems; their contents spontaneously divide into eight spore cells, never more; each contains a colourless viscous liquid, which is mixed with protein and yellow-green matter, and is inclosed in a double coat. 'The 'coats are united at the base, and when the spores are ready for dispersion, the inner coat bursts through the apex of the outer one, dragging with it a portion of the latter in the form of a little peduncle. The immediate covering of the spores at length bursts, and they are set free.'[3] In

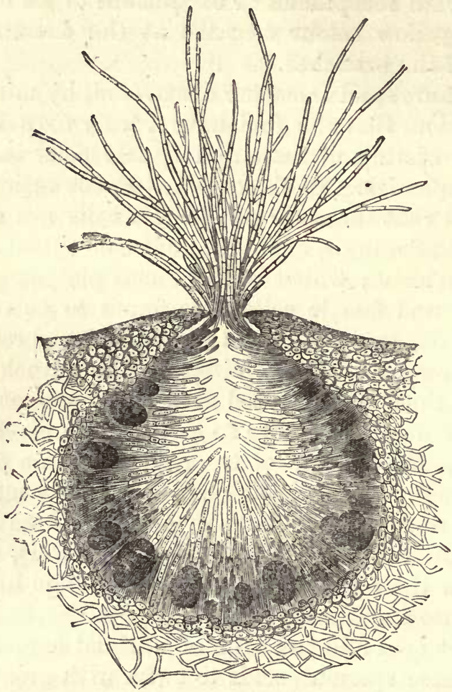


Fig. 31. Vertical section of receptacle of Fucus platycarpus.

Fucus serratus, vesiculatus, and nodosus, swarms of spermatozoids are produced, but M. Thuret has proved by experiment that they never come to anything of themselves, and the unfertilized spores perish.

When a fertilized spore begins to grow, it assumes a

[3] In the Fuci each kind of fruit is discharged on the surface of the receptacle before fructification.

pear shape, and sends out from its narrow end filaments or footstalks containing solid yellow grains at their extremities, where a hook or claw is formed by which it fixes itself to rocks or stones. The spore then divides itself into four equal cells of a brown colour, and by the continued subdivision of these into four, the plant increases in size, and assumes a form corresponding to the genus and species of the spore. Dr. Carpenter mentions that in the Fucaceæ there is also a multiplication by zoospores. These bodies are produced within certain of the cells that form the superficial layer of the frond, and swim about freely for a time in the water after their emission, until they fix themselves and begin to grow; but these are merely gemmæ.

All the Fucaceæ are tough leathery plants. This is even characteristic of the genus Cystoseira, various species of which may be seen on our coasts at low water mark, or in the tide pools. They are little shrub-like and somewhat thorny plants, not more than three feet high, with a cylindrical stem and many branches, near the extremities of which there are inflated air-vessels, sometimes two or three together; in some species they are lower down. Long spiny conceptacles are situated at the tips of the branches, but the endochrome does not divide in the germ cells as it does in the Fuci, so that each cell produces but one spore.

'Throughout all latitudes the two divisions of Fucaceæ—Fucoideæ and Cystoseireæ, form the prevailing marine vegetation to which the name of sea-weed is commonly applied, and the different genera so arrange themselves as to present, with a few exceptions, a most harmonious assemblage.' 'None of these approach the tropics; the Fucoideæ abound towards the poles, and there attain their greatest bulk, diminishing rapidly towards the equator, and ceasing some degrees from the line itself; while the immense genus Sargassum finds its maximum in lower latitudes and under the equator itself.' In the opposite cold and frigid zones the waters are inhabited by certain genera of Fucoideæ, which are in a great measure representatives of one another.'[4] The huge D'Urvillæa and the Sarcophycus in the Antarctic Ocean represent the Himanthalia and Fucus proper in the north, and the Cystoseireæ and Halidrys of the northern seas are represented by the Blossevillea and Scytothalia in the southern.

The frond of the Himanthalia lorea is a knob about an inch high, somewhat like a small mushroom; by degrees the top of the knob sinks in, and the frond becomes cup-shaped. In the second year of growth it throws out from its centre strap-shaped receptacles from two to three feet long and the sixth of an inch wide; they are slimy, forked, and entirely covered with fruit. The true frond sometimes becomes hollow and swells into a bladder. This singular plant, which grows on our coasts, extends from Norway to Spain. In the D'Urvillæa, its representative in the southern hemisphere, the frond and receptacle are united, for the plant, which is of large dimensions, has dichotomous fronds ten feet long, and an inch or more in breadth. Their surface is ornamented with large cavities like a honeycomb, and the fruit imbedded within them consists of antheridia and club-shaped germ cells with four spores in each. These plants form a large portion of the wrack and also of the living Algæ which surround the Falkland Islands and Cape Horn; and they extend to Western Chili, where the poorer class make a sweet mucilaginous soup of them. The Sarcophycus potatorum, the only species of its order, is nearly allied to the D'Urvillæa by the structure of its fruit, and is so named from pieces of its frond being used to carry water. Many other olive-green Algæ are peculiar to the southern

[4] Hooker's 'Flora Antarctica.'

hemisphere—among them the Hormoseira, in which the frond, at first even and filiform, becomes inflated so as to produce moniliform chains of vesicles, parts of which are at length rough with the apertures of the conceptacles; this plant has bladder-like air-vessels formed by swollen parts of the frond, like many of our Fucaceæ.

Those genera which have distinct organs containing air, as the Sargassum, of which there are numerous species, are either of low latitudes or tropical, but are sometimes drifted by currents to the extra-tropical shores. The Sargassum vulgare, however, grows on the rocks in the Mediterranean. The whole plant is of a translucent reddish brown; the stem has alternate branches, bearing lanceolate serrated leaves with a midrib, and generally dotted with dark pores. The air-vessels are small translucent round balls about the size of a currant, borne on flat stalks in the axils of the branches, and the spores are in conceptacles borne on the branchlets just above the air-vessel. In one variety of this most variable plant, the Uva di mare, the main stem ends in a loose bunch of these little air-balls.

The Sargassum bacciferum is often found in the Mediterranean, but only as a wanderer drifted in from the Atlantic, where masses of it, like floating meadows, occupy an area west of the Azores equal in extent to that of France, which has never changed its position since the time of Columbus, on account of the surrounding currents. Fields of it cover the seas near the Bahama Islands, and another permanent area of Sargassum of great extent occurs in the South Pacific. The Sargassum bacciferum is of a pale translucent olive colour, having branched stems, with lanceolate, midribbed, and serrated leaves, destitute of pores, and little stalked air-balls in the axils of the branches. The same individual continually produces new branches and leaves, and thus multiplies its species, but it never produces fruit; consequently its habits exactly resemble those of the Macrocystis, and as that plant becomes detached and floats after fructification, it is supposed that the Sargassum bacciferum may grow on rocks at the bottom of the Atlantic, between the parallels of forty degrees north and south of the equator, and when detached after fructification that it is uniformly drifted to particular spots which never vary. 'Multiplication is so rapid in the floating beds of the Sargassum and Macrocystis, as to render fruit needless; and even the common Fucus vesiculosus occurs in the Mediterranean under a peculiar form consisting entirely of specimens derived from sea borne weed carried in by the current which sets in towards the Mediterranean from the Atlantic.'[5]

Kelp, the ashes of sea weeds, is the commercial source of iodine. Algæ growing in deep water contain most of that substance; consequently the kelp made at Guernsey, consisting chiefly of the ashes of Laminaria digitata, is richer in iodine than that made elsewhere.

Marine vegetation varies both horizontally and vertically with the depth, and it seems to be a general law throughout the ocean, that the light of the sun and vegetation cease together. It consequently depends upon the power of the sun, and the transparency of the water; so that different kinds of sea weeds affect different depths, where the weight of the water, and the quantity of light and heat, suit them best. One great marine zone lies between high and low water marks, and varies in species with the nature of the coasts, but exhibits similar phænomena throughout the northern hemisphere. In the British seas this zone does not extend deeper than thirty fathoms, but it is divided into two distinct provinces, one to the south and another to the north. The former includes the southern and eastern coasts of England, the southern and western coasts of Ireland, and both

[5] Berkeley's 'Cryptogamic Botany.'

the Channels; while the northern flora is confined to the Scottish seas, and the adjacent coasts of England and Ireland. The second British zone begins at low water mark, and extends below it to a depth of from seven to fifteen fathoms. It contains the great tangle sea weeds or marine forests mixed with fuci, and is the abode of a host of animals. A coral-like sea weed is the last plant of this zone and the lowest in these seas, where it does not extend below the depth of sixty fathoms; but in the Mediterranean it is found at seventy or eighty fathoms, and is the lowest plant in that sea. The same law prevails in the Bay of Biscay, where one set of sea weeds is never found lower than twenty feet below the surface, another only in the zone between five and thirty feet, another between fifteen and thirty-five feet. In these two last zones they are most numerous; at a greater depth the kinds continue to vary, but their numbers decrease. The distribution in the Ægean sea was found by Professor E. Forbes to be perfectly similar, only that the vegetation is different and extends to a greater depth in the Mediterranean than in more northern seas. He also observed that sea weeds growing near the surface are more limited in their distribution than those that grow lower down, and that with regard to vegetation, depth corresponds with latitude, as height does on land. Thus the flora at great depths in warm seas is represented by kindred forms in higher latitudes. There is every reason to believe that the same laws of distribution prevail not only throughout the ocean, but in every sea.

SECTION III.

FUNGI.

THE Fungi are enormously numerous. No less than 2,000 of the highest and most conspicuous of these plants have been figured; many more have been described; multitudes of those inhabiting the torrid zone are unknown; and the microscopic and parasitic tribes are innumerable. Though with a few exceptions entirely formed of cellular tissue, the fungi resemble animals in respiration and chemical constitution. They contain more azote than any other of the Cryptogamia, and obtain it chiefly from their food, which consists of animal and vegetable substances alive, dead, or decomposed. They inhale oxygen, and exhale carbonic acid gas, so that they never form true chlorophyll. No plants are more dependent on heat and moisture; many perform all the functions of life and reproduction independently of light, preferring dark and shady places to sunshine.

The Fungi form two principal groups, distinguished by their mode of fructification. In the higher group, *Sporiferi,* the fungus produces naked spores either single or compound, by means of which it may be multiplied. In the lower group, *Sporidiiferi,* the fructification consists of sporidia, enclosed in a distinct sac. The Sporiferi include the following orders, Hymenomycetes, Gasteromycetes, Coniomycetes, and Hyphomycetes. The Sporidiiferi include the Ascomycetes and the Physomycetes. These various groups we may now proceed to examine.

The most important family of Fungi is, without question, that of the HYMENOMYCETES, the species of which far excel all others in their richness of colouring, and beauty of form. In this group the hymenium is free and mostly exposed. It comprises six orders, of which the Agaricini hold the first place. The genus Agaricus alone comprises 1,000 distinct species, which assume as many different forms and colours, with only slight modifications of substance, and it surpasses in number of species all the other generic groups known.

The Agaricus campestris, or common mushroom, is a type of that vast group; it consists of two distinct parts, the nutritive and reproductive. The nutritive part is the mycelium or mushroom spawn of gardeners, which resembles a mass of white spider's threads mixed in inextricable confusion, and carries on for a time all the functions of the plant. Mycelia may exist for years without bearing the reproductive part, but fruit never can be produced without spawn. The mushroom itself, which springs from the spawn, is the fruit-bearing part, in which the spores are formed and ripened. It is distinguished by a kind of hat or bonnet called the pileus, supported by a stem. The pileus is lined by a number of gill-shaped plates or lamellæ radiating from a common centre; they are the reproductive organs in which the spores are produced by free cell formation, a process always preceded by a concentration of the matter within the parent cell, which is then divided into as many nuclei as there are to be spores. In the higher fungi, the number of spores thus formed is definite; in the Agarics they are in groups of four placed at the extremity of a stem, springing from the summits of these reproductive gills. Most of the Agarics rise from the ground without any cover; the pileus or cap may show every variety from a smooth polished surface to hairs or shaggy scales, but some of the more highly organized have a general wrapper or volva, which encloses the whole plant, and bursting at last, it leaves some traces behind. In others, the pileus is at first clothed with fibres, which vanish or leave traces on its margin forming a veil or curtain. Some have a membrane attached to the stem, either connected with the volva, or spread under the gills when young, and, when more or less persistent, it is called a ring.

The spawn, which is the earliest product of the spore, has a great variety of forms. Sometimes it is filamentous, sometimes tubular, creeping extensively, or concentrated in a felted mass, sparingly developed, or produced in abundance. Besides, it is developed in a great variety of situations often difficult to detect. The fructification is alone evident, under innumerable forms, which are as rapid in their growth as they are for the most part ephemeral in their duration. Some species have been known to acquire several square inches of surface in a single night; the plant, however, is often far advanced before it appears above ground. Some Agarics grow most readily after thunder storms and abundant rains; certain species are always single; others grow in dense aggregations; while in several species there is a tendency to assume a circular arrangement, and that not merely when the spawn is perennial, but when the whole existence of the fungus is confined to a few days or weeks.

A mass of spawn is not always produced by a single spore, but by a collection of spores, from whence it spreads in every direction, and forms a common belt. In the Agaricus arvensis, Marasmius Oreades, &c., it spreads in a circle and bears fruit; and, as it continues to spread, the same process takes place at each circumference. In this way are formed the Fairy Rings so frequently seen in pasture lands. The fairy rings are sometimes of very ancient date, and attain enormous dimensions, so as to be distinctly visible on the side of a hill from a considerable distance. It is believed that they originate from a single fungus, whose growth renders the soil immediately beneath unfit for its reproduction. The spawn, however, spreads all around, and in the second year produces a crop, whose spawn spreads outwards again, for the soil behind forbids its return in the opposite direction. Thus the circle is continually increased, and extends indefinitely till some foreign cause destroys it. The manure arising from the dead fungi of the former years makes the grass vigorous around, so as to render the circle visible even when there is no external appearance of the fungus; and the contrast is often the stronger from that immediately behind it being killed by the old spawn. This mode of growth is far more common than it is supposed to be.

The depth to which spawn penetrates and the rapidity of its growth even in the hardest timber if exposed to damp is quite astonishing. Instances occur in which the spawn of dry rot not only enters wood, but penetrates solid structures of brick. It overcomes an immense resistance.

The genera of the Agaricini differ in substance; some are almost ligneous, others leathery or tough, occasionally they are delicate and deliquescent, and although most of them are entirely formed of cellular tissue, the Lactarii and Russulæ form remarkable exceptions in having laticiferous vessels mixed with their cellular structure. These vessels exist in all parts of the plants, especially in the gills, where they give out the liquid on the slightest touch. In the Russulæ it is watery; but in the Lactarii, in which it is either mild or acrid, according to the species, it is also of different colours, which sometimes change their tint upon exposure to the air, probably from ozone. In all fungi there is a small amount of poisonous matter, and the quantity in any given species is extremely uncertain, so that the same fungus which may be eaten with safety in one country, is deleterious in another.

In the dark coal mines at Dresden, luminous Fungi cover the roof and pillars with the most dazzling phosphorescent light, which increases with the temperature of the mine. Agaricus Gardneri, a species parasitic on the Pintado palm in Brazil, is highly luminous; and the Agaricus olearius in the south of France also possesses that rare quality. The gills under the pileus shine as brightly as a glow-worm, in the dark crevices of the olive stems in November and December. M. Tulasne found that the light was extinguished in vacuo or non-respirable gases, whence he concludes that it is due to a slow combustion without heat, arising from a chemical combination of the oxygen of the atmosphere, inhaled by the fungus, with a substance peculiar to the plant.

In a few Agarics the cells are so connected by veins or lateral branches, that they assume the character of pores, as in the Chantarelle, a sweet-scented lemon-coloured fungus, whose gills pass into mere veins, and its inferior fruit-bearing surface is all but even and uniform, so that it forms a connection between the Agarics and the Polyporei, a most extensive order of the higher fungi, essentially distinguished by having a multitude of pores in the smooth under-surface of the pileus, instead of gills. The pores are generally small; in some species they are hexagonal, and so large that they look like a honeycomb. In all, they are the mouths of cellular tubes, packed closely together side by side, or more closely connected, sometimes easily separated, sometimes inseparable. They constitute the fructiferous surface or hymenium of the fungus, and contain the spores. This structure gives the pileus a thick heavy appearance, and a vast variety of characters; besides, the substance itself varies in density and colour. The stem also may be long or short, sometimes wanting altogether, when the pileus or cap is attached to the surface on which the fungus is growing. The growth of individual fungi, whether Polyporei or Agarics, is centrifugal, that is, they spread from the centre of the pileus, as in the Polyporus fraxineus, which involves every stick and blade of grass it meets with as it increases in diameter, and continues to increase for years, till it is occasionally a yard across.

The fructiferous surface in the higher fungi is essentially turned away from the light, yet, although in many of the lower Agarics it is uppermost and exposed, such is the tendency to produce the fructification on the lower side, especially in the Polyporei, that if the position of the plant be reversed the hymenium or fructiferous surface is gradually obliterated and a new one is formed on the other side.

The Polyporei abound in the tropical forests, but species are found in all latitudes. The higher fungi are more or less plentiful in forests everywhere, and every genus of trees seems to have one or more species of fungus peculiar to itself. The Boleti, a genus of the Polyporei, which are thick fleshy fungi of various forms, and for the most part brilliantly coloured, grow under trees in the temperate zones, sometimes in conspicuous circles. When a slice of the Boletus luridus, cyanescens, or other species is exposed to the air, the white fleshy part acquires a blue tint in consequence of the action of ozone upon the acetate of aniline, which was ascertained by Dr. Phipson to be a constituent of these fungi. According to M. Dutrochet more heat is evolved by the Boletus æneus than by any other vegetable except the Arum.

The Polyporei destroy decaying trees and timber, and the Merulius lacrymans or common house fungus, attacks and induces the decay of timber previously sound. The cap is large, fleshy, spongy and moist, but delicate and velvety on the under-side, with wide porous dentate folds. The plant is yellow with a white woolly margin. It grows in a circle, and its mycelium attracts moisture from the atmosphere, which falls down in drops from the pileus. The decay of wood induced by the attacks of this mischievous fungus, is what is called dry rot.

The four principal sub-orders of the Hymenomycetes, or highest fungi, have a cap or pileus, and an inferior fructiferous surface characterized by gills, pores, or tubercles, and are connected by intermediate species; but the other two sub-orders are quite different. The Clavariei are club-shaped, upright, branching fungi, with the fructification surrounding the uppermost extremity of some of the stems. The finest species grow in the Swiss forests where they form an article of food; some are edible in Britain, but of smaller size.

The Tremellini consists of plants forming a gelatinous mass of a bright orange, purple, or dark brown colour, which may be seen on rotten sticks in hedges, and in enormous masses resembling the convolutions of an animal's brain on the stumps of dead trees, or at the base of living ones. They are mostly plants of temperate climates, but the Exidia Auricula Judæ, or Jew's ear, is universal. All fungi have a mycelium, but in this order it is not apparent. The structure of the fruit, as determined by the microscopic observations of Mr. Berkeley and of M. Tulasne, is unusual. The fructiferous part is very extensive, being uppermost and spread over the surface of the gelatinous mass, so as to follow all its inequalities. Threads rise from this fructiferous surface bearing on their extremities globular cells exhibiting a concentration of coloured matter generally divided into four lobes, and from the upper surface of these globular bodies, a number of flexuous threads spring, carrying on their tips cymbiform spores.[6]

In the preceding family (Hymenomycetes) the fruit-bearing surface has free access to the air, but in the group of the GASTEROMYCETES, which consists of five or six sub-orders, it has neither access to air or light till the fruit is ripe, for the fructification is enclosed in a rind of one or two coats, and springs without a stem from a gelatinous thready, or cellular mycelium. The most important group, Trichogastres, includes the puff-balls, which grow on the ground. Of these the Lycoperdon, found everywhere on pasture grounds and meadows, is a familiar instance. When young it has a milk-white coat filled with closely packed cells, some of which bear naked spores set upon spicules. When mature, the whole of the interior vanishes, leaving nothing but a mass of threads and fruit; the coat becomes brown, bursts open at the top, and gives vent to a cloud of microscopic spores like the finest dust. In general the ball is sessile, or it has merely the rudiment of a stem. The Lycoperdon giganteum, an exceedingly large species, is a native of a warm climate. The tops of some of the branched threads of its hymenium swell into pear-shaped cells surmounted by short spicules ending in spores; when young it is edible, when dry it is used for tinder and as a styptic, and when ignited its fumes possess a property similar to that of chloroform. The Batarrea forms a contrast to the common puff-balls, being mounted on a stem sometimes a foot and a half high. It has several coats enclosing a thick gelatinous substance in which the threads carrying the spores are distinctly spiral and closely twisted.

The sub-order Hypogæi is subterranean, as the name

[6] Berkeley's 'Introduction to Cryptogamic Botany.'

implies. The exterior coat of these fungi is inseparable from the internal matter, which is for the most part fleshy. In some species it is dry, in others it abounds in milky juice; but in all the fruit is formed in hollows excavated in the interior mass. In some species these cavities are traversed by threads, and in many species the spores accumulate in such multitudes within the cavities, as to make it certain that the spicules, on which the spores are borne, produce successive crops. They are set free by the rupture of the rind. A species of the genus Melanogaster, abundant in the south of England, is edible and sold as the red truffle of Bath; but it is far inferior to the real truffle.

The order Phalloidei has a club-shaped or globose head, composed in the interior of large cells mixed with fruit-bearing cavities. This head has a coat consisting of a jelly inclosed between two heterogeneous strata. The whole interior of the fungus deliquesces, changes to a mucilage, and drips out of the exterior coat in drops dark with microscopic spores. The colour of these fungi is often beautiful, but their smell is most loathsome, tainting the air to a considerable distance; yet the gelatinous volva of more than one species—an Ileodictyon—is eaten by the New Zealanders under the name of thunder dirt, and Phallus Mokusin is an article of food in China.

Certain species of these fungi have a rudimentary stem in their early stages, but it becomes full of deep pits or cavities and suddenly acquires an enormous development when the plant approaches maturity. The cavities are at first strongly compressed, but as the stem increases, they acquire a rounder form, till at length their vertical tendency is so strong that the coat or volva of the fungus is ruptured, which could only be effected by a very strong force. Moreover, the stem is fixed to the base by so small a point that the plant could not remain erect were it not for the tubes of the volva which contract on the stem and act as a sustaining force. Thus these very revolting fragile plants afford a very striking instance of mechanical power exerted by vegetable matter.

The Myxogastres are an anomalous group of fungi which often appear as black or coloured spots on dead leaves and twigs. Sometimes their mycelium or spawn is large and conspicuous, as that of the Reticularia maxima, which overruns cucumber beds, choking up the breathing pores, and killing the plants. Species of these fungi are found upon mineral and vegetable substances dead and alive, and the same species grows upon plants of very different affinities, so that they depend upon the atmosphere for their nourishment, and not on their matrix. Like the puff-balls they end their lives in myriads of microscopic dust spores, but they begin it as a gelatinous mass, sometimes sparkling as a gem, brilliant with the metallic tints of gold, silver, steel, or copper.

The gelatinous or creamy mucilage of which these fungi consist, forms a mycelium which is either diffuse, or creeps over the matrix on which it grows in anastomosing filaments like a network, or it is arranged without any definite order. This spawn gives rise to many bodies having an envelope of one or more concentric membranes, technically called a peridium, enclosing a gelatinous fertile substance which, when mature, becomes a mass of scales or threads mixed with spores; the spores are mostly attached to short threads singly or in groups, sometimes surrounded by a firm coat or cyst. These bodies are either sessile on the mycelium or stalked, and are either free or confluent. In their soft state the tissues are so delicate that they exhibit no structure, but just as they are passing from the puffy to the dry dusty state there are indications of it.

It would be tedious to describe the variety of forms assumed by the fruit-bearing bodies in the different genera of these fungi, or the manner in which they are ruptured to give egress to the spores, which differ in colour according to the species, though they are for the most part red. The forms of the chaffy scales and threads are equally diversified: in the species of Trichia, the threads contain one or more spiral filaments, a form peculiar to the vegetable kingdom.

Botanists are now generally of opinion that the Myxogastres are vegetables, although the singular Amœba-like motions some of them exhibit, and the nature of the motile bodies they produce, seemed to assign them a place in the animal kingdom; indeed, even now little is known of the reproduction and final life-history of these singular fungi.

Motions precisely similar to those of the Amœbæ, the lowest class of animal existences, were observed by MM. Hoffmann and Tulasne, and more especially by M. de Bary,[7] in the Æthalium septicum. It is a yellow pulpy mass, produced upon a spawn or mycelium consisting of semi-fluid gelatinous anastomosing filaments, often widely spread through the moist tan in hothouses.

M. de Bary describes the filaments of the mycelium as full of a multitude of small colourless corpuscles mixed with large yellow ones; moreover the branches of this mucous network are described as continually changing their form, in a manner closely resembling the pseudopodia of the animal Amœba. They push out new branches, others are withdrawn, and the whole mycelium frequently advances with a creeping motion of translation. The yellow pulpy mass produced by the mycelium is entirely composed of similarly con-

[7] 'Des Myxomycetes,' par M. Antoine de Bary; et Mémoires par MM. Tulasne et Hermann Hoffman, 'Annales des Sciences Naturalles,' 4me séries.

stituted soft filaments about the thickness of a bristle closely interlaced. They anastomose in all directions, in long or short meshes, and their upper free extremities form groups of projections which bristle the exterior surface of the pulpy mass.

When that mass is about to form spores, all the asperities on its surface are withdrawn and replaced by a bright yellow network of irregularly interlaced filaments, which constitutes an envelope to the interior spore-forming part, consisting of a white central liquid or plasma containing an innumerable multitude of colourless granules. Both of these parts are formed at the expense of the filaments which are decomposed, the yellow granules are absorbed in the envelope, while the colourless granules retire with the gelatinous matter towards the centre to constitute the plasma, which is the fruit-producing part. Transparent globular cells containing nuclei are generated simultaneously in every point of the plasma, round each of which a portion of the granular matter is consolidated; it takes a dark purple colour and constitutes a spore, myriads of which, fine as dust, are thus generated. The whole of the plasma is consumed in the spores, except a very small quantity, which forms the threads found mixed with the spore dust. According to M. de Bary the complete development of the Æthalium, from the instant it appears above the tan in a hothouse of high temperature to the maturity of the spores, is accomplished in about fifteen hours. The rapidity of growth of this fungus is therefore astonishing. Mr. Berkeley mentions that a mass of it two feet long, formed of many confluent individuals, was formed upon a piece of iron that had been red-hot twelve hours before—a proof among many others of the meteoric nature of these fungi, the atmosphere affording them a sufficient supply of food.

The motions of the plastic matter contained within the dust-like spores of the Æthalium septicum exhibit amœban motions of the same character as its mycelium. For when M. de Bary placed ripe spores of that fungus in water, their skin burst open and the plastic granular matter was set free under the form of a coherent globular mass without any exterior membrane. These globular corpuscles exhibited amœba-like changes of form; processes were pushed out, and then drawn in, till at last they assumed an elongated cylindrical shape round at one end, prolonged at the anterior end into a long cilium with which they turned convulsively round their axis. At the same time vacuoles were frequently seen to expand and contract alternately in the round extremity. Ultimately these bodies lost their middle, and at last were divided into two equal parts, each of which went through the same changes as the primary globule, and at length assumed the ciliated active form. Besides these active bodies, there were others which never acquired cilia. The motile bodies were also discovered in other species of these fungi by M. Hoffmann; there can be no doubt that they are either zoospores, or of the same nature as the eel-shaped motile bodies in some of the Algæ; possibly the bodies which never acquire cilia may be germ cells. There is still much obscurity with regard to the Myxogastres, inasmuch as the origin of their mycelium is unknown, whilst in all other fungi mycelium or spawn are produced by the germination of the spores. The spiral vessels found in the threads of tbe Trichia prove that the members of this singular family are truly vegetables. Professor Fries places the geographical maximum or centre in the temperate zone, but different species are found from New Zealand to high northern latitudes.

The Nidulariacei constitute a beautiful order of this family of fungi. The plants are exactly like a bird's nest with eggs, sometimes with a stem, sometimes without. At first the nest or cup has a cover consisting of several coats, which either burst open with a stellate or irregular figure, or by the separation of a little lid; then the hollow of the cup or nest is exposed, and at the bottom are seen one or more sporangia, that is spore cases, often immersed in jelly and either free or fixed to the nest by an elastic string. The spore-coats at first contain a compact circular mass, but a cavity is afterwards formed in the centre, and the cells which terminate in the walls of the cavity bear spores on their tips. When ripe the spore cases are ejected by elastic power. The force with which the sporangium of the species of Sphærobolus is ejected, far exceeds *in proportion* the force with which a shell is projected from a large mortar; this fungus sometimes grows in damp hot-houses.[8] Many Nidulariæ are widely spread, but they thrive best in warm climates.

The intimate structure and fructification of the higher fungi are for the most part microscopic but an innumerable mass of the lower fungi are themselves invisible to the naked eye, living upon all kinds of vegetable and animal substances, dead, alive, fresh or putrid. They vegetate upon decayed linen, flannel, leather, and even on metallic and poisonous solutions. They yield myriads of minute spores wafted by every breeze. They float in the air we breathe, seeking a nidus in anything that will supply them with suitable food. There is scarcely a spot on the earth where these minute spores may not exist, and being insoluble, they wait where they fall for the growth or decay of the plant or animal which suits them. As parasites they are most destructive, producing disintegration, disease, and even death, both in vegetables and animals.

[8] 'Introduction to Cryptogamic Botany,' by the Rev. M. J. Berkeley.

It is the mycelium or spawn which does the mischief, by supplying the fungus with food at the expense of the victim. The spores of the Botrytis Bassiana find a nidus in the breathing pores which open into the trachea of the silkworm; they develop their mycelium in the air-tubes, which are soon filled up; it then extends into the fatty matter under the skin, which nourishes the worm during its dormant state, and, as soon as that matter is exhausted, the victim dies.

In autumn, the common fly, though quite dead, may be seen adhering to many parts of a room, especially to the window glass, as if it were alive. In this state it is always surrounded by a halo about an inch in diameter of whitish dust, consisting of the spores of the Empusa Muscæ, or fly fungus. The body of the fly is much distended, the rings of its abdomen are separated by the growth of the mycelium from within, and all the contents of the body having been consumed by the parasite, nothing remains but a hollow shell with a thin felt-like layer of the interlaced mycelia of innumerable fungi, for the fly fungus increases with wonderful rapidity within the insect. Mr. Berkeley believes the fly fungus to be merely a condition or phase of one of those anomalous moulds which grow on dead fish, making them conspicuous as they float on the surface of the water, by the foggy halo which surrounds them. Different kinds of parasitic fungi may exist at the same time. Dr. Leidy found a variety in the stomach of the Passalus cornutus, a beetle that lives upon decayed wood. Fungi do not attack the carnivorous beetles.

Man is not exempt from these parasites. Fourteen different species of fungi were discovered by Mr. Hogg in as many cutaneous diseases. There cannot be the smallest doubt of cutaneous disease being induced by inoculation with fungi; merely rubbing certain species on the skin is sufficient. Fungi cause baldness by fixing themselves on the roots of the hair, and destroying the internal structure of the bulb. Our eyes are not exempt from attacks of these parasites, for in performing an operation upon a diseased eye Dr. Hannover found several species of fungi in it; one of them was globular, and strongly refracted the light. There is a fungus consisting of from four to sixty-four cells united in square groups, which infests the stomachs of men and animals, even in a healthy state; but although fungi produce certain cutaneous diseases, there is no proof as yet that fever, cholera, or any other epidemic, is owing to the spores of the fungi which we inhale from the atmosphere.

The family of Coniomycetes consists of six groups, two of which are parasites on living vegetables, the other four growing on those which are dead, decaying, or dying. They are microscopic plants, and their mycelium is filamentous, or vesicular, often obsolete; short threads rising from it bear on their tips either septate spores, or spores like fine dust, inclosed in oval or bottle-shaped cases, called perithecia, or in cells united in a cell, like a necklace of beads. We are chiefly indebted to M. Tulasne and his brother for the obscure and extraordinary life-history of these fungi.

The parasites on living plants form the two vast groups of Epiphytes and Entophytes. The Epiphytes exhibit their fructification on the surface of the plant, while their mycelium penetrates the moist texture of its interior, which feeds them. All parts are liable to be attacked by these fungi; they may insinuate their mycelium into the leaves, stem, flowers, stamens, anthers, and the very heart of the seeds. The mycelium is generally annual, but sometimes it is perennial, and leaves a crop of fungi year after year; it disintegrates the tissues of the plant on which it feeds, and distorts or kills it. Occasionally, the chlorophyll in the leaves is oxidized, and becomes yellow by the oxygen which the parasite absorbs.

The Entophytes, which constitute the second group of parasites on living plants, form microscopic congregations in the interior of the leaves and tender shoots, the only indication of their existence being a white, red, or orange coloured spot, which usually becomes black or brown when the fungus attains maturity. It appears that the same individual of these entophytes may assume two or more different forms during the course of its life, and bear two or more totally dissimilar types of fructification. Of these, the sub-orders Pucciniæ and Uredines furnish many examples.

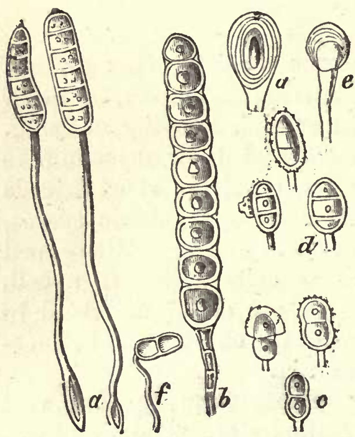


Fig. 32. Pucciniæi:—*a*, Aregma speciosum; *b*, Xenodochus paradoxus; *c*, Puccinia Amorphæ; *d*, Triphragmium dubens; *e*, Young spores of an unknown Puccinia; *f*, Puccinia lateripcs.

Fig. 32 represents various species of Pucciniæi, which consist of a thread ending in club-shaped or elongated cells called asci, containing a definite or indefinite number of septate conidia or spore dust cells. Each order of plants, as the Rosaceæ, has its own form of these entophytes. In the tissue of a rose leaf, immediately beneath a bright golden coloured surface spot, M. Tulasne found two distinct forms of fungi, living together in a small cavity. The forms were exactly those of a Puccinia and Uredo. The Puccinia consisted of a short colourless stem, ending in a club-shaped cell, containing two conidia or spore cells. These fungi were crowded together in multitudes in a small space so as to form a solid rounded mass, with their broad tops immediately under the skin of the upper-side of the leaf, but sometimes they were arranged in concentric circles. The Uredines, on the contrary, had colourless branching stems, like threads, bearing on their tops pointed spore sacs. In some species these Uredines are scattered through the mass of Puccinia, in others disposed in a circle round it, or in the centre of the concentric ring where the Puccinia takes that form. It was long believed that these two forms of fungi living together in the same cavity were totally different plants, but as in various instances M. Tulasne perceived that the Uredo had sprung up, shed its spores, and vanished before its companion had ripened its fruit, he concluded that the two different forms are merely two states of the same plant, that the larger spores of the Uredo thus early matured, immediately germinate and produce the Puccinia, whose fine dust-like spores are merely the secondary fruit of the Uredo. These minute spores issue through a pore in the conidia or dust cell and a puncture in the upper skin of the leaf into the air, whence they are wafted in myriads by the winds; and, if not too late in the season, they enter into the pores of the leaves and tender parts of the same or other plants that may suit them, and within these they form a mycelium, and produce a young Uredo. Even if the autumnal leaves fall in a moist place before the spores have germinated, the entophyte will grow on the approach of spring, and ultimately send its dust spores to enter into young leaves, and grow with their growth.

Although there cannot be a doubt of the existence of the Uredines as a numerous natural family, M. Tulasne considers the species of certain genera to be only secondary forms of certain genera of Pucciniæ. Many of these minute fungi have a third and even a fourth order of fruit; the principle being carried to a maximum in the order Cæomacei. These entophytes have a delicate mycelium, which gives rise to short or obsolete fertile threads, terminated by single spores or chains of spores. These spores when they germinate produce a second order of spores; these occasionally produce a third order, and so on successively even to a fourth or a fifth order. It is always the last and smallest spores which reproduce the plant. The object of the successive orders seems to be to diminish the size of the spores and to increase their number, that they may more easily enter the stomates of the plants they live upon, and be more easily and widely dispersed by the winds.

The Uredo candida, or Cystopus candidus, which takes its name from the white spot it forms on the leaves of the cabbage and other vegetables, is found to produce both female or germ cells and spermatozoids. Long before the white spot is formed on the leaf, the presence of the abundant spawn may be perceived by swellings and deformities in the victim plant. Its filaments, which creep exclusively in the intercellular canals of the cellular tissue, are tubular, of unequal diameter, and exceedingly branched, and are always formed of cellulose, either thick-walled and gelatinous, or thin-walled and membranous. From this mycelium, little threads hang down, ending in globular vesicles containing a nearly homogeneous colourless matter, and ultimately an aqueous liquid; they are supposed to fix the mycelium to the cells of the victim. According to the examination of Mr. Berkeley, M. Tulasne, and others, the branches of the mycelium accumulate in a hollow immediately under the white spot in the skin of the leaf of the plant attacked. From these branches spring bundles of club-shaped tubes, directed perpendicularly towards the upper skin of the leaf, and forming a tuft or little cushion of variable extent. The summit of each of these club-shaped tubes is formed into a conidium, or spore dust cell, which separates itself from that below it by taking a globular form. In the upper end of the remainder of the tubes, new spore dust cells are formed, and so on indefinitely. These conidia remain attached to one another in a string by slender constrictions which become thinner, and at last give way from above downwards, and they escape in succession through a crack in the skin of the leaf. The quantity of spores that are generated by the dense mass of these club-shaped tubes must be enormous.

The Cystopus has female reproductive cells, which had escaped notice from being hid in the plastic matter which nourishes them. They appear before the spore dust bearing cells, and are formed by terminal or interstitial swellings in the tubes of the mycelium, which become large oval cells, separated ultimately by a closure from the rest of the tube that bears them; they are filled with a granular liquid mixed with large granules of a coloured fatty matter. The tips of some branches of the mycelium swell into oval or club-shaped cells containing spermatozoids, which fertilize the female cells; then the matter within the latter assumes a globular form, gets a coat of cellulose, and becomes the true fruit of the Cystopus.

As early as the year 1807, M. B. Prévost had seen that the sporangia, or spore cells of the entophytes produced zoospores, and recently M. de Bary has seen them produced, during the germination of the spores, collected within a sporangium of the Cystopus. When they came into the water they had two cilia, one of which was short and went first, the other was long and trailed after the zoospore. Neither M. de Bary nor M. Tulasne have ever seen zoospores in the fungus itself, but if the drops of rain or dew round the white spot on the leaf of a plant be examined, empty sporangia are generally found, and spores in different states of development.

The Puccinia Fabæ, an entophyte on the common bean, has but one spore in its cylindrical case, and is considered identical with the Uromyces appendiculatus. Besides male organs like those of the Æcidium, M. de Bary found that the bean entophyte has four kinds of reproductive organs, of which one alone reproduces the original form, while the others present a well-marked alternation of generations. The Puccinia forms a prothallus on which conidia, or secondary spore dust cells, arise; these secondary spores form a mycelium, on which an Æcidium appears, whose orange-coloured fruit gives rise to a Uredo, and the dust spores of the Uredo enter the leaves of beans or peas, and grow into a Puccinia. All the species of Æcidium are similar to one another, and M. Tulasne is of opinion that they do not constitute a distinct genus, but that, like many of the Uredines, they are merely a secondary form of some other fungus, and inhabit the same cavity, as in the case of Æcidium cyparissiæ and Uromyces scutellatus, Æcidium leucospermum and Puccinia Anemones, and others.

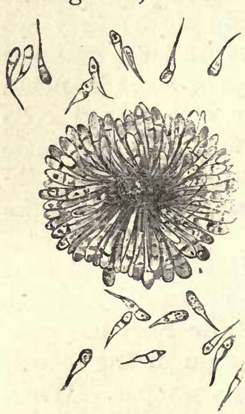


Fig. 33. Puccinia Graminis.

The order Pucciniæi comprises epiphytes, as well as entophytes. The mildew on wheat is caused by the Puccinia Graminis (fig. 33), which attacks the stem of the plant, and appears on its exterior in a circular cluster of pear-shaped septate spore cases. These spore cases spring from a filamental mycelium, whose threads interweave themselves among the soft tissue of the stem of the wheat, and the fertile threads make their way through the stomates to the surface. Professor Henslow has proved that the rust which appears on the leaves and chaff scales of wheat is owing to the Uredo linearis, a secondary form of the Puccinia Graminis, and that rust is only an earlier form of mildew; so that the Puccinia Graminis is a dimorphous and epiphytic fungus. It may be a question whether the Uredo segetum, which destroys the blossom of wheat, and reduces the ear to the sooty mass of powder called smut, may not be the form of some other fungus. The epiphytes of the order Pucciniæi often appear on the exterior of plants in tufts of brown, yellow, orange-coloured, or white sporangia.

Fungi are extensively propagated by fragments of their spawn, and the threads of the mycelia are sometimes diminished in thickness in order that they may more easily penetrate into the stomates of the plant they invade. This was discovered by Mr. Berkeley while investigating the germination of the spores of bunt, a fœtid rust which attacks wheat and other grasses. It is perfectly analogous to the diminution of the size of the dust spores in the successive orders of fructification. It is thought probable that in many of the parasitic fungi, new spores are formed at the tips of the fructiferous threads of the mycelium as fast as the ripe spores fall off, whence that enormous mass of minute spores which a single individual is capable of producing.

Among the multitudes of known parasitic fungi, there is not one that does not form a mycelium more or less distinct. They do not arise from a disease in the plant they attack, though they ultimately cause disease and often death. Each parasite has its own mode of penetrating into the tissues, and its own manner of vegetating; they attack certain plants, and avoid others though nearly allied.

Dust spores, single or septate, oozing out of a dark or coloured fungous mass is characteristic of the group

Melanconiei, which is more remarkable in regard to the mode of fructification than any of the preceding Coniomycetes, for instead of successively assuming the form and fructification of two genera, or two orders, the plants successively assume the form and fructification of two distinct families.

The family of the HYPHOMYCETES takes its name from its filamentous character. The mycelium gives rise to white, dark brown, or bright coloured threads, simple or compound, bearing naked spores on their extremities. Of these there are five sub-orders and many genera.

The sub-order Isariacei has four genera found on the pupæ of moths, on dead spiders, dead fungi, and dead plants respectively. The group is characterized by compound threads ending in pulverescent spores. Most of the caterpillars of the Bombyx Rubi, or bramble moth, fall victims to a species of Isaria, which has several distinctly different periods and modes of fructification, and at last assumes the form of a very beautiful fungus belonging to a different family.

Near Paris, in the month of October, when the caterpillars of the bramble moth seek for shelter from the cold, in the earth, or under long grass and withered leaves, M. Tulasne and his brother found that most of them were surrounded by tufts of a whitish down, which increased so rapidly that it killed the caterpillars and covered the whole of their body except the bristly hairs, and assumed characters similar to the muscardine fungus that kills the silkworm. This down is a mycelium composed of extremely fine branched filaments felted together, the upright fertile branches of which bear whorls of branchlets each terminated by chaplets of from ten to fifteen equal and spherical cells filled with dust spores. These most minute spores germinated, and put out filiform creeping germs which quickly emitted many branches ending in long chaplets of fertile dust-bearing cells.

Points here and there on the felted envelope of the caterpillars became of an orange colour, took the form of a mycelium, and produced little orange coloured club-shaped cells which shed abundance of reproductive dust spores from a ring of white hairs on their summit. Each caterpillar had from ten to fifteen of these coloured clubs on its sides, which lost their brightness when they grew old, and had shed their dust spores. These fungi possessed all the characters of the Isaria crassa, or Isaria farinosa of Fries.

Later in the season other caterpillars on which this club-shaped Isaria had not been produced, but which were swollen and white with the felted spawn of the parasite, gave out orange red club-shaped vessels of a larger size and deeper tint than those of the nascent Isariacei. They had no terminal ring of hairs, but some of them had a red spore dust-bearing felt at their base. Ultimately they assumed all the characters of the Sphæria militaris of Ehrenberg or Cordyceps militaris of Fries, which is a bright scarlet fungus half an inch high with a fleshy upright stem ending in a cup-shaped head containing long cylindrical sacs called asci, in which the spore cells are so numerous as to resemble strings of beads.[9] This fungus, therefore, begins as a member of the family Hyphomycetes, and ends as a member of the family Ascomycetes.

The order Stilbacei are little globose fungi with or without a stalk, covered with semi-gelatinous spores. They are united in cushion-like masses, on decayed wood and dead twigs. The little scarlet masses on dead currant branches so often seen in gardens, are examples.

The order Dematiei are the black moulds found on

[9] 'Sur des Isaria et Sphæria Entomogens,' par MM. L. et H. Tulasne, de l'Institut, 'Annales des Sciences Naturelles,' 4me série, 1857.

damp paper, old damp linen, dead wood and plants. Their spawn is seldom much developed, the fertile threads are erect, rigid, dark brown approaching to black, sometimes of an olive green. The spores on their tops are either simple, in whorls, or collected into heads, which are large, septate, and even spiral.

The Mucedines are beautiful microscopic objects both as to form and colour; they are very numerous both in genera and species and are well known as red, blue, or green moulds. These fungi spring from many points of a generally abundant mycelium, in erect coloured threads, bearing on their tips simple naked spores, spores collected into little tufts, or spores strung together like beads forming threads either branched or simple. In this order of fungi there are, moreover, instances of dualism, the second order of fruit being that of the family of the Ascomycetes.

The Botrytis, or Peronospora infestans, which causes the murrain in potatoes, shows how destructive the Mucedines can be. Like other entophytes, its spores enter the stomates in the leaves of the potato, and fill the cavities of the leaves with spawn, the ramifications of which are said to be very beautiful. This creeping spawn then insinuates itself into the stem and tuber, and from thence it finds its way to the exterior of the plant, or to some internal cavity, where it fructifies, bearing large globose sessile bodies yielding fruit of the second order, and spores on the tips of its fertile branches. The spawn of the Botrytis spreads rapidly in a circle, and soon destroys the texture of the leaves and stem, but although it attacks the tuber or potato generally so called, it does not penetrate deeply. The destruction of the potato is aided and completed by the Fusisporium Solani, a microscopic fungus, which takes various forms according to its age and changing conditions, the last of which seems to be partly gelatinous;

it sometimes hardens the tissues of the potato, but sometimes causes rapid and loathsome decay.

The thread-like fibres of the spawn of the Peronospora permeate even the branches and wood of trees. Wasps are frequently seen to frequent hollow trees, probably in search of the mycelia of some of these parasitic fungi, which is identical in structure with the material of which their nests are built. Signore Panceri, professor of comparative anatomy in the university of Naples, has discovered seven species of Mucedines in the albumen of hens' eggs.

Chemical changes in preserved animal and vegetable substances afford suitable food for the Penicillia mould, if indeed they are not the immediate cause of these changes. The threads rising from the mycelium of these moulds terminate in bundles of branchlets carrying at their summits strings of spores, like necklaces of small beads collected into bunches like tassels, white, yellowish, blue or red according to their age or kind. Figure 34 represents various species of Mucedines, in which *c* is the Penicillium armeniacum, and *f* is a spore of Helminthosporium Hoffmanni; all are magnified. Different species of the Penicillia form the blue and brick-red moulds on cheese, and the greenish and grey moulds on jam and preserved fruit. They appear as dry rot, as orange coloured spots on long kept potatoes, as mildew on cloth, silk, sugar, meat, and even on weather-beaten window glass. They can exist in metallic and poisonous solutions by decomposing the chemical combination, rejecting the metal or poison, and living on whatever nutriment may be found in the remainder. Like the larger fungi, these minute plants are sometimes poisonous; the fatal effects occasionally produced by sausages and spoilt meat are supposed to be owing to poisonous moulds.

The Mucedines conform to the law prevailing in other low organizations of having their species widely distributed. The Penicillium glaucum is found in all countries, especially in the vicinity of man; it inevitably appears in all saccharine substances, and, according to M. Fries, it is met with alike in the alps of Lapland and in the oasis of Jupiter Ammon in the Lybian desert, an example which has no parallel in the geographical

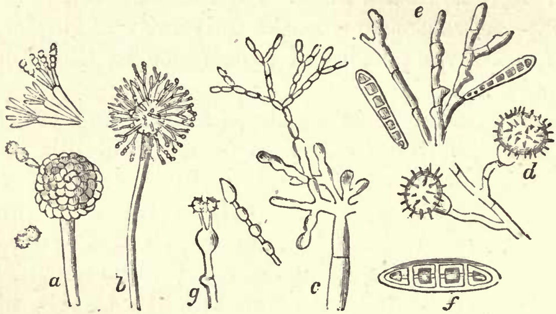


Fig. 34. Mucedines:—*a*, Aspergillus glaucus; *b*, Aspergillus dubius; *c*, Penicillium armeniacum; *d*, Sepedonium mycophilum; *e*, Helminthosporium nodosum; *f*, Helminthosporium Hoffmanni, spore; *g*, Zygodesmus fuscus.

distribution of the higher plants.[1] Ferment, that is to say, the yeast plant, is a peculiar condition of certain fungi, including the present species, and is capable of unlimited propagation.

The real spore-bearing filaments of the Penicillium glaucum are only developed in air, for when the spores of that fungus are kept submerged in a liquid favourable for their growth, as in a saccharine solution, or the juice of the grape, they form an aquatic mycelium on the filaments of which cells are produced, and carbonic acid gas is given out. These cells increase by budding or division into chains of ferment, easily separated into single cells. The Penicillium glaucum is thus developed

[1] 'On the Geographical Distribution of Fungi,' by M. E. P. Fries, of Upsala, Sweden.

in all kinds of liquids, and in almost all kinds of conditions; even the peculiar knotty filaments observed in its submerged mycelium are not constant in different liquids. M. Hoffmann has observed with certainty the passage of Penicillium glaucum into Penicillium candidum, into a sulphur-coloured Penicillium, and, lastly, into the Coremium glaucum, so that this fungus is polymorphous, although the conditions under which the changes take place are unknown.[2]

It appears that substances and liquids do not ferment spontaneously, for upon examining with a microscope the dust obtained by scraping the exterior of gooseberries, plums, vine leaves, potatoes, &c., M. Hoffmann found the

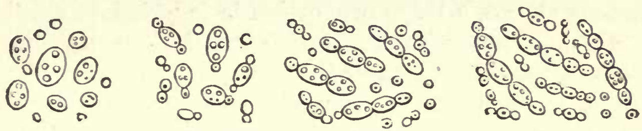


Fig. 35. Torula Cerevisiæ, showing successive stages of cell-multiplication.

short chains of the Torula, the necklace-like ferments of the Mucedines, and the chaplets of others. Some had already begun to germinate, and were developed readily when put into water. They had no doubt been carried by the wind from the dry refuse of fermented substances which are thrown away.

The yeast of beer was at one time considered to consist entirely of the cells and chains of the Torula Cerevisiæ (fig. 35). This, which is one of the Coniomycetes of the order Torulacei, is in its early stage a colourless transparent globe capable of endless increase by budding. When in a liquid favourable to its growth, as the wort of malt, buds in the form of young cells spring from the walls of the globes; these soon become perfect and acquire buds also, so that in a few hours the parent cells

[2] Memoir by M. Hermann Hoffmann, upon Fermentation, in the 'Ann. des Sciences Naturelles,' 4me série, 1860.

develop themselves into rows of four or five globes, which remain in contact while the plant is growing, but separate if anything checks the fermentation. The full development of the plant only takes place when the fermentation is allowed to continue for some time, and then it is capable of producing a variety of forms, which show that it has other modes of reproduction besides budding.[3] In fact, when the fermentation is active in the upper parts of the liquid it appears in chaplets of from four to twelve articulations, or sometimes it ramifies into little branches.

More recent observations show that yeast is a peculiar state of the mycelium of various fungi, of which, as already stated, a large proportion is believed to consist of Penicillium glaucum, though it is known that other kinds of mould also enter into its composition. These plants grow naturally in a state of exposure to the atmosphere, but they have the property of also developing themselves when submerged; and as in this unnatural condition, which they bear when developed as yeast, they cannot produce their proper fruit, they propagate themselves by means of shoots from the altered mycelium. It has been observed that mechanical injury destroys the vitality of German yeast, which consists of yeast globules in a dried state. Thus a fall on the ground, or a bruise caused by a blow or by careless handling, will kill the plant, and such dead yeast becomes dark-coloured and glutinous, and soon acquires an offensive smell.

The form of Penicillium glaucum which produces acetic fermentation, known as the vinegar plant, has a filamental submerged instead of a vesicular mycelium.

Ferments may be formed in the wort of beer, in the solutions of grape and cane sugar, in the juice of gooseberries, currants, &c., by means of the submerged spores

[3] 'The Microscope,' by Dr. Carpenter.

of the Uredines segetum and Rosæ, of Ascophora elegans, Mucor Mucedo, Periconia hyalina and others. There are active exchanges continually going on between the contents of the globules of ferments and the exterior liquid, and therefore a continual chemical action.[4]

M. Pasteur's experiments on the nourishment of the Mucedines concur with the observations of others in showing that these plants are the origin of all fermentation properly so called. When he put a mere trace of the beer yeast fungus into pure water holding in solution the three crystallizable substances, sugar candy, an ammoniacal salt, and some phosphates, the globules of yeast were seen to multiply, deriving their nitrogen from the ammoniacal salt, their carbon from the sugar, and their mineral material from the phosphates; at the same time the sugar fermented. The same results were obtained from lactic yeast. M. Pasteur now sowed the spores of the Penicillium, or of some other mucedinous fungus in pure distilled water holding in solution the same ingredients, except that an acid salt of ammonia was employed to prevent the development of infusoria, which would soon have stopped the progress of the microscopic plant by absorbing the oxygen without which fungi cannot live. The result was the same as in the preceding case. There is consequently a complete analogy between the ferments, the mucedines, and plants of more complex structure. If in these experiments any one of the principles in the solution be omitted, the vegetation is arrested. The quantities of these substances in the air, the water, or in the spores themselves, are not sufficient to make up for the suppression of any one of them. For example, the carbonic acid in the air or water does not make up for the omission of the sugar. The mucedines and fungi generally obtain their carbon from their food and from rain water, for

[4] M. Hoffmann.

rain water holds in solution nitrates and ammoniacal salts together with salts of potash and lime, and M. Barral has ascertained the existence of phosphates also. M. Barral found that the nitrates and ammonia disappear under the influence of cryptogamic plants.[5]

In the genus Oidium, belonging to the Mucedines, the short threads have a string of spores, like a necklace of beads, on their tops. Species of this genus are found on damp paper and honeycombs; also on decayed oranges, and other spoilt fruits.

The family of the ASCOMYCETES produces spore-bearing cells, called sporidia, enclosed in long cylindrical sacs or asci, in the definite numbers two, four, eight, sixteen, thirty-two, &c. The great characteristic of this large group, consisting of six orders, is the fleshy soft texture and the more or less complete exposure of the fructiferous surface. In one division the asci are persistent; this includes the Elvellacei, the Tuberacei, the Phacidiacei, and the Sphæriacei. In the other division the asci are often evanescent, and this includes the Perisporiacei and the Onygenei.

The genera Peziza and Helvella are the principal fungi belonging to the order Elvellacei. The Pezizæ are a very numerous race, and consist of brilliantly coloured little cups, with or without stems, and more or less concave. They grow in the cooler part of the temperate zone, many show themselves in spring, and some of the largest and most beautiful appear during the melting of the snow.[6] A few are subterranean, and 128 species inhabit Great Britain, many growing on the ground, others on stumps of trees, dead sticks and timber, on living plants, damp walls, &c. They are singularly beautiful, including 'many of the most elegant

[5] 'Comptes rendus,' Nov. 12, 1860.
[6] 'Geographical Distribution of Fungi,' by M. Fries.

fungi, from the little white and red Peziza elegans, which is sprinkled over almost every fallen twig of the larch and other conifers; the pale toothed cups of the P. coronata, which abounds on the dead stems of herbaceous plants; the scarlet P. scutellata with its edge fringed with tawny hairs, and the graceful mouse-grey P. macropus, to the gorgeous P. coccinea, which attracts attention from its elegant form and bright colours; the more irregular, but not less brilliant P. aurantia, and the font-shaped P. acetabulum, which might form an elegant pattern for an architect or silversmith. Fifty others might be mentioned of equal pretensions to grace of form and brilliancy of colouring.'[7] Some of the genus are peculiar in their fructification, for in several plants of this group, besides asci containing eight sporidia, M. Tulasne met with cells full of eel-shaped particles like those in the Algæ, and although without motion he considered them to be analogous to the pollen of flowering plants. In the Peziza aurantia, however, the particles were staff-shaped and motile.

The genus Helvella may be regarded as Peziza with the cup inverted; consequently, it assumes the character of a pileus or hat, like a common mushroom, though often very different in shape, and, instead of spore-bearing gills, it has asci containing eight sporidia sunk in its fleshy texture. The pileus is ovate or mitre-shaped in some species and the margin free, in others it is more or less attached to the stem. When the pileus and stem are perfectly soldered together, we get the club-shaped species of the group.

Some obscure forms of this group, forming the genus Ascomycetes, cause the leaves of the peach, walnut, and pear to blister. They consist of little more than asci, accompanied by short necklace-shaped threads.

The Morchella esculenta, which is the morel, is so

[7] Berkeley's 'Cryptogamic Botany.'

plentiful in some parts of England, that it is used for making katsup; while the Cyttaria, which is indigenous in the southern hemisphere, is the staple food of the Fuegians during many months of the year; its subgelatinous consistence indicates a nutritious principle. This species has the peculiarity of growing upon living branches, after the manner of the jelly-like fungus of the juniper.

M. Tulasne has discovered in Peziza, and in the genus Bulgaria and others, certain minute bodies, which he considered to be of the nature of the eel-shaped particles or antherozoids in the Algæ. Besides, he has shown that several species of Peziza have a second form of fruit. Fries had long before pointed out the identity of Fusarium tremelloides and the orange coloured Peziza common on nettle stems. Many of the larger Pezizæ and Helvellæ eject their sporidia with great elastic force. This is particularly remarkable in the Peziza vesiculosa, common in hot-beds, when the sun is shining; the least agitation raises a visible cloud of sporidia like vapour. The motions of the sporidia in the genus Vibrissea, which grows on twigs partly immersed in water, is very peculiar. They are exceedingly long and slender, and, when partly ejected, they wave about in the sunshine till they are expelled.

The fungi of the order Tuberacei are nearly all subterranean, and their fruit-bearing surface, as in the truffle, is internal. The asci are either irregularly deposited in cavities, or in the denser tubers they are sprinkled through a dark substance which is mottled with a paler tissue. The truffle, which is the most important and best known of the order, has a dark corrugated exterior, and the asci are represented by large pyriform sacs containing sporidia covered with a reticulated or spinose coat; but these spines are only the angles of continuous cells, and are beautiful microscopic objects. Truffles prefer calcareous soil, and a temperate climate. In England, they are found in Rutlandshire, and numerous species grow in Northamptonshire, but they are smaller than the continental truffles, which increase in abundance and size towards the south, and have their maximum in Italy, where they grow on the roots of trees and vines, and are hunted by dogs, or traced by the presence of a peculiar fly, and dug up for sale. Sometimes the dogs dig them up, to the annoyance of the proprietors of vineyards, from the mischief they do to the roots of the vines.

The Sphæriacei, another order of Ascomycetes, are enormously numerous. There are 1,000 well known species of this order, and probably twice as many undetermined; for there is scarcely a twig or dry branch in the forests, hedges, or gardens on which they may not be found. The rose tree, the oak, and other plants harbour more than one species at a time. The genus Cordyceps and many so-called species of Sphæria are only the ultimate development of fungi of other families. The Cordyceps purpurea, discovered by M. Tulasne on the ergot of wheat, has a short, upright, slender stem, with a minute pale purple globose fruit-bearing head. In this ergotized state the white substance of the grain is converted into a firm mass without any appearance of meal, and having very powerful properties. When sown, it is found to produce the Cordyceps. Mr. Currey found the same plant on the ergot of the common reed, and there are several other species of Cordyceps, all of which are only the second form of ergot. To these may be added the Cordyceps militaris of Ehrenberg, already shown (p. 283) to be the ultimate development of the Isaria, which attacks the caterpillars of the bramble moth; and the Cordyceps Robertsii, which grows like a bunch of rushes from the head of the Hepialus virescens of New Zealand; whilst a kind of wasp in the

West Indies, which continues to fly about after it is attacked, is at last killed by branching Cordyceps, which project from its head like a pair of antlers. But the largest of all these parasites grows on an enormous larva found on the banks of the river Murrumbidgee in Australia. It appears that species of Sphæriæ are parasitic on insects of very different affinities in China, America, and Europe. It may be presumed that, like the Cordyceps militaris, they are the ultimate development of fungi belonging to other families.

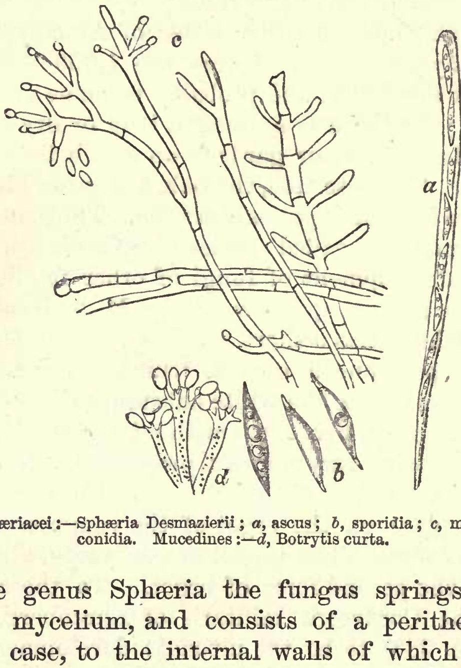


Fig. 36. Sphæriacei:—Sphæria Desmazierii; *a*, ascus; *b*, sporidia; *c*, mycelium with conidia. Mucedines:—*d*, Botrytis curta.

In the genus Sphæria the fungus springs at once from its mycelium, and consists of a perithecium or external case, to the internal walls of which the asci are fixed. Each ascus contains eight sporidia or spore cells, and when the fruit is ripe the asci are emitted through a pore or slit in the perithecium or external coat. Fig. 36 represents the fructification of Sphæria Desmazierii. Sphæria bombarda is like an assemblage of minute black beads lying flat and crowded together upon decayed wood; each bead is an oblong vesicle pierced at the apex for the emission of the microscopic sporidia, or spore cells. The Sphæria aquila, found upon decayed wood, has its fruit-bearing vessels seated upon thickly matted fine threads. In some species they are in tufts; others have bottle-shaped perithecia sunk into the stems of the berberry, laburnum, and decayed oak palings; and lastly the candle snuff Sphæria may frequently be seen like patches of soot at the bottom of stakes or gate posts. More than two hundred well ascertained species of the genus Sphæria are native in Great Britain alone.

The genus Nectria, which forms a connecting link between the genera Peziza and Sphæria, has several interesting species, as the Nectria Peziza, which grows in a congeries of most minute cups forming a bright orange-coloured patch on decayed stumps of trees.

In the order Perisporacei the perithecia, or external cases, are free and become dehiscent at last, but when young these fungi consist of cellular jointed filaments like necklaces, rising upright from their mycelia, and bearing reproductive bodies. In this state they constitute the mildew on the vine, rose tree, turnip, hop, pea, &c. They are true parasites, appropriating the juices, and filling up the breathing pores of the leaves, so as to cause disease and often death. The vine mildew, which has been called Oïdium Tuckeri, but which is now supposed to be an imperfect state of Erysiphe, never advances beyond this state, consequently it never has more than one form of fruit. Mr. Berkeley has discovered that, on the contrary, the hop and pea mildews, which belong to the genus Erysiphe, have five different modes of reproduction. The destructive power of these fungi is strongly illustrated by the extraordinary energy of their mycelia in draining the vital juices of the plants on which they live in order to form such various kinds of fruit; and the quantity of fruit produced is so enormous, that if the whole were to germinate no genus of plants for which they have an affinity could escape annihilation. Other species of Erysiphe have at least three different modes of reproduction. The perithecia of some of these fungi are beautiful objects for the microscope.

The PHYSOMYCETES, which form the sixth and last order of the great fungus family, have bladder-like fertile cells scattered on threads, the number of sporidia within the cells being indefinite. The Antennariei are dark coloured felt-like fungi which run over the leaves of living trees, and have fruit on black threads, which in some species, when magnified, resemble the antennæ of certain beetles. The species of this order are not common in Britain, and they are supposed to be only a condition of some other fungi. They are certainly spore-bearing plants, yet the fruit-bearing cells of the Antennaria Robinsonii sometimes contain a ready formed miniature of the parent plant waiting to be set free,—a singular analogy between these microscopic fungi and flowering plants.

The order Mucorini, or moulds, has threads springing from the spawn, bearing on their extremities large vascular sacs containing asci with spore cells. The genus Ascophora contains several remarkable species, as Ascophora elegans, which has two kinds of fruit, and attacks bread while yet hot from the oven: however, the spores were probably in the dough, for it has been ascertained that the spores of some of the lower fungi retain their vitality after being exposed to the temperature of boiling water. The Mucors are probably found on decayed and decaying matter all over the world; they grow on fat, on greasy walls, and on decaying fruit and vegetables.

The extreme minuteness of the reproductive bodies of the microscopic fungi, many of which are not more than the 20,000th part of an inch in diameter, and their extraordinary and varied forms even in the same plant, have made these fungi one of the most difficult studies in the whole science of botany. There is still some obscurity with regard to those minute motile bodies supposed to be male particles, and their analogues, which have not been seen, or have rarely been seen to germinate. These bodies have been observed in comparatively few genera, and nothing more than mere molecular motion has been observed in them.

One of the most unaccountable circumstances in the history of the lower fungi is their sudden appearance in immense numbers, and the rapid extension of disastrous and destructive epidemics caused by them among plants and animals, as the potato murrain and the vine disease, which, though widely spread through Europe and Madeira, leaves the North American vines unscathed, whether grown at home or abroad. The black mildews at one time raged so much in the Azores and Ceylon as to threaten the complete annihilation of the orange and coffee plantations. Their ravages have been scarcely less among the olive trees in some parts of Europe; and the Lanosa nivalis, which grows in the melting snow in spring, is supposed to be the cause in many instances of the death of the germs of the sprouting rye. The destructive course of most of these has abated, but the silkworm disease still continues. The fungi require warmth and a moderate degree of moisture for their development, but the unwonted multitudes in which the parasites occasionally appear, possibly indicate some meteoric influences of which we are ignorant.

SECTION IV.

LICHENS.

Lichens are essentially air plants, being nourished, like the Algæ, by the medium in which they grow. They vary from a pulverulent or dry papillose crust, to a leathery or horny expansion, and even acquire an erect stem. They are independent of the matrix to which they are attached. Hence they spread their coloured frond, or thallus, in circular or indefinite patches on old walls, the tiles of houses, stones, and rocks. They appear in large expansions of red, golden yellow, grey or white, on barren heaths, under plantations, and on the stems of aged trees; while others of them often hang from the branches like long shaggy grey hair, and many form forests of miniature bushes on the northern plains. The lichen is the last trace of vegetation on the tops of the mountains, and on the arctic deserts. Some lichens are patient of severe cold, yet in general they prefer heat and moderate warmth, and they love bright light so much, that they are usually barren, or else yield little fruit under shade. Though differing greatly from fungi in slowness of growth, length of life, and the power of forming chlorophyll, they resemble them in having a mycelium in their youth, and in their ascigerous fructification. A perfect lichen without an ascus would be an anomaly, for the asci contain the true fruit, associated with vertical threads or elongated cells called paraphyses, which sometimes bear secondary spores on their summit. The asci with their paraphyses inclosed in vessels of various shapes, called perithecia, are aggregated in discs or shields, which form projections on the surface of the plant. Some of these discs are closed, and give egress to the spores through a fracture or pore on their surface; others are open cups of various forms, either with stalks or sessile on the frond, and through these the spores have egress. Hence the whole order of lichens is naturally divided into two groups, according as their discs are open (Gymnocarpei), or closed (Angiocarpei), the first being incomparably the most important. Fig. 37 shows open, and sections of closed cups, or perithecia.

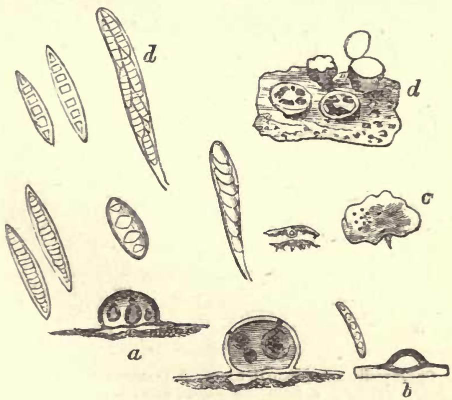


Fig. 37. Lichens:—*a*, Trypethelium Sprengelii, pustules, with sporidia; *b*, Verrucaria variolosa, section of perithecium with sporidium; *c*, Endocarpon lacteum, thallus with section and fruit; *d*, Stegobolus Berkeleianus, portion of plant with ascus, and sporidia.

The highest type of horizontal lichens, of which fig. 37 *b* is a perpendicular section, has a firm, spreading, superficial crust or surface, formed of oblong coloured cells, or of coloured filaments closely aggregated, and which covers two distinct layers of cellular tissue. In the layer immediately below the surface, the cells are globular and of a paler colour; the second layer, or marrow, which is the origin of fructification, consists of lax, detached, branching rows of elongated cells and gelatinous matter. These branches of cells spring up from a fourth layer, which is the base of the plant. It is of a strong, firm, and tough nature, composed of interlaced filaments and is often ribbed on the under-side. White fibres fix the base of the plant to the surface on which it is spread; they are the remains of a mycelium or matted mass of fibres, from whence lichens spring, which vanishes when the plant is full grown.

Globular bodies of vegetable green called gonidia, like those at the base of fig. 39 *a*, are arranged in regular parallel rows, and placed between the surface

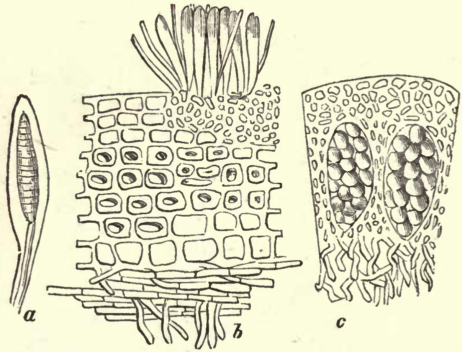


Fig. 38. *a*, Sporopodium Leprieurii, ascus; *b*, Coccocarpia smaragdina, section; *c*, Lecanora affinis, section.

and the base of the lichen, as in fig. 38 *b* and *c*; they are said to proceed from the medullary layer, though Mr. Berkeley has seen them springing from the threads of the mycelium of Parmelia parietina. The gonidia find their way to the air through rents in the surface of the plant, and are washed off by the rains, after losing a little of their green colour. When they germinate they only produce a *facsimile* of the mother plant, as buds do in the highest classes. But according to the microscopic observations of M. Tulasne, the true fruit differs little if at all from the asci-bearing fungi. Through the open discs of the higher lichens, sporidia are discharged from perpendicular septate asci which, with their paraphyses, are imbedded in the substance below. The asci are formed by the elongation of some of the cells of that layer into cylindrical septate vessels, generally containing from four to eight sporidia, the ultimate result of as many free cells. In whatever part of a lichen the perithecia may be placed, the asci and paraphyses invariably originate in the medullary layer.

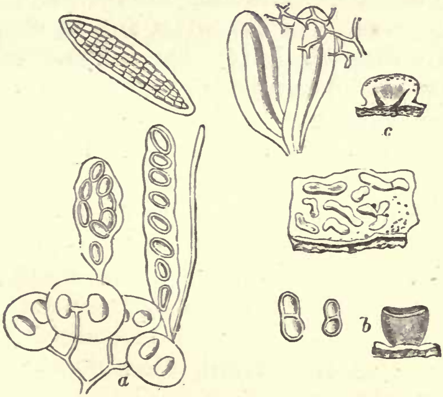


Fig. 39. *a*, Paulia perforata, gonidia, paraphysis, and asci; *b*, Calicium tympanellum, perithecium and sporidia; *c*, Graphis Leprevostei, with excipulum, asci, and sporidium.

The thallus or frond of many of these lichens is irregularly covered with thick convex scales, in each of which are concealed white or grey bodies, which become flask-shaped, with pores in their extremities. When mature, they exactly resemble the bottle-shaped perithecia in the genus Sphæria among fungi. They are lined with branching filaments or other supports, ending in minute ovoid particles, which escape in myriads from the flask-shaped vessels long before the spores appear. They are motile, though not provided with cilia, and are supposed to be fertilizing particles like pollen, since they do not germinate as spores do. In this vast family of open-shielded lichens, which comprises every form and habit of the plant, the preceding type, which is the highest, undergoes many modifications; but the essential character remains the same, and the group is so natural, that the species run into one another so as to leave no very striking distinction.

Commencing with the Gymnocarpei, the Parmeliacei first claim notice as containing the highest types which lichens are capable of assuming, and as abounding in species. The disc, which is the hymenium, is orbicular or kidney-shaped, and surrounded by the frond, without any proper excipulum or cortical covering. A large portion of our most widely diffused lichens, whether growing on the ground or attached to rocks and trees, belong to this tribe; they form patches two or three feet in diameter, which are often of marvellous antiquity, and they grow so slowly that even small patches are of great age. This tribe consists of three distinct groups: in two of these the plants are horizontal and sometimes foliaceous; in the third they are vertical, often branched, and occasionally pendulous.

The latter group of this large division of lichens comprises the genera allied to Usnea, which are erect, centripetal lichens, that is to say, their body or thallus is an upright and generally cylindrical stem, in the centre of which the layer of marrow, the origin of fructification, is condensed, and the open discs, or hymenia, are in connection with it, whether they be situated at the ends of the branches, or on the surface of the upright stems. The Usneæ have three forms, the pendulous, the inflated and erect, and the branched or shrubby. The Evernia jubata is an example of the first, and remarkable for its long, pendulous, cylindrical branches hanging down like bunches of bluish grey hair. It is often attached to the branches of aged larch trees, and is exceedingly picturesque. With the exception of Evernia vulpina and flavicans, which are brightly coloured, all the rest of the genus have dull tints. The genus Ramalina has the dull tints of the Evernia, and some species approach very nearly in form to that genus. The Ramalina polymorphum and R. scopulorum abound in dyes, while the R. calicaris is rich in gluten.

Lichens have lost much of their importance since the discovery of the coal tar colours; nevertheless they afford dyes still in use. In many species the dying principle is colourless like aniline; but it yields the most brilliant colours by means of alkalies. The Parmelia parietina, common on walls and the roofs of houses, gives the chrysophonic acid, a colourless liquid which becomes bright yellow when treated with an alkali; and in like manner the vulpinic acid, given by Evernia vulpina, gives a brown dye. Notwithstanding the quiet greyish green tints of the Rocella fuciformis and R. tinctoria, no lichens are richer in the purple substance known as orchil, from which, by means of soda or potash, the valuable blue substance litmus is manufactured, so important as a test for acidity. Many of the small moss-like lichens yield orchil, but none in such abundance as the R. fuciformis, which grows in Madeira, Angola, Madagascar, and South America. Oxalic and usnic acids are produced by lichens; indeed the usnic acid combined with green and yellow resins seems to be more or less a constituent of various lichens. It is evident that the colour of the dyes is altogether independent of the colour of the lichen from whence they are obtained.

These aërial plants have a marvellous power of decomposing the light, and adorning themselves in brilliant hues. In our own country, where the colouring is often cold from the excess of verdure, the lichen affords a happy relief by giving a little warmth to the landscape. Even at Rome, where nature is so gorgeously coloured, the ruins owe much of their picturesque beauty to the red, white, and golden lichens with which they are clothed.

The Usneæ are perhaps the most beautiful of the lichens, the colours being sometimes brilliant, the forms elegant, and when the broad discs are amply ciliated, the appearance is very striking. The same species are widely diffused, but the colours are brighter in exotic specimens. Usnea melaxantha and Usnea Taylori are splendid productions.[8] The Usneæ are cosmopolitan in genera and species. The genus Cetraria, of which the Iceland moss is a well known species, forms a connection between the vertical and horizontal lichens; its thallus is neither cylindrical nor quite erect, though it becomes more so towards maturity. The Cetraria tristis has only that degree of inclination which arises from its crowded mode of growth, and springs like a sea-weed from a little peltate disc.

The most typical species of lichens occur in the second group of Euparmeliaceæ, or Parmeliacei proper, in which the disc is at first closed, and surrounded after expansion by a border arising from the thallus or frond. The thallus is always horizontal, and expands from the centre towards the circumference. The genus Sticta, belonging to this group, is often highly foliaceous, and is not excelled by any horizontal lichen in brightness of colouring or elegance of form. Even in our own country the Sticta pulmonacea spreads over a wide area, and is remarkable for its pitted frond. In this genus the under-side of the plant is covered with a delicate velvety

[8] Berkeley's 'Introduction to Cryptogamic Botany.'

down, amidst which are scattered round white spots, which penetrate to the medullary strata.

The erratic lichens are among the peculiarities of the genus Parmelia. The Parmelia saxatilis, common on stones and boulders of the primary and metamorphic formation, curls up into a ball, only fixed to its matrix by a slender thread, which soon gives way, and the ball being dry and as light as a balloon, is driven bounding by the winds, over the sheep walks and downs of England. The globular Lecanora esculenta sometimes suddenly covers large tracts in Armenia, Persia, and Tartary, where the plants are eaten by the cattle and by the nomade tribes. This species, with Lecanora affinis, is largely used by the inhabitants of the countries east of the Levant, and in some parts of Africa is mixed with wheat in grinding. These species are found, scattered over the ground without any attachment, in the form of rugged truffle-like objects of the size of walnuts. Sometimes they are piled together in strata a few inches thick, by the whirlwinds, after traversing the air for many miles, which gives rise to the histories of the miraculous descent of food. During a scarcity, a shower of these lichens fell at Erzeroum, and there are other well-authenticated instances recorded.[9]

The Peltigeri, or the third group of Parmeliacei, are so named from the target-like discs on their surface, covered by a veil, which afterwards disappears. The species frequently spread their beautifully foliaceous fronds upon the ground, and as the fruit is marginal, it gives the thallus a digitate appearance. They are often spotted by a little red fungus. The genus Solorina has the fruit scattered over the frond; in the Solorina saccata it is at first superficial, but a number of fibres are formed on the under-side of the discs, which penetrate the soil, and draw them down below the general surface—

[9] Berkeley's 'Introduction to Cryptogamic Botany.'

a very peculiar structure, in strong contrast with that of the Solorina crocea, which has veins on the under-surface but no fibres, and as no rootlets are sent out from the base of the disc, it remains superficial. M. Tulasne discovered fertilizing particles in several species of this group.

The order of the Lecidinei contains numerous species of the most varied habits. There is a distinct and regular series upwards in the genus Lecidea, the species of which are always crustaceous, and often form merely a thin, close, adherent fibrous stratum on the hardest flint or quartz. Some of them disintegrate the hard rocks on which they spread, possibly by the action of some acid which they contain. From this low type, the genus rises to the exalted forms with erect branching stems clothed with foliaceous scales, and brightly coloured. The order is distinguished by an orbicular disc, contained in a distinct excipulum or cortical envelope, which is open from the earliest age; but it is frequently obliterated afterwards by the development of that part of the medullary stratum where the fruit is formed, the disc in consequence becoming convex and capitate. This transformation takes place in the highest forms of the genus Lecidea. The genus Bæomyces has rose or chestnut coloured convex discs, supported on a stem called a podetium. The genus Cladonia has a foliaceous thallus producing free scale-like fronds, from the midst of which spring cylindrical or cup-shaped podetia, which are sprinkled with leaves. The margins of the cups or tips of the branches bear an abundant crop of convex, irregular brown, or deep red discs, often as brightly coloured as sealing wax.

The species of Lecidea bear severe cold, and are wonderfully long lived. Mr. Berkeley mentions that there are patches of the Lecidea geographica which probably date from almost fabulous periods.

The fronds of the order Collemacei are gelatinous; the medullary stratum seems to occupy the whole, though in two species of the genus there is a distinct epidermic cellular coat. There are moniliform strings of minute gonidia in the gelatinous matter, and others that are single, arising from the division of each gonidium and its supporting thread into two: both kinds differ from the gonidia in other lichens. The fruit-bearing discs on the surface are open. Members of this order occur in Europe, Africa, and Australia.

The order Coccocarpei is mainly distinguished by having orbicular discs entirely deprived of the cortical envelope called an excipulum, or, if it does exist, it is confounded with the thin membranaceous thallus. The discs spring at once from the medullary stratum, and contain asci and sporidia, similar to those of minute fungi (Sphæriæ). Some species of the genus Coccocarpia only differ from Lecidea in the total absence of an excidium. The order is chiefly parasitic, and in some cases the whole plant is little more than a mass of fructification, parasitic upon and continuous with the substance of other lichens, at whose expense they live, thus forming an exception to the general habit of lichens, which are fed by the atmosphere alone. M. Tulasne has discovered that the genera Abrothallus and Scutula, though consisting almost entirely of fruit, produce secondary spores—they are the only lichens in which they occur; while Phacopsis and Celidium bear spermatogonia, which, analogous to antheridia, contain minute fertilizing particles. The parasitic genera occur in most parts of Europe and North America.

The Pyxinei are horizontal foliaceous lichens, for the most part fixed by the centre. They have orbicular discs, and form one of the most singular groups, both with regard to the superficial fruit, and the curious convolutions of the perithecia. The fruit-cup, or excipulum, is at first closed, and in the genus Gyrophora the disc produces a number of partial fructiferous discs on the original fruit-bearing surface. As usual the cells from whence the asci spring belong to the medullary stratum; the border on the contrary is cortical. The thallus is always foliaceous, and more or less peltate, but it becomes dry and brittle when exposed to drought. Several of the species have tufts of strong rootlets by which the frond is fixed to rocks, and some have deep pits, with corresponding swellings on the upper-surface, from whence they have their popular name of Tripe de Roche. These lichens, together with some species of Gyrophora, afforded a miserable sustenance to Sir George Back and his companions during their journey along the frozen regions of Arctic America in quest of the north-west passage. It is evident that plants which derive their sustenance solely from the medium in which they live, whether air or water, can never become a permanent and wholesome food for man, though erratic lichens and laver may be eaten from necessity, certainly not from choice. In the Gyrophora the perithecia are convolute, in the Umbilicaria they are not; but both of these genera, which have their seat in Arctic Europe and America, possess fertilizing particles like most of their class.

In the order Graphidei the disc is linear, simple, or branched, with or without an excipulum, which is carbonaceous. Many of these lichens are crustaceous, and in most of the genera the perithecia are much elongated, pointed at both ends. When they are parallel, or placed at different angles to each other, they form groups like Japanese or Chinese characters, whence their name. The genera are determined by the position of these perithecia, which are much varied. M. Tulasne has found linear male particles immersed in the crust of some of these lichens. They have their principal seat in tropical America, though a few species occur in the frigid and temperate zones of both hemispheres.

The order Glyphidei has no true excipulum; the coloured discs are at first immersed in the medullary stratum of a crustaceous thallus, the crust then rises into distinct expansions, in the centre of which the coloured discs are set like gems in a mosaic. 'There is in fact no true border to the disc, the perithecium being reduced to a thick conical base, from which proceed immediately the asci and paraphyses; each individual hymenium being surrounded by the intervening medullary matter injected, as it were, into the interstices.' The whole surface of Chiodecton monostichum is productive, and in that genus M. Tulasne found vessels in the form of little scattered perithecia, containing filiform curved fertilizing particles. The species of this order are almost wholly tropical, though the Chiodecton myrticola has been found in Ireland.

The order Caliciei consists of horizontal lichens, with generally an ill-developed crust; the discs, which are at first covered by a veil, are contained in a stalked, or more rarely sessile, excipulum, looking like little flat-headed pins stuck into the crust; the veil at length vanishes, and exposes a pulverulent mass of spores, which adhere so loosely in the Calicium inquinans, that they soil the finger if touched; in other cases they come out of their ascus like little necklaces. The species of these lichens are almost entirely confined to Europe and North America.

In the second division of Lichenaceæ, the ANGIOCARPEI, the discs are enclosed in an excipulum, which projects from the surface of the plant, and ultimately discharges the spores from a rupture or pore in its surface. Besides the fructification consisting of perithecia containing paraphyses and asci with their enclosed sporidia, there is a nucleus in each disc, either of firm or deliquescent matter.

Some of the lichens of this group are parasitic, others are aquatic. The order Limboriei, like parasitic fungi, begin their existence under the thick skin of the leaves of tropical plants, spread their crustaceous thallus over their surface, and destroy their beauty, by stopping up their pores, and preventing the admission of light to their tissues. The excipulum and perithecia are black, and the latter burst in an irregular fissure, and are in most cases covered by a beautifully sculptured crust.

The crustaceous fronds of the Verrucariei are often so thin as to be inseparable from the substance over which they spread. The excipula are closed, the walls of the perithecia are often black, and in some species more or less crowded round a columella. In the Verrucaria muralis fertilizing particles have been discovered. The plants are widely distributed, and at least one species spreads its crust over the smooth stones in running streams.

In the group Endocarpei, the perithecia are immersed in the substance of the plant, which has, for the most part, a foliaceous horizontal crust, and a gelatinous nucleus. Some species grow on stones, perpetually or periodically submerged, or, if not under water, continually wet with its spray. The Lichina, a genus of the group Lichinei, lives on marine rocks, and is often dripping with salt-water, and often suddenly dried up.

The Sphærophorei, or sphere-bearing lichens, have upright stems bearing globular fruit at the extremity of their numerous branches. At first, the fruit is only indicated by a swelling, but in time the outer bark bursts, and exposes the contents of the perithecium, which consist of asci and paraphyses seated on a central columella. The sporidia are beautiful objects under the microscope on account of their spherical form, which is rare among lichens, and their more or less deep blue tint —a colour by no means peculiar to the sporidia of this order of plants, for in other orders they are bright scarlet, olive, golden yellow, or brown.

SECTION V.

CHARACEÆ.

The Characeæ are submerged annual water plants, growing in stagnant pools and ditches rather than in running streams. It is a small order containing but three genera, but the numerous species are dispersed all over the world, especially in temperate climates. The genera found in this country are Nitella and Chara. The Nitella flexilis (fig. 40) may be taken as a representative of the order. Its stem or axis is formed of very long cylindrical transparent tubes, joined by their flat ends, and surrounded at each junction by a whorl of long tubes which are forked or trifid at their extremities. In some species the branches are jointed, and have whorls precisely like those on the main axis. On the internal surface of the tubes, which are sometimes several inches in length, there are four longitudinal bands parallel to the axis of the tubes, which are occasionally twisted: two of these bands are broad and covered with oval green particles; while the other two are narrow, transparent, and colourless. Each tube is filled with a limpid semifluid liquid, in which pale green particles and jelly-

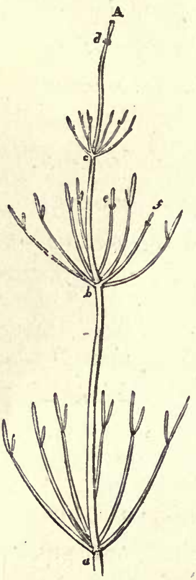


Fig. 40. Nitella flexilis.

like globules of a starchy nature float; and when these particles are watched with a microscope, they show that, in every tube of the plant, a continual current of that liquid, with its particles, ascends one of the green bands and descends by the other, even when the stem and branches are twisted; but they never flow in the colourless bands, though there is nothing to hinder them. According to the observations of microscopists there is probably a gyration of an azotized viscid fluid in all plants originating in, and maintained by, vital contractility of structure, but in none is it so evident as in the Characeæ. Its rate is increased by heat and diminished by cold, like the circulation of the blood in animals, because the activity of the vital energy bears a precise relation to the quantity of heat received. The gyration is instantly arrested by a shock of electricity.

The reproductive organs of the Characeæ are of two kinds, both growing in the axils of the branchlets, namely, dark-red globules, which are antheridia, and nucules or pistillidia, which contain germ cells. Sometimes they are found in different individuals, but in most of the Nitellas they are in the same individual, the globules being placed closely below the nucules, as in fig. 41, A, B. The envelope of the nearly spherical globules is formed of eight spherico-triangular valves. From the middle of the interior surface of these valves, a perpendicular orange-coloured column extends to the centre of the globule, where its summit is crowned with a mass of confervoid filaments, which are formed of a linear succession of minute cells; while from the base of the column, bands of orange-coloured spherules imbedded in gelatine radiate along the interior surface of the valve to its margin as shown at C, in the same figure. After successive changes in the matter within the confervoid filaments, (fig. 42, D–G), the microscope shows that 'in every one of the cells there is formed a spiral thread of two or three coils, which, at first motionless, after a time begins to move and revolve within the cell; at last the cell wall gives way, and the spiral thread makes its way out, partially lengthens itself, and moves actively through the water in a tolerably determinate direction, by the lashing action of two long and very delicate filaments with which it is furnished'[1] (fig. 42 H).

The nucule is an ovoid sac with five long cells spirally

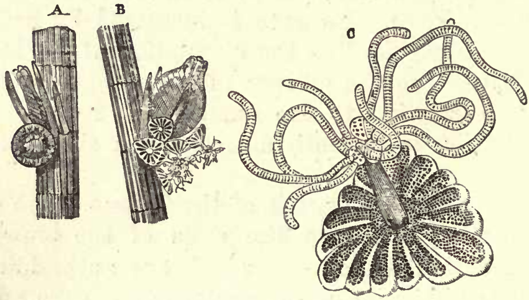


Fig. 41. Antheridia of Chara fragilis:—A, antheridium developed at base of nucule; B, do., the nucule enlarged, and the antheridium laid open by the separation of its valves; C, one of the valves, with its group of antheridial filaments.

twisted round it, the sac being full of a viscous fluid containing globules of starch and oil. This nucule falls off when fertilized by the spirally-coiled ciliated bodies, and then germinates.

The Characeæ may also be artificially reproduced by cuttings; while under favourable circumstances they are reproduced by nodular bodies rich in starch grains, which arise from the creeping root, and also by clusters of cells called bulbils filled with starch grains, which arise from a modification of the nodes.

The Charas, properly so called, are monœcious or diœ-

[1] Dr. Carpenter's 'Microscope.'

cious, more or less opaque and brittle, their many-jointed tubular stems bearing whorls of long slender awl-shaped branchlets. The fruit, accompanied by a cluster of short bracts or ramuli, is placed at intervals in the hollow side of the branchlets, one at each joint. In the bristly Chara the awl-shaped branchlets are simple, pointed at the

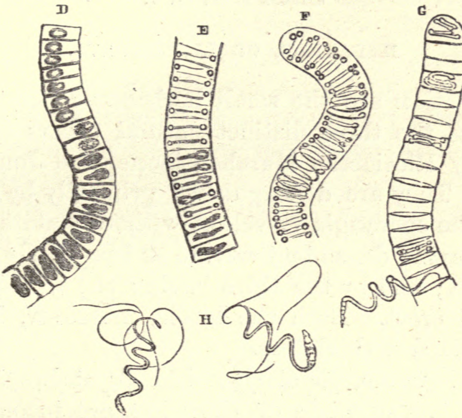


Fig. 42. Antheridia of Chara fragilis :—D, E, F, successive stages of formation of spermatozoids in the linear cells of the antheridial filaments ; G, escape of mature spermatozoids, which are shown detached at H.

extremity, and composed of about seven joints, with a whorl of from four to seven short bracts, and having fruit at each articulation. Many of the species of Characeæ are thickly incrusted with lime, and the whole order is exceedingly fetid.

SECTION VI.

HEPATICÆ, OR LIVERWORTS.

The Hepaticæ are the small herbaceous plants, which constitute the three distinct natural orders called respectively Ricciaceæ, Marchantiaceæ, and Jungermanniaceæ. They are distinguished primarily by the first having the sporangia valveless, without elaters; by the second having dependent valvate or irregularly bursting sporangia; and by the third having the sporangia valvate and erect. Both the latter, moreover, have the spores mixed with elaters.

The Ricciaceæ, popularly called Crystalworts, which form the lowest grade of Hepaticæ, are inconspicuous plants, growing in mud, or floating on water. They have spreading, horizontal fronds, of a delicate cellular structure and of indefinite form. Their fructification consists of valveless spherical sporangia, or spore sacs, imbedded in the frond; cells are formed within these sporangia, each of which cells is divided into four parts, which become spores, and, when ripe, the surface of the sporangia is fractured to give them egress. In some species there are many air passages in the cavities where the sporangia are produced. The under-surface of the frond is often beset with scales. The genus Riella differs from all the other genera in having an upright branchless stem with a distinct wing or limb forming a continuous spiral round it. In the male plant, the edge of the frond bears the antheridia containing spermatozoids; in the female plant the sporangia spring from the stem; they have a separate envelope, and the spores are echinate.

The Marchantiaceæ rank as higher forms of Hepaticæ. In the Marchantia polymorpha (figs. 43, 44), which may be taken as an illustration of the group, the structure of the horizontal frond is complicated, for, besides the colourless transparent skin, there are three distinct layers, the uppermost of which consists of cells filled with green matter, the lowermost (or base of the frond) being formed of close-set cells full of very solid matter, while between the two there is a cavity filled with air and loosely branching filaments, which spring from the base, and consist of green cells fixed end to end, as in fig. 44 B. The surface of the plant appears to be smooth and shining, but when magnified it is found to be marked with numerous narrow elevated green bands, crossing one another diagonally so as to mark out the surface into a number of small lozenge-shaped divisions (fig. 44 A). These elevated bands are merely the tops of very solid walls which descend perpendicularly to the base of the plant, consequently they divide the internal air chamber into a number of lozenge-shaped compartments, each of which communicates with the external atmosphere by means of chimneys opening in the centre of each compartment on the surface of the plant. These chimneys are so constructed of four or five superposed rings of cells (see fig. 44 B), that by the expansion and contraction of the cells of the lowermost ring, more or less air

Fig. 43. Marchantia polymorpha:—*a*, gemmiparous conceptacles; *b*, lobed receptacles bearing pistillidia.

can be admitted into the cavity below. This is a very beautiful instance of the contractile vital energy acting for the production of motion, its object being to supply air, so essential to the health of all plants. White filaments from the base at once fix the Marchantia to the earth, and supply it with food.

This is the youthful state of the Marchantia polymorpha, but after a time green points appear from under little reddish scales on the surface, and these are developed into stalks an inch or less in height, which terminate differently, some in lobed shields, others in spoked whorls, like a carriage wheel without

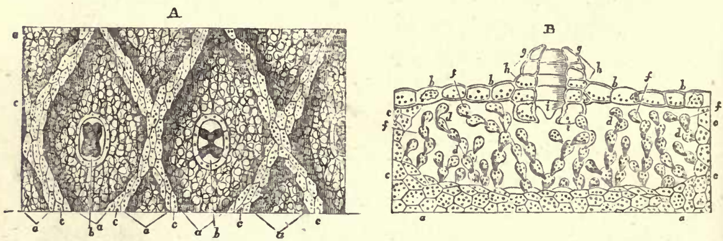


Fig. 44. Marchantia polymorpha:—A, portion of frond seen from above, showing lozenge-shaped divisions (*a*), with central stomata (*b*); B, vertical section, showing the layers of tissue, and one of the stomata (*g*).

the rim (fig. 43). The lobed shields are rather concave and covered with little elevations, in each of which there is a flask-shaped cavity with a long neck opening on the surface of the shield. In all of these hollows there is a mass of cells full of an amorphous substance, which is changed into spermatozoids, having the form of delicate spiral filaments, thicker at one end, and furnished with two cilia, with which they revolve in a spiral within their cell. At last they emerge from it, and come through the neck of the flask-shaped hollow to the surface of the shield.

In the companion female receptacles at an early age, certain objects called archegonia (fig. 45) are found to be concealed between membranes which connect the spokes of the whorl at their origin. These archegonia are shaped like flasks with long necks, and each has a germ cell in its interior, into which a canal leads down from the extremity of the neck. When this embryo or germ cell is fertilized by the spermatozoids, instead of producing a new plant resembling its parent, the embryo cell developes itself into a sporangium containing spores, which are isolated cells enclosed in firm yellow envelopes and elaters, or ovoidal cells, each containing a double spiral fibre coiled up in its interior. This fibre is so elastic, that when the surrounding pressure is withdrawn by the bursting of the sporangium at maturity, the spires suddenly extend themselves with such force as to tear open the cell membrane, and jerk forth the spores which may be adhering to their coils, and thus to assist in their dispersion. The spores, when they germinate, develope themselves into little collections of cells, which gradually assume the form of a flattened frond.[2] It is only when exposed to light and air that the Marchantias have regular fructification; in shady places they are reproduced by buds placed in open conceptacles, which are formed out of green globules that appear in different parts of the frond, and after a time split open at the summit and expand into

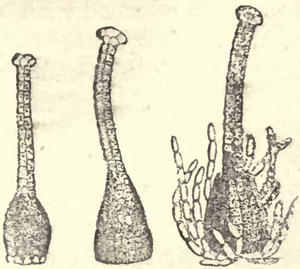


Fig. 45. Marchantia polymorpha:—archegonia.

Fig. 46. Elater and spores of Marchantia.

[2] Dr. Carpenter's 'Microscope.'

singularly graceful cups or baskets, whose edges are sharply and regularly indented so as to form a glistening fringe of teeth, while each tooth is adorned with a narrow fringe. When mature, the basket contains a number of little green round or oval discs raised on footstalks, and composed of two or more rows of cells. As soon as these objects, called gonidia, are ripe, they are detached from their stalks, and being washed out of their basket by the rain, they quickly grow on the moist earth around; sometimes they germinate before they leave their nest, and form irregular lobes on the parent plant. The Marchantia polymorpha, so admirably constructed, occurs in all temperate climates, and can bear considerable heat provided it has abundant moisture.

The Marchantiaceæ are divided into three groups, containing fifteen genera, which are distinguished from each other by the character of their fructification. They are minutely described in Mr. Berkeley's 'Cryptogamic Botany;' and are widely dispersed both in temperate and tropical countries, most of the genera being represented in Europe.

The Jungermanniaceæ, or Scale Mosses, in their lowest forms bear the same resemblance to Lichens that many of the other Liverworts do. These lichenoid forms are lobed, leaf-like masses, sometimes ribbed and sometimes not. There are forty genera of this group of plants, distributed amongst fifteen tribes, and exhibiting great variety of form and structure; but in external aspect they are so closely connected, that a graduated series may be traced from the flat-lobed frond to the higher forms of erect-stemmed foliaceous plants, approaching in size and structure to some of the smaller mosses.

The higher groups have a distinct upright stem with symmetrical leaves, which leaves, however, in the lower genera, are merely fleshy fronds without veins, of numerous and sometimes grotesque forms, while in the higher, they are generally oval, and disposed in spiral imbricated rows on each side of the stem and branches, every leaf overlapping part of that which is adjacent to it like a row of tiles. They are disposed after two distinctly different plans. In one, the leaves are arranged in a spiral, which turns from left to right; consequently, the anterior border of each inferior leaf is covered by the posterior border of that immediately above it. This constitutes the succubous group of frondose Jungermannieæ, which embraces five tribes. In the second case, the spiral of the leaves turns from right to left, and the anterior border of each inferior leaf covers the posterior border of that immediately above it. This constitutes the incubous group embracing three tribes of the frondose Jungermannieæ. Besides the imbricated spiral leaves, there are small leaves alternating with them, and applied directly on the stem between them.

The male fruit of the Scale Mosses consists of antheridia, which form ovoid masses of cells variously disposed; in each of these cells, there is a filiform spermatozoid coiled in a circle in active motion, which is maintained after leaving the cell. The female fruit consists of archegonia, containing embryo cells, which ultimately develope into sporangia; but the plants arrive at their full development before the archegonia appear. The same plant may produce more than one crop of these objects, which are occasionally abortive. The stalk of the sporangium is first surrounded by the sac of the archegonium, then by an involucre or circle of bracts, placed in a rosette of leaves. The sporangia contain cells which ultimately become spores mixed with long cells containing elaters, that is, elastic spiral filaments. When the fruit is ripe, the sporangia split into four equal parts, which form a cross on the top of their stems, and the elaters spring out of their cells, and disperse the spores.

The plants of this order are also reproduced by gonidia, but in such numerous genera and species the arrangement of the reproductive bodies and their minute details are exceedingly varied. They are chiefly distinguished by the insertion of the fruit, and the form of the different organs which surround it. They are pretty little plants, occasionally of a bright green, but oftener inclined to red, purple, and chocolate colour; a few are fragrant, but they are of no known utility. They are found in shady woods and moist situations, throughout all regions of the globe, but are most abundant in damp, tropical forests.

In all the families of the leafy Cryptogamia as well as in the Hepaticæ, antheridia exist; they differ much in form and structure, but they collectively agree in developing in the interior of delicately walled cells, an amorphous substance, coloured yellow by iodine, in place of which, at the epoch of maturation, spermatozoids appear, thick at one end and running to a very fine point at the other, and displaying several spiral convolutions. When rolled up like a watch-spring the motion is more or less rotary, but if it be coiled in the form of a corkscrew, the movement is at the same time advancing. The thin end of the filament always goes first both within the cell and after it comes out.[3] The whole structure of the Hepaticæ is full of objects of interest to the microscopic observer.

[3] 'Anatomy and Physiology of the Vegetable Cell,' by M. Hugo von Mohl.

SECTION VII.

MUSCI, OR MOSSES.

Mosses approach the higher classes of vegetable life in having roots, and a more or less upright stem or axis of growth. Like all other plants, they are chiefly formed of cellular tissue, yet, in the stems, there is an indication of a separation between the bark and pith by the intervention of a circle of elongated cells approaching to woody fibre, which passing into the branches and leaves form a kind of midrib, either extending to the extremity of the leaf or not. The delicate little leaves, which are arranged with great regularity, consist of a single or double layer of cells united by their flattened sides, and rarely exhibiting any epiderm or skin. Green is the prevailing colour in this order of beautiful little plants, but, when exposed to the sun and much moisture, they sometimes become red.

The urn-like vessels (fig. 47 B), containing the spores, are either terminal or lateral on the stem of the moss, and rise on a slender stalk from a rosette of narrow leaves possessing a skin perforated by stomata or breathing pores of simple structure. This is the ultimate result of fructification; for at a very early period, while the rosettes of narrow leaves are merely buds, they contain antheridia and archegonia, the latter or female organs being either inclosed in the same bud, or in different buds placed on the same or on different plants; but however that may be, the buds are invariably placed at the base of the leaves, close to the axis of the plant.

When a male bud is developed, the antheridia are found to be globular, ovoid, or elongated hyaline bodies, set in a cluster of hairs and paraphyses, or sterile cellular filaments. Fig. 48 represents the antheridia of Polytrichum commune, with the paraphyses and hairs, from the microscopic observations of Dr. Carpenter. The central antheridium is discharging its spermatozoids; the one on the right is empty, that on the left immature.

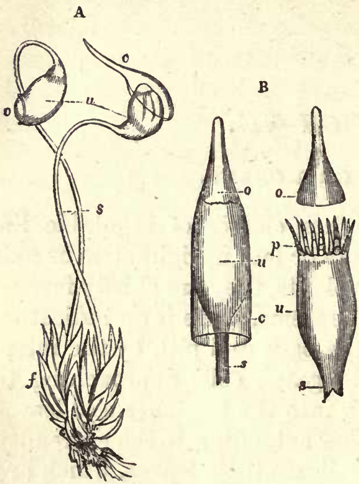


Fig. 47. A, plant of Funaria hygrometrica:—*f*, leaves; *u*, urns or capsules; *s*, seta or foot-stalk; *o*, operculum; *c*, calyptra. B, sporangia of Encalypta vulgaris:—*u*, urns; *o*, opercula; *c*, calyptra; *p*, peristome; *s*, seta.

The antheridia are filled with a mass of mucilage containing a multitude of cells, in each of which there is a spiral filament furnished with cilia, as in fig. 49. As soon as the filaments are mature, the cells open; the mobile filaments, or spermatozoids, are free, and come out through a pore in the antheridia, in multitudes like pollen out of an anther.

While the antheridia are in process of formation, the female buds expand and exhibit flask-shaped archegonia, similar to that in fig. 45, seated in a rosette of leaves. When this archegonium is fertilized by the spermatozoids, its internal germ cell is developed by cell division into a conical body elevated upon a stalk; and this at length tears across the walls of the flask-shaped archegonium by a circular fissure, carrying the higher part upwards as a calyptra or hood (fig. 47 *c*) upon its summit, and leaving the lower part to form a kind of collar round the base of the stalk.

Fig. 48. Polytrichum commune:—group of antheridia mixed with hairs and sterile filaments (paraphyses), the central one discharging its contents.

The urn-shaped organ or sporangium has a double wall, and in its centre a fusiform or deeply winged columella.

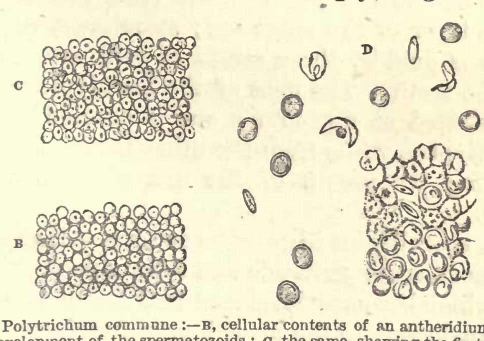


Fig. 49. Polytrichum commune:—B, cellular contents of an antheridium previously to the development of the spermatozoids; C, the same, showing the first appearance of the spermatozoids; D, the same, mature and discharging the spermatozoids.

Between these two there is a tissue of a most delicate texture, divided into spherical cells, each of which usually produces four unripe spores, which get an exterior coat when fertilised, and then it is that the stalk lengthens, and the flask-shaped archegonium is torn across.

The urns are closed by a lid or operculum of a flat, convex, or pointed form, which falls off when the spores are ripe to give them egress. The mouth of the urn in most of the mosses is surrounded by a deciduous annulus of two or three rows of elastic cells, which are supposed to aid in scattering the spores, for the mosses have no elaters. Although the separation of the lid may at once expose the spores, they may be covered with a membrane entire or toothed at the circumference, or there may be one or two rows of teeth surrounding the mouth of the urn like a fringe; these teeth form the peristome, and their number is always a multiple of 4, varying from 4 to 64 (see fig. 47 *p*). Sometimes they are divided half way down, sometimes they are prolonged into straight twisted hairs. The teeth arise from the thickening of the walls of two contiguous cells; when there are two rows of teeth, the outer row frequently arises from the layer of cells which line the outer wall of the urn, the inner row from the outermost layer of the spore sac; sometimes, when the peristome is double, three strata of cells are requisite to form the teeth. The urns of the Encalypta vulgaris are represented at fig. 47 B; one is covered with the hood or calyptra, while from the other the lid has fallen off, showing the mouth of the urn with its toothed peristome.

When a spore begins to grow, its outer coat is ruptured, its innermost coats protrude and form a projecting extremity, which becomes developed into a confervoid pro-embryo, analogous to the mycelium of fungi, but is distinguished by the chlorophyll contained in its cells. Many spores may concur or not in its formation; but the pro-embryo of each spore is capable of transforming one or more of the cells seated upon its various ramifications immediately into buds, which grow up into leafy stems, as the Funaria hygrometrica, so that here we have the peculiar condition of one spore giving rise to the development of a number of plants.[4] In process of growth each of these plants would produce antheridia and archegonia, and, by the process described, a full-grown Funaria hygrometrica with its urns and hoods, as represented in fig. 47 A, would be the result.

If the moss be annual or biennial it dies after bearing fruit; if perennial, two or more successive crops of archegonia are formed. The mode of fructification, therefore, resembles that of flowering plants, with this difference, that the fructification of the latter produces a young plant from each embryonic cell, while in mosses the fructification of one embryonic cell produces a sporangium or urn containing spores, that is, a multitude of reproductive bodies, which have no trace of cotyledons or axis.[5]

Mosses are also propagated by gemmæ or buds. They are produced in many situations, sometimes on distinct organs, sometimes on the tips of the leaves, or on rootlets which grow on various parts of the plants, and which in some of the mosses form a dense woolly or silky mass of a bright yellow or brown colour varying to purple. On the fibres of this mass, green cells appear, which are developed into reproductive buds. Almost every cell on the surface of a moss is capable of forming, by continued division, a cellular nodule, which falls off and gives rise to a germ which grows into a new plant. These nodules are generally situated at the extremity of the leaves, or on the leaves themselves, while pro-embryo fibres spring from the leaf cells of many mosses. M.

[4] M. von Mohl, on the 'Vegetable Cell.'
[5] Berkeley's 'Cryptogamic Botany.'

von Mohl observes that since the cells in the different parts of mosses are capable of being developed into a bud or embryonic confervoid structure producing a bud, it follows that in these plants, notwithstanding their rather complex structure, the subordination of the individual cell to the purposes of the whole plant is still but small; and even here individual life readily acquires the preponderance. This facility of reproduction possessed by the various individual parts of the plants, accounts for the extensive tracts over which mosses spread themselves; moreover, some are diœcious, and as the spores might not always be fertilized, the gemmæ ensure the continued existence of the species.

Mosses are divided into five principal groups, differing exceedingly in importance, and in comparative numbers. They are chiefly distinguished by the position of their fruit. The Pleurocarpi have their fruit lateral, whether on the stem or branches. They comprise thirteen tribes; many of them are found in the southern hemisphere, but a considerable number, especially of the Hypnei, Drepanophyllei, and Hookeriei, are European. The Cladocarpi are characterised by having their urns seated on the tops of very short lateral branches, and by their double axis of growth. The Acrocarpi are distinguished by their main stems ending in fruit. They comprise twenty-seven tribes, and embrace genera and species having a wide geographical range. In the Syncladei the branches of the plant are fasciculate; this group comprises the Sphagnums. The Schistocarpi are remarkable for their fruit splitting into valves, and consist of the tribe Andræaceæ. The various tribes depend on the structure of the urns and leaves, as well as on the natural habits of the plants. In this numerous class of plants only a few remarkable for peculiarity of structure can be mentioned.

The species of the acrocarpous tribe Phascei are exceedingly numerous, and contain the simplest of all mosses; they grow on newly turned-up soil, and are chiefly annual. Their leaves generally have nerves, and are bordered by large cells. The urns, which are either sessile, or upon a short stalk, have not a trace of peristome, and sometimes have a columella, sometimes not. The spores are large compared with those of other mosses.

The tribe Dicranei contains numerous species, some of which are the commonest of mosses in Europe. They are easily known by their single peristome of sixteen teeth divided half-way down. The leaves are extremely crisp and convolute, and the hood is spoon-shaped. The Leucobryum is remarkable for pallid leaves; it has three layers of cells, a narrow layer of green cells embedded in the centre of the leaf with a broader layer of colourless cells on each side, whose cell walls are perforated with large round openings, as in fig. 50 *b*. The mosses of this order live on sandstone rocks, shady banks, and trunks of trees. Fig. 50 shows the microscopic structure of the leaves of various mosses.

In the tribe Grimmiei we have frequently a sessile urn, with a single peristome, and a mitre-shaped hood. The leaves, which are dark green, have minute hexagonal perforated cells on their upper surface, and a white nerve projecting from their extremity.

In the tribe Polytrichei the mouth of the urn is mostly closed by a flat membrane and a hood rough with silky hairs. The leaves are sheathing at their base and spreading at their tips; except in a few cases they are rigid; and the nerve often exhibits lamelliform folds. The Polytrichum dendroides contains scalariform ducts, and starch granules.

The Bryei are of variable size, but a number of European species are among the finest of mosses, on account of their large leaves and beautiful double-toothed peristome, the great distinction of the group. The leaves are margined, toothed, and composed of a loose reticulation of large rhomboidal cells; in the genus Timmia they clasp the stem at the base and spread widely at the tip. There are thirty-three British species of the genus Bryum, many of which with their abundant urns are extremely ornamental.

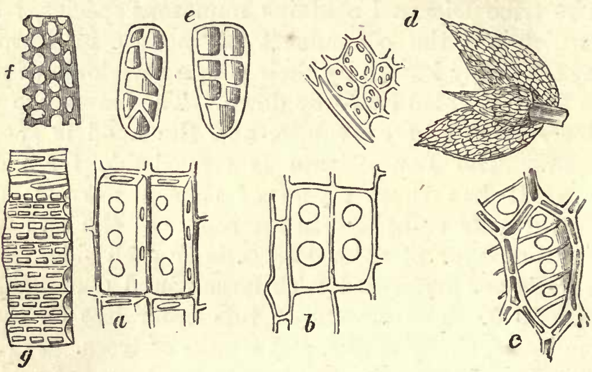


Fig. 50. Microscopic structure of leaves of mosses:—*a*, Octoblepharum albidum; *b*, Leucobryum glaucum; *c*, Sphagnum latifolium; *d*, Hypopterygium Smithianum; *e*, Eucamptodon perichætialis; *f*, Andræa subulata; *g*, Campylopus lamellinervis.

The tribe Splachnei contain many of the most singular and beautiful of the whole class of mosses. They have large-celled diaphanous leaves and a straight urn, with the spores radiating from the columella. The urn has a swelling at its base, often of greater dimensions than the urn itself. In the Splachnum vasculosum it is purple and very large, but nothing in comparison of that organ in S. luteum and rubrum, which are the pride of hyperborean Europe and America. The enormous size of the swelling, the variety of colouring, the singularity and elegance of form, and in some cases the unusual dimensions, make the species objects of great interest. The common S. ampullaceum, when growing in abundance on the shallow peaty banks of some mountain stream where cattle come to drink, is scarcely exceeded in beauty by any cryptogam. Species of this order are abundant in the two hemispheres, but the same species rarely occur in both. Their habits, too, are different, for while those in the north only grow on manure, those in the south grow on the trunks of fallen trees. Three genera occur in Great Britain. Gemmæ are found in the axils of the leaves in most species of this group.

The tribe of Schistostegei consists of but a single most elegant species. It inhabits shady caverns, which are sometimes lighted by a golden gleam from the refractions of the confervoid shoots of its mycelium-like pro-embryo, which is perennial, and produces a new crop year after year. The urn is subglobose without a peristome, and when young the spore cells radiate from the columella as in the Splachna. The leaves show various intermediate stages between a vertical and horizontal insertion, and are sometimes perfectly free, while at other times they are united. This moss is scarce, and confined to the northern hemisphere.

There are various genera of aquatic mosses in the different tribes, most of them floating plants. Of these are the pleurocarpous Fontinalei, which inhabit the northern hemisphere; their urn, with its double peristome of sixteen teeth, forms a beautiful microscopic object, on account of the latticed work in the inner row, and the cross bars on the outer teeth, which are united at their tips by two and two. The common species have sharp-angled triangular stems, and keeled leaves which clasp the stem at their base, and are sometimes cleft along the keel.

The syncladeous Sphagnei are aquatic bog mosses of a pale yellowish green colour. They form but one genus, Sphagnum, which consists of some eight or ten species and several varieties. The species of Sphagnum, or common bog moss, hold an important place in the economy of nature. They are floating mosses, entirely destitute of roots. The stalk of the full grown plant, like that of land mosses, is constructed of three kinds of cells; one forms the exterior or cortical layer, another forms the central pith or axial system, while the third, which is coloured and somewhat ligneous, comes between the other two. The leaves, which have their origin in the cortical layer while it is yet soft, consist of two kinds of cells, one kind being large, elongated, and colourless, and containing spiral fibres loosely coiled in their interior. The membranous walls of these cells have large round apertures by which their cavities have free communication; for certain animalcules, which sometimes live in the cells, have been seen to pass from one to the other. Between these colourless cells are some thick-walled, narrow, elongated green cells, which give the leaf firmness and colour. According to Mr. Wilson, the fascicles, or bundles of branches, are disposed round the stem in imbricated spirals, so that, for every complete spiral formed by five of these fascicles, there are eight spirals formed of twenty leaves, four leaves being inserted between each pair of fascicles. The fructification in all these floating mosses is immersed in the leaves of the stem, the antheridia being globose, and the spermatozoids having spiral motions, both within the cells of the antheridia and when they come out. The urns, which are the product of fructification, and are borne at the top of what appears to be a long footstalk, but is in reality a pedunculate vaginula, are globular, and their lids have been observed to be driven off when the spores are ripe, with such force as to give a distinctly audible report.

The common bog moss grows so rapidly that, rootless as it is, it soon covers a pool with its matted bundles of branches, and as in a few years it has no room to spread, the lower stems and branches decay, sink to the bottom, and begin to form a peat moss, while the upper parts grow on, so that new stems and branches are perpetually produced. Multitudes of spores no doubt germinate, and, in this way, the pool is filled up, and a peat moss is at length formed.

The Sphagnum moss has such a power of absorbing moisture from the atmosphere, that it forms and maintains the peat mosses and quagmires in the mountains which feed the streams at their feet. Mosses in general are almost as much indebted for moisture to the absorbing nature of their leaves as to their roots; but the loose, large celled, and perforated leaves of the Sphagnum suck up water like a sponge; even during the heat of summer, a quantity of water may be squeezed out of a handful of them. In fact the plant is a perfect hydraulic machine, for a small stem of it put into a glass of water with its drooping terminal branch hanging over the edge, acts like a syphon, and soon empties the glass, pouring the water out through its bending top. Though the peat from Sphagnum is often too spongy for fuel at present, yet that little moss now growing on our mountains will yield aniline, magenta, paraffin, and other illuminating gases to remote generations, although not in such quantities as the richer vegetation of the coal measures, the products of a warmer period.

Like all cryptogams the mosses are exceedingly variable and difficult to distinguish. Not only does the same species show great differences in size, but even in other respects the characters vary on account of climate, soil, and exposure.

Beyond that of becoming converted into peat, the uses of the moss family are not of any great importance. Brooms, mats, and other domestic articles are sometimes formed from Polytrichum, and in Lapland Sphagnum not only sometimes enters into the composition of bread, but is used in place of clothing for new-born babes.

SECTION VIII.

FILICES, OR FERNS.

Of all the spore-bearing families, the Ferns are the most universally known. They may easily be recognized by the coiling inwards of their young leaves in spring previous to expansion, and by the arrangement of the fruit on their undersides when expanded. The Ferns are exceedingly numerous both in genera and species, and vary from low herbaceous plants of an inch high, to trees with upright trunks forty or fifty feet or more in height, bearing a graceful coronet of leaves at their extremity. The tree ferns come to the utmost perfection in the warm, moist islands of the tropical oceans. Their boreal limit is about the thirty-seventh parallel of north latitude, but, on account of the vast extent of ocean in the southern hemisphere, they reach the fortieth or fiftieth parallel of south latitude, the more copious evaporation, and the consequently moister air and soil, being specially congenial to the fern tribe. For that reason a most luxuriant fern vegetation prevails in Juan Fernandez, Western Chili, and New Zealand. In the latter there are one hundred and twenty species, some of which are subarborescent, while others form tree ferns of considerable altitude. Shade is not absolutely requisite to ferns, for many of them grow luxuriantly when exposed to the sun, provided the soil be damp.

The range of the non-arborescent ferns is very extensive. According to Dr. J. D. Hooker, twenty-one species have been found in Fuegia and the Falkland

Islands, and one grows in matted tufts in Kerguelen's Land. In the north the Cytopteris fragilis has been found in the seventieth parallel of latitude at Minto Inlet, and both it and Polystichum Lonchitis have been gathered at Disco, on the west side of Greenland, and Aspidium fragrans on the eastern side.

On account of the extremes of heat and cold in North America there are only fifty species in all that enormous extent of country; while in Britain we are indebted to the humidity of our climate for a rich vegetation of thirty-six species, which adorn our woodlands, our valleys and mountains in wild profusion. One-half of our ferns are also native in the Himalaya mountains, where multitudes of British plants are indigenous. The fern floras of Great Britain and New Zealand are the richest in species of their respective latitudes, and have several species in common. The ferns of Tasmania are, with few exceptions, identical with those of New Zealand; and the occurrence of the rather common Australian and New Zealand Gymnogramma rutæfolia in the Pyrenees, and no where else in the whole world, so far as is known, is a remarkable fact in the distribution of plants.'[6]

Whatever the size of a fern may be, its spores (fig. 51 A) are microscopic. They are produced within the sporangium by cell division, and are therefore free and variously shaped. They consist of a grumous mass enclosed in a double coat; and when the spore begins to grow, it sends out from the cell wall of its inner coat a white tubular projection or root fibre (fig. 51 B), which passes through the cell wall of its outer coat. This root sucks up liquid till it expands the inner coat sufficiently to burst open the outer one, and then it begins to increase by the subdivision of its cells, till the primary

[6] Dr. J. D. Hooker on the 'Distribution of Ferns,' in Berkeley's 'Cryptogamic Botany.'

green leaf or marchantioid prothallus (fig. 51 D) is formed. This prothallus lies flat on the ground, and is furnished on the under-side with fibrous roots to fix it, and supply it with food.

Two sets of organs are subsequently developed on the under-side of this prothallus; one of these is a stalked cell called an antheridium, and is situated near the roots; the other is an archegonium containing a germ cell, which is sunk in the cellular tissue. In each of the

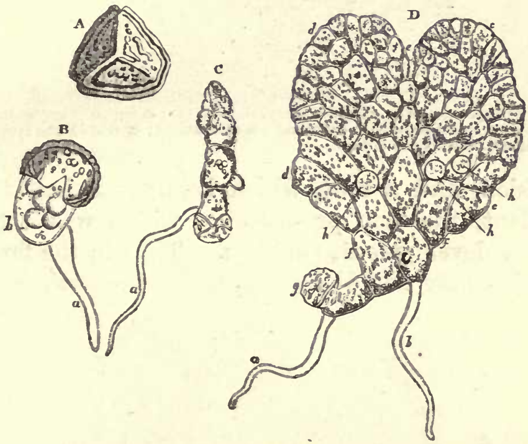


Fig. 51. Development of spores of Pteris serrulata:—A, spore; B, C, early stages of development; D, the prothallus with radical fibres (*a*, *b*) and antheridia (*h*, *h*).

antheridia, which are numerous, a cell is formed, which becomes filled with a mass of mucilage mixed with a number of free cells, containing a flat ribbon-shaped filament, or spermatozoid, coiled in a spiral manner, which, as soon as set free by the rupture of the cell, revolves rapidly by means of several long cilia placed close to the large end. Fig. 52 shows the globular antheridium and the spermatozoids of Pteris serrulata. The archegonia are fewer in number, and contain the germ cell, represented in fig. 53, as viewed from above, and sidewise; it is placed at a little distance from the antheridia, and after being fertilized by the active filaments or spermatozoids, and matured, it contains the primordial cell of the young fern, which soon sends forth leaves rolled up and curled inwards previous to

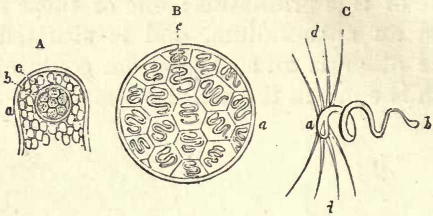


Fig. 52. Antheridium and Spermatozoids of Pteris serrulata:—A, projection of one of the cells of the prothallus showing the antheridial cell (*b*); B, antheridium fully developed, containing sperm-cells, each enclosing a spermatozoid; C, one of the spermatozoids magnified, showing the cilia.

expansion, and a root, which being sufficient to feed the plant, the flat pro-embryo, which was the first stage of development, perishes. Thus in the family of ferns there are two distinct periods of growth, and one

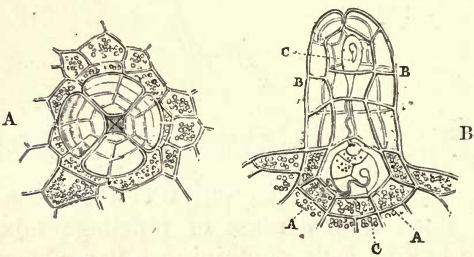


Fig. 53. Archegonium of Pteris serrulata:—A, as seen from above; B, side view, showing at A the cavity containing the germ cell; at B, the walls of the archegonium made up of four layers of cells; and at C, the spermatozoids within the cavity.

only of fertilization. In flowering plants, fertilization and its products are the final result of vegetation, and the maturation of the fructification is frequently followed by death. In the ferns, on the contrary, fertilization precedes the development of the plant, which, if perennial, continues to bear fertilized fruit year after year.

It is evident that there is an essential difference between the archegonium of the Marchantia, and that of the ferns. The archegonium of the Marchantia merely produces a sporangium, while that of the ferns produces a new plant, and is therefore, in some sense, analogous to the seed of one of the higher vascular plants, though there is no affinity between the two.

The roots of ferns, like those of forest trees, are delicate fibres, which descend either from a woody stem called a rhizome, from *rhiza*, a root, or from a caudex, so named from the Latin, *caudex*, a trunk. Thus the stems of ferns are of two distinct types. The rhizome generally grows horizontally, and creeps along the surface of the soil or rock, or tree trunk to which it is affixed, but it is sometimes subterranean. In this, the growing point is in advance of the fronds, which appear at intervals along the exposed side or sides, and after they have reached maturity drop off, leaving a clean scar or cicatrix. The caudex varies from the size of a small wire-like thread to the size of a tree trunk. It is sometimes elongated, as in the superfine wiry thread-like stems of Hymenophyllum, the scandent ivy-like rooting stems of Stenochlæna, and the subterranean, horizontal, widely-creeping stems of Pteris aquilina, all of which develop single fronds at intervals, but fronds which adhere permanently to the stem, and which do not fall off, leaving a scar, as do the fronds borne by the rhizome. The more frequent form of caudex, however, is that of a short stocky stem producing fronds on all sides from its apex: very frequently this is a globose or oblong mass growing erect, yet scarcely reaching above the surface of the soil; but sometimes it is more lengthened, showing a more or less elevated stem, or turning sideways, and taking a decumbent position, the young fronds, however, always rising from its apex. It is on the latter plan, by a continuous erect and upward growth, that the trunks of tree ferns, which rise sometimes sixty or eighty feet high, are formed. The common Lady Fern, Athyrium Filix-fœmina, furnishes an example of the ordinary herbaceous caudex; as also does the Male Fern, Lastrea Filix-mas. In the Hart's-tongue, or Scolopendrium, the caudex is generally compact, and increases by the formation of new crowns or centres of growth around the older one, till the whole becomes an almost spherical mass of considerable size.

The stipes or leaf-stalk of a fern is often of considerable length, and in its upper part, called the rachis, which bears the leafy portion, is commonly more or less branched, as well as furrowed on its upper surface. The fronds, or parts analogous to leaves, are sometimes simple, as in the Hart's-tongue, the rachis of which has a symmetrical limb or wing on each side, so as to form a long, even-margined, narrow, tongue-shaped frond. If the limb on each side of the rachis be deeply divided, as in the Polypodium vulgare, the frond is said to be wing-cleft, or pinnatifid, and the divisions are called segments or lobes. In most ferns, however, the frond is once, twice, or three times winged or pinnate, and in such cases the first divisions are called pinnæ, and the secondary or subsequent ones when present, pinnulæ or pinnules. The leafy portion, whether simple, pinnatifid, or pinnate, is always traversed by veins arranged on some definite plan, a most important circumstance, since the sori or fructification of the ferns is always produced in connection with the veins.

The fertile fronds, in certain groups, differ in form from the sterile, generally by the greater or less contraction of their parts. In most ferns the full-grown fronds are flat, that is, with all their parts lying in one plane; but, during their vernation, that is, when they first rise from the stem, they are circinate or curled inwards, like a crosier.

When a fern acquires a considerable stem, as in Tree Ferns, it consists of a central or medullary part, consisting of cellular tissue, and an external or cortical portion, formed of the consolidated bases of the fronds, in which may be seen, on cutting a section of a trunk, an irregular zone, formed of fibro-vascular bundles, scalariform ducts, and woody fibre. Prolongations from this zone pass into the leaf-stalks, and thence into the midrib of the leaf, whence they spread into its lateral branches, and ultimately appear in the leafy parts in the form of veins. It is the arrangement of these bundles of coloured woody tissue in the cellular tissue of the leaf-stalks of the herbaceous ferns, which give rise to those peculiar figures on their transverse sections, such as a star, the letter T, and the heraldic spread eagle, from which latter the common Brake Fern (Pteris) takes its botanical specific name of aquilina. Fig. 54 shows an oblique section of the footstalk of a fern leaf with its bundles of scalariform ducts, as determined by Dr. Carpenter's microscopic observations.

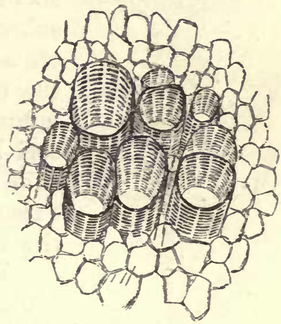


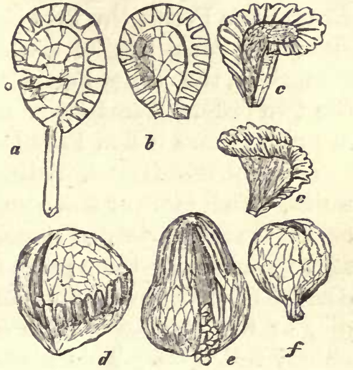
Fig. 54. Section of footstalk of Fern frond showing scalariform ducts.

The fructification of the ferns is arranged with the most perfect symmetry, usually on the under surface of the leaf, but sometimes at the margin, and assuming a great variety of forms and positions. It consists of sori, that is, groups of nearly globular spore cases or sporangia, sometimes sessile on the frond, sometimes with a footstalk. They are always situated on a vein or its branches, or at the extremity of the veins on the margin of the frond. In fact the sporangia originate in the cellular tissue immediately in contact with a vein, beneath the epidermis or skin of the leaf, which is forced up as the sporangia increase in size, in the form of a whitish membrane, which constitutes the indusium, or protecting cover of the sori. While the fruit is advancing to maturity, the indusium separates partly or wholly from the surrounding skin or epiderm, and subsequently either shrivels or falls off altogether. In some few species the opening is in the centre of the indusium, and then it surrounds the sori like a cup; in other ferns, the skin from both surfaces of the leaf extends beyond the margin, includes the sori between it, and fulfils the office of an indusium.

Fig. 55. Pinnule of Polypodium bearing sori.

The sori, as already noted, take a variety of forms, and are variously situated. Some are round and dot-like, some are oblong and straight, some are hippocrepiform or horse-shoe-shaped, while some are continuous in a line-like band. The indusium, when present, takes more or less exactly the form of the sorus. These peculiarities are so well marked that they are taken advantage of in the discrimination of genera.

The sporangia or spore-cases are for the most part of globular form, and are nearly or quite surrounded by a strong elastic ring, which in some cases is continued so as to form a stalk. When the spores are ripe, this ring, by its elastic force, tears open the sporangia, and gives free egress to their contents. The ring assumes various forms. In one large group it passes vertically up the back of the sporangium, and is continued to a point called the stoma, where the horizontal bursting takes place. This form is seen in fig. 56, *a*, *b*. In other groups it is, though vertical, somewhat oblique, as in fig. 56 *c*. Sometimes, though more rarely, it is transverse and complete; in which case the rupture is vertical, as in fig. 56 *d*. In a few cases it is apical, fig. 56 *e*; and in a few others it is obsolete, fig. 56 *f*. These are the true Ferns. In one or two small groups, sometimes called Pseudo-Ferns, the ring is altogether wanting.



ig. 56. Sporangia of Polypodiaceous Ferns:—*a*, *b*, Polypodiaceæ; *c*, Cyatheineæ; *d*. Gleicheninеæ; *e*, Schizæineæ; *f*, Osmundineæ.

The systematic arrangement of the Ferns is chiefly founded on peculiarities of the sori and sporangia, characters which are quite intelligible by the aid of a good magnifying lens, these spore-cases being very pretty opaque objects under the microscope. Thus some of the primary divisions are founded on the presence or absence of the ring or annulus on the spore-case. Another series of divisions are founded mainly on the nature of the ring in those cases when it is present; and, for the rest, the form and position of the sori come in as discriminating characters. In this way the main groups are marked out, but, in the case of the genera, still further recourse is had to the sori and its covering, and by some modern authors supplementary characters derived from the venation are brought into use. The following is the arrangement adopted by Mr. Moore,[7] and

[7] 'Index Filicum,' by Thomas Moore, F.L.S.

which agrees in its general features with that of most modern observers.

The two leading groups are the *Annulate* and the *Exannulate* Ferns, the first being much the larger division, and consisting of the order Polypodiaceæ, which comprises the True Ferns, while the second includes the two orders Marattiaceæ and Ophioglossaceæ, which are some times called Pseudo-Ferns.

The Polypodiaceæ, distinguished by the ring or annulus, which more or less completely girts the sporangia, offer so much variety of structure that it becomes necessary to subdivide them; and for this purpose characters derived from the form, number, or position of the sporangia, or the structure or development of the ring, are chiefly relied on. This gives several groups, *e.g.* Polypodineæ, the most comprehensive of all, including some ten or twelve minor groups, in which the sporangia are almost equally convex, and have a vertical and nearly complete ring, and in which the dehiscence is transverse at a part called the stoma, where the striæ of the ring are elongated, and apparently weaker; Cyatheineæ, in which the spore-cases are sessile or nearly so, seated on an elevated receptacle, with the nearly complete ring more or less obliquely vertical, that is, vertical below, curving laterally towards the top, and the dehiscence transverse; Matonineæ, a single species only, in which the sporangia are sessile, bursting horizontally, not vertically, the ring being broad, suboblique, and nearly complete, and the dorsal sori oligocarpous, covered by umbonato-hemispherical indusia, affixed by a central stalk; Gleicheninineæ, with the ring complete, transverse, either truly or obliquely horizontal, the sporangia globose-pyriform, forming oligocarpous sori, *i.e.* sori consisting of but few spore-cases (two or four to ten or twelve), situated at the back of the frond, sessile or nearly so, and bursting vertically, the fronds, moreover, being rigid and opaque, and usually dichotomously-branched; Trichomanineæ, with the ring resembling that of the Gleichenineæ, but the sporangia lenticular, numerous, clustered on an exserted receptacle, which is a prolongation of the vein beyond the ordinary margin of the frond, so that the sori become extrorse marginal, or projected outwards as well as opening outwardly, while the fronds are pellucid-membranaceous; Schizæineæ, with the ring horizontal or transverse, situated quite at the apex of the oval sporangia, which is, in consequence, said to be radiate-striate at the apex; Ceratopteridineæ, one or two aquatic species, the sporangia sometimes furnished with a very rudimentary ring, reduced, as in Osmundineæ, to a few parallel striæ, sometimes furnished with a very broad and more lengthened ring; and Osmundineæ, with the spore-cases two-valved, bursting vertically at the apex, the ring very rudimentary, reduced to a few parallel vertical striæ on one side near the apex. In all but the last of these groups, the sporangia are not valvate, and consequently, when they open for the liberation of the spores, they burst partially or irregularly; but in the Osmundineæ they split at the top in two equal divisions.[8]

A large portion of the Polypodineæ are either tropical or subtropical. The genus Polypodium itself is one of the most extensive and diversified genera of the group. It is chiefly distributed over the tropical regions of the western hemisphere, but four species are indigenous in Britain, and of these the Polypodium vulgare, or Common Polypody, is abundant about the trunks of moss-grown trees, on banks, rocks, and old thatched roofs. The young fronds appear in May, and rise from five or six to twelve or eighteen inches in height. They are lanceolate, deeply pinnatifid, with obtuse, linear, lanceolate, indistinctly serrated segments. The genus is

[8] Moore, in 'Treasury of Botany.'

distinguished by its naked globular sori, which in this species are regularly disposed in a line on each side of the mid vein, half way between it and the margin of the leaf. When young, they are of a yellow or bright orange colour, which changes to brown when they are ripe. The rhizome, which branches in all directions, is at first clothed with a skin densely covered with yellowish brown membranaceous lanceolate scales, which at length fall or become obliterated, leaving the surface nearly smooth. The Polypodium vulgare has many varieties, several of which are well marked, especially that called cambricum, which is twice pinnatifid. The plant is common in temperate climates.

The Aspidieæ form an extensive and widely distributed group, embracing several of our common British species. One of these is the genus Lastrea, which has, for the most part, lanceolate fronds, bipinnate or tripinnate in division, with linear lanceolate, and usually pinnatifid pinnæ. The sori are nearly circular, seated upon the back of the veins, and covered by a reniform indusium, which is attached by its sinus. In Lastrea Filix-mas (fig. 57), one of our commonest ferns, the fronds spring up in a rather spreading mass, from the extremity of a long scaly caudex, and often present a vase-like tuft hollow in the centre. The rachis, leafy through a third or a fourth of its length, is more or less clothed with thin membranaceous scales, of a pale often brownish-golden hue, a peculiarity common to the other Lastreæ. Lastrea Thelypteris, the Marsh Fern, however, has them not, and differs also from most of its congeners in having its sori submarginal. Its rhizome has a widely creeping habit of growth. The Lastrea æmula has globular glands, sessile over the whole under-surface of the fronds, which

Fig. 57. Pinnule of Lastrea Filix-mas with sori.

secrete a perfume like new-made hay. From a similar cause, Lastrea rigida was botanically known as Polypodium fragrans. This coumarine odour is possessed by several other ferns, notably by Cheilanthes odora.

The Oleandra, which is a foreign genus, has simple fronds articulated near to the rhizome, and its sori are placed on the tips of the parallel veinlets. The Oleandra neriiformis, which grows on open spots, has an erect rhizome, and assumes quite a shrubby habit, rising to from four to six feet, and bearing at intervals whorls of fronds.

In the genus Polystichum, the fronds spring in tufts from a short slow-growing caudex. They are rigid, linear or lanceolate, and either pinnate, bipinnate, or tripinnate. The upper terminations of the fronds are sharp and spinous, while the pinnæ are auriculate at their base above, and oblique below. Circular sori are seated on the anterior branches of the parallel veins, and these are covered by circular indusia, opening all round and remaining attached by a short central stalk. The free venation and this peculiar form of the sorus and indusium are the distinguishing characters of the genus. Fig. 58 shows a sorus and indusium of Polystichum or Aspidium, which differ only in venation. One of the spinous, serrated pinnæ of the Holly fern, Polystichum Lonchitis, is represented in fig. 59; it is auriculate at its base above and oblique below, with its sori disposed in regular series on each side the mid-vein; these often become confluent at maturity. This beautiful Alpine fern, which is of a deep glossy green, has linear lanceolate, and simply pinnate fronds. The

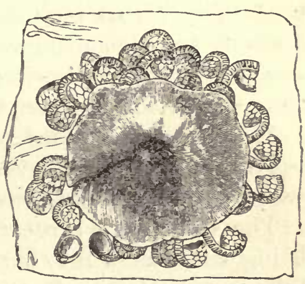


Fig. 58. Sorus and Indusium of Polystichum or Aspidium.

pinnæ are short, arranged alternately and obliquely on the rachis, and extend nearly to its base, which is rather densely clothed with reddish-brown chaffy scales. The other British ferns of this genus are bipinnate. P. aculeatum is rigid, but P. angulare is lax, and drooping. One of its varieties, named proliferum, is abundantly viviparous, producing small bulbils about the bases of the lower pinnæ and pinnules, which readily reproduce the plant.

Fig. 59. Pinna of Polystichum Lonchitis.

All the preceding genera, from Lastrea inclusive, belong to the Aspidieæ, an enormous tribe, abounding in species, and almost conterminous with the old genus Aspidium.

The Nephrolepis tuberosa and other species bear subtranslucent tubers on the rhizome. They are subterranean, ovoid, an inch and a half long, and filled with a nearly translucent mucus. The tubers have a circle of vascular bundles forming a sort of balloon, proceeding from a common base below, and converging to the apex.[9]

Most of the species are tropical, but Lastrea and Polystichum include several European species, some of which are extremely variable.

The Onoclea is a remarkable genus from the pinnæ being contracted into berry-like globes. Onoclea sensibilis is a handsome free-growing American species and appears to have been named sensibilis, from the particularly rapid withering of the fronds after being gathered.

The genus Cystopteris, which has species in both hemispheres, is the type of the Cystopterideæ, a small group which approaches Aspidieæ through Nephrolepis and

[9] Berkeley's 'Cryptogamic Botany.'

Acrophorus. The British species of Cystopteris are small, fragile ferns, growing on walls and rocks in Alpine and Subalpine districts. Their fronds are for the most part erect, lanceolate or deltoid, and bipinnate or tripinnate. They are generically distinguished by having each round sorus covered by a hood-shaped indusium, which is hollow and attached by its base, and opens towards the apex of the segment, its free margin being elongated and fringed; in this respect it bears some resemblance to Woodsia, in which, however, the indusium projects from beneath the spore-cases equally on all sides, becoming incurved in a cup-like form. The Cystopteris fragilis, or Brittle Bladder fern, flourishes in most shady mountainous and rocky districts, but is also found in the lowlands. It has a decumbent caudex, which extends slowly, branching and forming new crowns around the old one, often to the number of several during the summer and autumn. The fronds rise in tufts from these crowns in April, rapidly attain their maturity, and die away in succession as their place is supplied by others, till the frost comes and destroys them all. The tufts vary in height from two or three inches to a foot or more. The fronds differ much in form and division even in the same crown, but both they and the pinnæ are usually lanceolate; the pinnules are ovoid or oblong, always deeply pinnatifid, and having the segments sharply toothed or serrated.

The Dicksonia group, Dicksonieæ, contains some of the finest tree ferns. The Dicksonia antarctica sometimes attains a uniform girth of twelve feet throughout its height of forty feet. In the stem of this fern, the vascular bundles are symmetrically disposed round the axis so as to form a closed cylinder. The New Zealanders slice the fibrous coating of the trunk, and use it for constructing their houses. D. squarrosa reaches the farthest south of the tree ferns. The D. lanata sometimes forms a distinct stem but not always, for tree ferns vary much with regard to the dimensions and elevation of their stem. The caudex of Cibotium Barometz is covered with long tawny hair; each has its own peculiarity. The species of Dicksonieæ belong principally to the tropics and southern isles. The ferns of this group have globose sori, which are submarginal, seated at the tip of a vein or veinlet. The indusium is lateral, persistent, and bivalved; the lower valve is formed by the true indusium, the upper by the altered tooth of the frond folded back. In Dennstædtia the indusium is cup-shaped, and curiously deflexed; while in Deparia, another section of the group, the cup-shaped indusium containing the sorus is extrorse marginal, as shown in fig. 60.

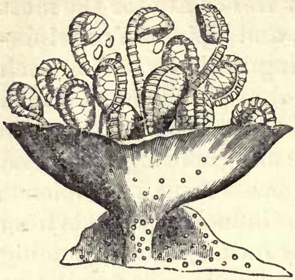


Fig. 60. Sorus and cup-shaped indusium of Deparia prolifera.

The group Peranemeæ, or Woodsieæ, is represented in the British Flora by two species of Woodsia, which are amongst the rarest and most curious of our ferns, and inhabit the crevices in our highest mountain tops. Their tufts of fronds are not more than two or three inches high, sometimes less, and the fronds themselves are lanceolate, and pinnate; in Woodsia ilvensis they have oblong and usually opposite deeply lobed pinnæ, whose under-surface is clothed more or less with jointed hairs and long attenuated scales. The sori in both species are circular, and situated at the extremity of the lateral veins. When young they are covered with an indusium, which opens at the centre, and forms a cup round the sori; afterwards it is divided into numerous jointed and usually incurved threads.

The Davallieæ are mostly tropical and subtropical ferns. Their sori are submarginal, placed upon the tip of a vein or veinlet, and enclosed within a tubular indusium, which is either short and approaching to cup-shaped, or more or less elongated. In this group the stem assumes the form of a rhizome, often creeping extensively, and the fronds are articuled, falling off with a clean scar when they perish. Davallia canariensis is cultivated in most conservatories, and is known as the Hare's-foot fern, from the stoutish scaly rhizomes resembling the foot of a hare.

Somewhat allied to these are the Lindsæeæ, including Lindsæa and its allies; these have linear marginal sori, for the most part continuous, but sometimes regularly interrupted, in which state they approach some of the Davallieæ, Microlepia to wit. The indusium opens towards the margin of the frond, and the sori more or less connect the tips of the veins and veinlets.

The group of Asplenieæ is a very comprehensive one, including, besides the extensive typical genus Asplenium, the cognate subdivisions of Diplazieæ and Scolopendrieæ. The latter is represented by Scolopendrium vulgare, the Hart's-tongue fern, in which the sori are linear, and situated in pairs on two parallel veins, so closely approximate that, though really double, they seem to form but one straight line; they are not covered with one indusium splitting down the middle, but each has its own indusium opening in opposite directions. On the under-surface of the long strap-shaped entire fronds of the common Hart's-tongue, which is a

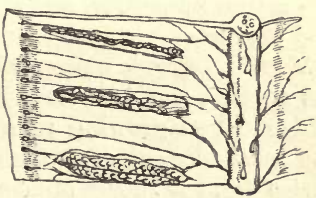


Fig. 61. Scolopendrium vulgare.

type of the genus, the double sori with their opposite indusia form parallel equidistant straight lines, diverging on each side from the mid-vein of the frond, as in fig. 61. The fronds are cordate at the base; sometimes they are forked, and occasionally crisped and wavy, and the leaf-stem is shaggy with narrow membranaceous scales. The caudex is very compact and deep-rooted; it does not much elongate, but increases slowly by the formation of new crowns round the older, attaining considerable bulk. From this the fronds rise in circular tufts to the height of a foot or more, and attain from two to three feet, in favourable shady localities. At first the tufts are straight, but ultimately they radiate and bend outwards. This plant is exceedingly variable; hundreds of varieties have been found or raised in Great Britain. Though twin sori are characteristic of the Scolopendrieæ, they diverge somewhat in Camptosorus, a North American genus, sometimes called the Walking fern, from its habit of throwing forward a bud on a thread-like prolongation of the point of the frond, which becomes established as a new growing centre, and thus carries the plant onwards.

The group of ferns called Diplazieæ, another section of the Asplenieæ, typified by the genus Diplazium, is altogether tropical. The sori are bilateral or double, but placed back to back on the vein, exactly the opposite of Scolopendrieæ; so that the indusia, instead of opening face to face, open in opposite directions. The species are rather numerous, and embrace much variety of form and character.

To the Asplenieæ proper belongs one of our commonest species, the Athyrium Filix-fœmina, or Lady Fern, which, when growing in moist shady places, is one of the most elegant of British ferns. Its bipinnate frond varies from a broad almost ovate outline to a linear lanceolate form. The numerous fronds often spring from the caudex in a vase-like arrangement, to the height of four or five feet, those in the centre nearly erect, but the outer ones, drooping around in all directions, forming a tuft of lovely feathery foliage. The sori have commonly a semilunar outline, as in fig. 62; but they are occasionally so much curved as to acquire a horse-shoe form, and more rarely they are linear, and they become at length reflected by the growth of the sporangia. In some varieties they are distinct, in others so close as to become eventually confluent and completely cover the surface. The Filix-fœmina is distinguished by the linear junction of the indusium with the frond. It is one of the most variable of all the known ferns, and is remarkably prolific, so that new forms may be raised from the spores. There are a very large number found in this country.

Fig. 62. Athyrium Filix-fœmina.

All the Asplenieæ have linear sori attached to the side of the vein, so that they are said to be lateral. The indusium opens on its inward side, and is sometimes ciliated. There are many tropical ferns of this group, but the genus Asplenium, which has representatives in all parts of the world, yields eight or nine species in Great Britain.

The Asplenium Ruta-muraria, or Wall Rue, is an indigenous mountain plant growing in tufts six or eight inches high in the clefts of the rocks, but has diminished much in size in migrating to the plains, where it is found on old brick walls and outhouses. The fronds are deltoid and bipinnate, the pinnules are wedge-shaped and notched, or toothed, on their upper margin; their colour is deep green, but in

Fig. 63. Asplenium Ruta-muraria.

exposed situations they are always covered with a glaucous secretion. The veins diverge from the footstalk at the base of the pinnules, branch out above, and extend to the teeth or serratures, as in fig. 63. The sori, which are produced on the inner side of the veins, are linear, elongated, and eventually become confluent, covering the whole under-surface of each fertile pinnule. The indusium, which is only traceable in the earlier condition of the fructification, is white, and the free inner margin is somewhat jagged.

Changes as remarkable take place in the sori of the Asplenium lanceolatum. At first, when the sori are covered by their white indusium, they are oblong, but they become circular as they enlarge, and eventually often confluent, so as to form a line round the whole under-margin of the sharply toothed pinnule. This fern, which is indigenous in the Atlantic islands, and is found in the Channel Islands, as well as in the maritime counties of England and Wales, grows in the crevices of rocks and old walls, or clothes the sides of wells and deserted mines. It belongs to the section which has a mid-vein.

The genus Ceterach apparently belongs to that section of ferns which have a vertical ring, and no indusium; but its affinities ally it closely with Asplenium. Its want of an indusium is supplied, perhaps occasioned, by the abundance of chaffy scales which cover the back of the fronds. The lateral veins are alternate and irregularly branched, with the branches anastomosing towards the margin. The sori are oblong or linear, attached to the upper side of the anterior branches except the last, which is on the opposite side of the lower branch. The British species, Ceterach officinarum, or Scaly Spleenwort (fig. 64), has deeply pinnatifid, lanceolate fronds, with oblong, obtuse, alternate segments, and linear sori. The whole of the under-surface is densely clothed with brown, pointed, imbricated scales, finely serrated at their margins, the outermost of which extend beyond the edges of the segments. They completely cover the sori, and at first hide them entirely from view. On the unexpanded fronds, the scales are white and silvery. 'This plant has an obscure indusium, only perceptible at an early stage of fructification, and subsequently as a nearly erect membrane, attached to the back of the vein. It is rendered unnecessary by the arrangement of the scales, which are disposed in regular series along each side of the veins and veinlets, pointing outwards, and concealing the sori with their broad bases, which completely overlap them in their immature condition.'


Fig. 64. Ceterach officinarum.

It is well known that the seeds of tropical plants have been brought to the western coasts of Scotland and Ireland by the great Atlantic currents; it might therefore be expected, that the spores of Cryptogams brought to our shores by the same means, and finding a congenial climate, should become naturalized, as appears to have been the case in ancient times, with regard to the Ceterach and Asplenium marinum, from their migrations, as traced by Mr. Johnson. 'The countries bordering on the basin of the Mediterranean and the islands and eastern shores of the North Atlantic appear to have been the original stations of this remarkable fern. In the British islands its distribution is too partial to admit of its being regarded as strictly indigenous, though probably naturalized here at a period little subsequent to the arrival of Asplenium marinum. It occurs here on limestone-rocks, but more frequently on old walls and ruins, rooted deeply in the decaying mortar, and often accompanying Asplenium Ruta-muraria and Asplenium Trichomanes. Like other natural importations from the south, it is found most abundantly on the western maritime counties that receive the more direct flow of the tide, and has progressed slowly towards the northern and central parts of the kingdom. In Scotland it has not yet traversed beyond Perth, and is still regarded as a rare species; while in Ireland its copious distribution seems to indicate an earlier arrival.'

The group Vittarieæ, consisting mainly of Vittaria and Tæniopsis, is essentially equatorial or sub-equatorial. The plants have narrow ribbon-like fronds, with naked sori immersed in the very margin of the frond, in a more or less sunken furrow, there being no indusium.

The Blechnum Spicant, which may be taken as a type of the Lomarieæ, is a very ornamental fern, with its dark green, linear-lanceolate fronds, of two forms; the fertile ones erect, pectinate, pinnate, with distinct narrow linear and acute pinnæ, while the barren ones are smooth, spreading, and pinnatifid, with broad linear, blunt, approximate lobes. The rachis is generally smooth, and of a dark purple hue, its leafless portion being shaggy with membranaceous scales. The barren fronds lie on the ground in the winter, while the fertile ones are erect, bear fruit from May to October, and wither when they have shed their spores. In the fertile fronds the lateral veins are alternate, and extend obliquely upwards, about half way towards the margin of the lobe, when, by a sudden turn, each runs parallel to the mid-vein, and anastomoses with the one above it, thus forming an apparently longitudinal vein on which the sorus is placed, so as to form a line on each side of the mid-vein; this is covered with a continuous indusium like a hem, which opens on the interior side (fig. 65). In the barren fronds the veins do not anastomose at the margins of the lobe. This species is common in almost every part of Great Britain, and extends on the Continent from Swedish Lapland to the borders of the Mediterranean.

The species of Lomaria are marked by having the fertile fronds contracted, so that the sorus is quite marginal; but there are many species of Blechnum in which the elongated sorus, placed parallel to the midrib, is quite distant from the margin, much more so than in Blechnum Spicant.

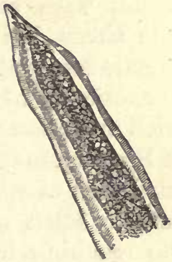


Fig. 65. Blechnum Spicant.

The genus Pteris is the type of another group, the Pterideæ, in which the sori form a continuous marginal line covered by the attenuated edge of the frond folded over it, and forming an indusium. This is the structure in most of the species of Pteris, a large family abounding in the tropics, and very widely distributed in almost every part of the globe. In the Pteris aquilina, or Bracken (fig. 66), however, in which the lateral veins of the leaf are divided two or three times before they reach the margin, and the extremities of the branches anastomose and form a vein at the exterior or extreme margin of the leaf, the sporangia are produced on the upper-surface of the marginal vein, and are enclosed by an extension of the skin from both surfaces of the leaf; so that the fructification, which is folded back on the under-surface of the leaf, is in the earliest stage of its development enclosed between two thin membranes, both of which have their margins ciliated with jointed hairs, while, under the microscope, their cellular structure will be found to differ in accordance with that of the

Fig. 66. Pteris aquilina.

upper and under epidermis, from which they are individually extensions. This fern is so universal in Britain, as to exclude in some places almost every other kind of vegetation, and is so well known, that it may appear superfluous to mention that the fronds are deltoid, with an elongated, stem-like petiole two or three times divided, the primary pinnæ opposite, the ultimate segments oblong, obtuse, and confluent. There are exotic forms of Pteris in every part of the world, which are mere varieties of the Pteris aquilina, so that the Bracken may be said to rank as the most universally distributed of all vegetable productions, extending from West to East, over both continents and islands, in a zone reaching from Northern Europe and Siberia to New Zealand, where it is represented by, and perhaps identical with, the well known Pteris esculenta.

The Allosorus crispus, Parsley fern, or Curled Rock Bracken, which may be taken as a type of its genus, is by some authors referred to the same group of Pterideæ, though others regard it as one of the Polypodieæ. It is a pretty little fern, growing in tufts in sheltered crevices of mountain rocks, from Lapland to the Mediterranean. The fronds are deltoid, twice or three times pinnate, and of two kinds. The ultimate divisions of the barren fronds are wedge-shaped, cut, and toothed; those of the fertile fronds are linear, oblong, and entire. Although the sori are at first circular, and situated near the extremities of the lateral veins, they become confluent in maturity, and being covered by the reflexed margin of the pinnules of the contracted but scarcely altered fertile frond, instead of by an indusium, they bear some resemblance in fructification to Pteris aquilina.

The Adiantieæ form an exceedingly numerous and mostly tropical group of ferns, in which the rhizome is creeping or globose. Their sori are linear or oblong, straight or curved, and growing on the under-side of the edges of the leaf, which are folded over with them, and thus serve as an indusium. Adiantum has a free venation, but Hewardia, a related genus, has a reticulated venation. The Adiantieæ have linear, oblong or lunate sori, seated on the margin of the leaf. Of the seventy species of Adiantum, only A. pedatum and A. Capillus-Veneris, the first American, the latter British, are inhabitants of a cold climate. The A. Capillus-Veneris, which is universally distributed in warm latitudes, is believed to have migrated in ancient times to the mild and damp south-western counties of England and Ireland.

The Adiantum Capillus-Veneris, or Maiden's Hair, has a slender, black, scaly, creeping, and branching rhizome, from the extremities of which spring lax tufts of fronds growing from a few inches to a foot high. The stems with their alternate branches and branchlets are slender, hair-like, and of a blackish purple tint. The capillary branchlets bear at their extremities thin, bright, but glaucous green, wedge-shaped leaves, serrated at their edges. The fibro-vascular bundles which traverse the stems and branches, on reaching the leaves, spread into a palmate venation, which terminates at the margin in bifurcations; and upon these, in the fertile leaves, roundish sori are placed, and covered by the transverse oblong folds of the edge of the leaf, as in fig. 67. These delicately graceful ferns flourish almost exclusively in damp shady crevices of rocks under the spray of cascades, and still more luxuriantly in deep tropical forests, where the air is loaded with warm vapour.

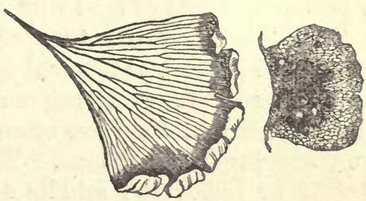


Fig. 67. Adiantum Capillus-Veneris.

The Acrosticheæ are among the most remarkable of ferns in having the whole under-surface of the frond indiscriminately covered with naked sori, and in a few species the upper-surface also. They are situated on the veins and veinlets, from whence they extend into the interstices of the fertile fronds, which are sometimes much contracted. The species are almost all tropical or subtropical. A New Zealand species of Lomariopsis climbs high trees by means of its stout rooting caudex, and has different leaves on different parts of the plant.

The Cyatheineæ are chiefly arborescent ferns, and, with the exception of some fossil species, contain the noblest representatives of the cryptogamic flora. Their fructification consists of dot-like sori, in which the usually compressed oblique sporangia are placed on an elevated receptacle, which forms a raised point on the surface of the fronds when the sporangia are removed. Of these the Alsophileæ are without true indusia, while the Cyatheæ have a spherical indusium, bursting above or below, and forming a cup round the sorus. The pulpy substance of the stem of Cyathea medullaris was a common article of food with the New Zealanders.

The Gleicheninæ have a creeping or climbing rhizome, and globose or trigonal sporangia, few in number, and disposed in a radiating manner, so that the narrow end is internal. They are often seated in a little cavity, and are highly deciduous. The fronds are generally forked or trifid, the middle division being sometimes supplied with a little bulb-like body. They are mostly tropical or subtropical plants, but some species grow in Chili, New Zealand, and Japan.

The Trichomanineæ are pretty well distinguished from other ferns by their pellucid membranaceous texture. As regards their technical characters, they have an oblique and complete ring to the sporangia, which are of a lenticular form, and are collected about a more or less elongated receptacle, which is free within either an urn-shaped cup or a two-valved indusium, projecting from the edge of the frond. They are chiefly inhabitants of the moist tropical forests, or extra-tropical regions of damp and mild temperature. Great Britain only owns one species of the genus Trichomanes, and two of the genus Hymenophyllum, while species of these two genera constitute one-fifth of the fern vegetation of our antipode islands of New Zealand. It is more than doubtful even that the Trichomanes radicans, or Bristle fern, is indigenous, as it is found in no other part of Great Britain except the Irish counties of Cork and Kerry, growing on dripping rocks and waterfalls, or depending from the walls and roofs of caverns; and as it is also found in the West Indies and the North Atlantic islands its transit may be accounted for, as in other cases.

The fronds of the Bristle fern, Trichomanes radicans, are somewhat deltoid, or of a more elongated form, flimsy, and beautifully reticulated when viewed with a microscope. They rise at intervals from a creeping rhizome, bristly, with narrow articulate scales, which often covers the most precipitous rocks on which it grows with a dark-coloured network. The rachis is branched and rebranched three or four times, and the whole being distinctly winged on both sides in the plane of the frond, the successive branches and branchlets running through the leafy part become the veins of those parts, so that a segment of the frond is merely a winged vein, the wings on the branches being however broader than those on the rachis. The veins, which divide alternately, are hard, woody, and wire-like, and, when barren, terminate before reaching the ends of the segments; but, when fertile, they extend beyond the segment, the tissue of which separates and distends in the form of a more or less

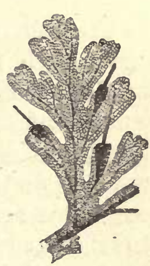


Fig. 68. Trichomanes radicans.

elongated cup around the prolonged vein. At the base of that vein the sporangia form a small globular cluster; and, as they advance towards maturity, the vein extends in the form of a bristle, far beyond the mouth of the cup (fig. 68). The cup is winged in the more luxuriant form of the plant, in consequence of the double layer of tissue composing the segment to which it belongs not separating through its whole breadth. The cup-like cylinder being slightly compressed in the plane of the frond is indicative of its origin.

A slight difference in fructification separates the Hymenophyllum tunbridgense, or Film fern (fig. 69), from the Trichomanes, for both have a creeping rhizome, from which single fronds spring at short intervals. The leafy parts of the fronds are merely winged veins, and the wings consist of two layers of cellular tissue finely reticulated. The Hymenophyllum is distinguished from the Trichomanes by a two-valved cup spinously serrated, which completely conceals the fruit-bearing vein, while, in the Trichomanes, the cup is more cylindrical, smooth-edged, with the fertile vein projecting far beyond it (fig. 68). The beautiful little Film fern, with its semi-transparent fronds not more than two or three inches high, grows on shady wet rocks, among the moss on the branches and roots of old trees, and on the ground near lakes and rivulets. It is hardy enough to live in the Highlands of Scotland; but the H. unilaterale, a far less beautiful plant, has its limit in Unst, the most northern of the Shetland Islands. The fructification in the latter plant, though the same in position, is stalked instead of being sessile. The involucre is rounded and

Fig. 69. Hymenophyllum tunbridgense.

ovate, instead of being cup-shaped, with much swollen convex valves, meeting by their edges but not compressed towards the apex.

The Schizæineæ are many of them climbing ferns, and for the most part tropical. Lygodium articulatum climbs trees in New Zealand to the height of fifty or one hundred feet, and its tough wiry stems are used for cordage. In one group of this order, represented by Lygodium, the sporangia are disposed at the back of the frond in imbricated marginal spikes, formed by a transformation of the ultimate pinnæ. In the other division, represented by Schizæa, the fruitful spikes are really on the under-side of the frond, but the frond being reversed they seem to be on the upper.

The Ceratopteridineæ, sometimes called Parkeriaceæ, are tropical aquatic ferns, whose sterile fronds, which are membranaceous, with a thick vascular footstalk, float on the surface of the water, and by the time these are nearly decayed the fertile fronds are perfected. The latter are more erect, repeatedly divided and forked, the divisions being linear. There is only a single genus, Ceratopteris, which has continuous sori occupying the longitudinal veins at the edge of the frond, and covered by the indusioid margin. The sporangia have a very broad incomplete ring, and connect the ringless ferns with the group which possess them. The spores are triangular, and marked with three sets of concentric ridges.

The order Osmundineæ contains the Osmunda regalis, considered to be the finest of all European ferns, which is common throughout Great Britain in wet spongy soils, and appears to be the only species of the group that is European. The fronds grow in tufts from a thick woody caudex, which branches and extends widely by the formation of lateral crowns, but, if impeded, it elongates and rises in an erect position to the height of two or even three feet above the soil. The barren fronds of the large luxuriant tufts are highly developed, and are from six to nine or even eleven feet high; the fertile fronds are shorter and fewer in number. The bipinnate character prevails throughout; the primary divisions are opposite, the secondary alternate, and the pinnules are oblong and opposite. The sculptured sporangia have a very rudimentary ring, and, in the fruit-bearing fronds, four or five of the lower pairs of pinnules have the leafy character, while the remainder develop clusters of sporangia in place of pinnules. The sporangia on the fruitful branches are at first pale green, but gradually become reddish brown, hence the name of Flowering fern. The Leptopteris section of the genus Todea, almost peculiar to New Zealand, has beautiful transparent fronds, with naked sporangia placed upon the veins, forming very much scattered sori.

The MARATTIACEÆ may be partly known by their huge globose rhizome projecting above the ground, and rough with the processes from which the leaf-stalks have fallen. This sends out a few large fibrous roots, and consists of cellular tissue abounding in starch, with small bundles of fibro-vascular tissue regularly distributed through it. The stipes have a pair of stipule-like organs at their base; and the sori are either oblong fronds of a double row of sporangia, which in some cases is concrete, or they are circular with the sporangia annularly concrete, or they are connate throughout the fertile portions. These peculiarities respectively distinguish the smaller groups of Marattineæ, Kaulfussineæ, and Danæineæ, while the group Marattiaceæ itself is distinguished from Ophioglossaceæ by having its sori dorsal, that is, set on the back, or under-surface, of flat leafy fronds. The leaves of Angiopteris evecta are used as a perfume in the Sandwich Islands, and its rhizome serves for food, as that of the Marattia salicina does in New Zealand.

The OPHIOGLOSSACEÆ, or Adder's Tongue ferns, are few in number, and present comparatively little difference in structure. They are known among the exannulate series, from the Marattiaceæ, by having their fertile fronds contracted, bearing their sporangia at the margin, so that being entirely occupied by sporangia, the fertile fronds appear as if they were an inflorescence distinct from the foliaceous organs, as indeed they are analogically. In this group there is the further difference that the fronds are not circinate, but straight, in their æstivation.

These Adder's Tongue ferns are dwarf herbaceous plants, differing greatly in structure from the true ferns, though there is some similarity to them in the fructification. They are divided into four genera, of which Ophioglossum and Botrychium are best known. The base of the stem is thick and bulbiform, and sends off spreading succulent roots, The species of the genus Ophioglossum are chiefly plants of a warm climate, but Ophioglossum vulgatum, or common Adder's Tongue, is distributed in almost every part of the globe. In England it is exceedingly abundant in meadows and pastures, and varies in height from a few inches to a foot, in moist soil. It has one barren ovate and one fertile linear frond. The barren frond, which is of a yellowish-green colour, invests the stem of the fertile frond like a spathe; its form is ovate, varying to ovate lanceolate, and more or less obtuse, with a complicated network of anastomosing veins. Bivalved sporangia form two parallel series on the margins of the club-like terminations of the fertile frond. Soon after the fruit is shed the fronds die, but one or two buds are previously formed at the base of the plant, which remain dormant till the following spring.[1]

The genus Botrychium has few species, about half of which grow in North America. Botrychium Lunaria, or Moonwort, is the only species indigenous in Great Britain. This plant, which is from five to six inches high, has a rather long succulent stem, invested at the base by the dark-coloured membranous remains of withered leaves. It has one barren frond, the base of whose stem is a sheath, through which the tall, fertile frond rises. The barren frond has from three or four to seven pairs of opposite smooth pinnæ, of a lunate shape and glaucous green colour, overlapping each other; they are smooth, crenated on the margin, and occasionally lobed, which gives them a fan shape. The fertile frond is longer than the barren one, and ends in a panicle or thyrse. The sporangia, which are large and bivalved, are disposed in two regular series upon the divisions of the panicle, and directed towards the upper or inner face of the frond. This fructification bears a strong resemblance to that of Osmunda regalis, the Flowering fern.

The stem of this plant has been assumed to be solid and branched, which is by no means the case; for, upon dissection, it is found to be hollow, and at its base the fronds of the following year may be detected more or less perfectly formed, and the rudimentary bud of the succeeding year within the latter; the position of the barren and fertile fronds being reversed in the successive developments.

[1] Charles Johnson, Esq.

SECTION IX.

EQUISETACEÆ, OR HORSETAILS.

THE Equiseta are leafless, herbaceous plants, annually renewed from a creeping rhizome, and growing in marshy land, in pools and ditches, on the banks of rivulets, and in rivers, from Lapland and Siberia to within the tropics. There is but one genus, and few species. The largest of the ten or eleven species, which are indigenous in Great Britain, is not more than five or six feet high, but they are of greater size in warm climates. The Horsetails begin their lives precisely like the Ferns; for, when a spore begins to germinate, it forms a marchantioid leaf or prothallus lying flat on the ground, upon which are produced antheridia, full of cells, in each of which there is a spermatozoid with numerous cilia. Archegonia are also formed on the prothallus. These, after fertilization, give rise to the perfect plant, which throws out a rhizome, whence new shoots are produced. 'The structure of the rhizome is very different from that of ferns. In an early stage it consists of a central column of cellular tissue, sending off about eight radiating plates, which connect it with an external cylinder of the same tissue, and opposite to each of which there is, in the central column, a vascular bundle consisting of annular vessels passing into spiral. At a later period, tissue grows from the walls into the cavities, in such wise that they are more or less perfectly obliterated.'[2]

[2] Berkeley's 'Cryptogamic Botany.'

From the rhizome, which often extends to a great length, the stems of the Equisetums rise in the form of rough, rigid, hollow cylinders, striated longitudinally, and articulated at intervals by separable joints. Each articulation is invested at its base by a toothed membranaceous sheath, from beneath which, in the greater number of the species, whorls of branches spring, jointed like the stem, and similar to it even to the number of teeth in the sheaths and striæ on the surface, but unbranched.

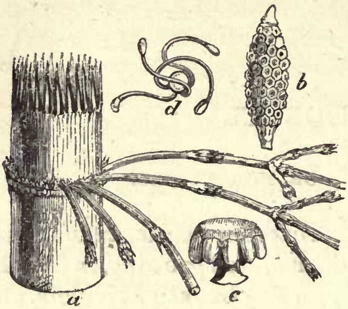


Fig. 70. Equisetum giganteum:—*a*, fragment of stem with branches; *b*, cone or spike of fructification; *c*, one of the scales of the cone; *d*, spore with its elastic filaments.

The fructification is occasionally on separate stems, which make their appearance before the barren ones, and are in general unbranched and succulent, bearing a cone on their apex. The surface of the cone is at first smooth or indistinctly reticulated, but it eventually splits into numerous octagonal, brown, shield-like discs, spirally arranged, which, separated from the stem, are found to have a stalk, and to bear on the under-side four or eight pendent sac-like bodies of a whitish hue. These are the sporangia, which open on the inside by a slit for the discharge of the spores. The inner coat of the cells of the sporangium is composed of beautifully spiral tissue. The spores arise by cell division, each being covered by a separate membrane, which ultimately forms a pair of elastic fibres attached by their middle, closely coiled round the spore, as it is formed within the cell; but, when the spore is liberated, they extend; the least moisture, however, even the breath, makes them contract.

The Equisetaceæ differ from the Ferns in having spiral instead of scalariform vessels in their structure; but they agree in having only one period of fertilization, after which they produce a crop of spores year after year, and these, when sown, give rise to the primary leaf with its antheridia and archegonia—a perpetual cycle.

The whole substance of the stems of the Equisetums is so completely penetrated with silex, that a silicious skeleton remains after the herbaceous part is destroyed, and in some species as much as thirteen per cent. of the whole plant, and fifty per cent. of its ashes are found to be pure silex. On account of the crystallization of the silex, the Horsetails form some of the most beautiful of microscopic objects. If a fragment of the cuticle is magnified and viewed by polarized light, the colours are seen to be intense and vivid, and the arrangement of the silicious particles so elaborate and symmetrical as to resemble necklaces of diamonds and coloured gems. The rows of crystals run in lines parallel to the axis of the stem, the greater number being so disposed, but the rest are grouped so as to form ovals joined together by a chain of particles forming a sort of curvilinear quadrangle, these rows of oval combinations being arranged in pairs. The effect is brilliant when they are seen in polarized light. According to Sir David Brewster every particle has a regular axis of double refraction; but Professor Bailey, of the United States of America, states that the effect under polarized light is not produced by the silicious particles, but by the organized tissues, since, after these have been destroyed, the silex shows no double refraction.

The vascular tissue of the Equisetums shows them to be of a higher class than the Ferns. The recent forms vary much in size, but even the Equisetum giganteum of Brazil, which is eighteen feet high and three-quarters of an inch in diameter, is incomparably less than the Calamites and other fossil Equiseta, which appear in the coal measures and new red sandstone. Recent species are found in Iceland and the high northern latitudes of America, in the tropics, and in most parts of the world, except Australia and New Zealand.

SECTION X.

MARSILEACEÆ, OR RHIZOSPERMÆ.

The Marsileaceæ, a natural tribe of small perennial aquatic herbs, have a filiform creeping rhizome with alternate erect leaves, curled in vernation like those of the ferns. The sporangia are enclosed in oval or spherical leathery capsules, or receptacles, which contain two dissimilar forms of reproductive organs—sporangia and antheridia, and are sessile, or nearly so, on the rhizome at the base of the leaves, whence the general name of Rhizospermæ. The Pilularia globulifera, or Pillwort, the only British species of its genus, may be taken as a type. Its rhizome creeps over sand or mud, at the margins of lakes and pools, where it is always submerged, or in sandy or gravelly places, which are only occasionally overflowed. At regular intervals the rhizome sends off a tuft of roots and a tuft of leaves opposite to them; the leaves are smooth, erect, and very slender, in deep water almost hair like, varying from four to five inches in height. The solitary globular receptacles, brown, hairy, and about the size of a small peppercorn, spring from the axils of the leaves, supported on so short a stem that they appear to be sessile. Fig. 71 shows an Algerian species of its natural size. The receptacles are divided by cross partitions into two or more cells, and separate at ma-

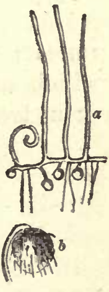


Fig. 71. Pilularia minuta :— *a*, mature plant, natural size; *b*, receptacle, slightly magnified.

turity into four equal valves. Each cell has a sort of placenta to which the sporangium and antheridia are attached; and its upper half is lined with three minute, sessile, obovate, yellowish bodies, which are the antheridia; the other half is occupied by a larger, roundish, or oblong sessile sporangium, containing one spore, which has a firm outer coat, tapering to a point, and leaving a cavity at the top of the nucleus. According to Hofmeister, this cavity becomes filled with cellular tissue, constituting a conical prothallus confluent with the nucleus. A single archegonium is formed in the centre, the orifice of which corresponds with the apex of the prothallus. The antheridia contain numerous granules, from which long spiral delicate spermatozoids are ultimately developed.[3] The embryos of the young plants push forth their radicle in one direction to fix them to the soil, and a frond or leaf in the opposite direction. Thus these minute plants, approaching so nearly to a monocotyledon, exhibit a high organization, only inferior to that of the Lycopods.

The group contains the genera Marsilea, which has leaves made up of cuneiform lobes, and resembling those of some leguminous plant; and Salvinia and Azolla, both of which consist of small floating plants, which mostly occur in tropical or subtropical countries.

[3] Berkeley's 'Cryptogamic Botany.'

SECTION XI.

LYCOPODIACEÆ, OR CLUB MOSSES.

The Club Mosses are mostly perennial plants, with slender creeping stems, often several feet or yards in length, occasionally erect, and clothed by small, sessile, closely set, often imbricated leaves without veins. They have in some instances a habit resembling that of Conifers. The stems consist of a mass of thick-walled, often dotted cells, enclosing one or many bunches of scalariform tissue, which sends off branches to every leaf and bud. The scalariform tissue is accompanied by fine, elongated, and sometimes rather coarser cells, which are occasionally reticulated. The stem approaches to that of ferns, but the bundles of vascular tissue are confined to the centre. The branches of the stems are often bifurcate, and terminate in one or a pair of cone-like spikes, which are either sessile or stalked. The sporangia are sessile in the axils of the imbricated leaves or bracts that cover the cones. Two kinds grow on the same plant, one of them bivalved, containing a powdery substance, whose particles a high magnifying power shows to be globular spermatozoids: these do not germinate; and the other three-valved, enclosing comparatively large, nearly spherical granules, marked with three prominent ridges, radiating from one extremity. These certainly germinate, forming by cell-division a prothallus of hexagonal cellular tissue, adherent to and confluent with the spores, as in Marsileaceæ, or penetrating their cavity, but without the protrusion of threads, as in ferns or mosses. On this prothallus, archegonia are soon produced, the embryo being formed from a cell at its base; this sends down roots on one side, and a minute stem with the two primary leaves of the young plant at the other. The plant thus bears a close resemblance to a young plant of the dicotyledons, and exhibits, with regard to fructification, the highest organization of which the Cryptogams are capable, although in their tissues the Lycopods are inferior to the Equisetaceæ and Marsileaceæ.

There are four genera of this order, very widely dispersed, most abundant and larger in the hot moist parts of India and the Indian islands, but large tracts are covered with them within the arctic circles and in temperate latitudes. There are 200 species of the genus Lycopodium, or Wolf's-claw, and of these, six only are indigenous in Britain; they grow in very exposed situations, as in the case of L. clavatum, which lives on upland heaths and pastures, and which has a procumbent stem, creeping for many feet or yards, sending out branches in all directions, with a pair of cones at their extremities, and strong roots at intervals to fix it to the ground. Lycopodium inundatum forms large patches on the marshes in the south of England. New Zealand has many more species of this genus than Britain, and some of the noblest specimens. The dried spores of the L. clavatum are so inflammable, that they have been used on the stage to produce the effect of lightning. Some Club Mosses yield a blue dye, a colour which is now obtained of a better quality from coal tar. Others possess cathartic properties, but although they have been used as medicine, they are very dangerous from the violence of their effects.

The genus Selaginella has a moss-like habit. The stem is generally creeping, and flat-looking from being clothed with distichous leaves; but sometimes it is tall and erect, having feathery branches clad with leaves. The sporangia are sacs, with two or three valves containing large spores and sub-globose antheridia, containing orange-coloured or minute scarlet bodies, ultimately developed into spermatozoids. The species are very numerous and greatly varied, and mostly tropical.

From a comparison of the structure of the stems of the fossil plants, Sigillaria and Lepidodendron, Dr. Hooker concludes that they are highly developed Lycopods, approaching closely in structure to the highest class of plants. The stems of the former differ chiefly in size from those of the Lycopodium, and the cones of the Lepidostrobus differ in their greater development and in the thickness of their scales from those of the Conifers. The spores of the Lepidostrobus ornatus too are sphericotetrahedral, like those of the Lycopodium. But inferior as the existing Lycopods are to their fossil ancestors, their analogy to the Conifers gives them a more exalted position in the vegetable world than their tall and graceful allies, 'the tree ferns.'

The gradual change of structure from the lowest to the highest cryptogamic form is accompanied by a singular variety in the mode of reproduction, and a degree of vital energy scarcely to be expected, at least in beings of such low organization as the yeast plant, which produces gemmæ in vast and rapid profusion, each gem or bud being only a facsimile of the parent cell. In like manner the mother plant is reproduced by the germination of the green zoospores, the green globular cells in the fronds of the lichens, the motile gonidia, and the discs in the baskets of the Marchantia, especially those of the Marchantia polymorpha, which have such vigorous vegetation that they form stomates on whichever side is turned to the light, and roots on the other. The result of all these is an individual perfectly similar to its parent, like that produced by a bud and cutting of a tree, or the axillary fruit buds of the Begonia. The leaves of that flowering plant, as well as those of the Achimenes and Gloxinia, possess the property of reproducing the parent plant, for, when laid on moist earth and slit in different places, a young plant rises from the upper side of the fracture, and roots shoot down from the under. Although this manner of growth resembles the germination of the embryo of an archegonium, it is widely different, for the embryonic cell is fertilized by the spermatozoids, so there is a certain analogy but not the smallest affinity. The highest vegetable classes can reproduce the mother plant in many ways, but they have nothing akin to the alternation of generations exhibited by many of the lower tribes, nor yet to conjugation like the Desmidiaceæ and Diatoms. Possibly the spores resulting from these two modes of reproduction, as well as the resting spores, may produce new species; certainly those resulting from fructification do occasionally yield new varieties.

Many spores produce the plant directly, others indirectly, as most of the fungi; but if the definition of a perfect plant be that which bears the fructification, the mycelium of a mushroom constitutes the plant, for the mushroom itself is only a kind of sporangium or spore-case. Nevertheless, the spores of the Puccinia and other microscopic fungi, which are the cause of the rust and mildew in wheat, give rise to a kind of prothallus, 'a slight fore-shadowing' of the prothallus of the Marchantia and Mosses, which only produce sporangia, and those of the Ferns, Horsetails, and Club Mosses, whose archegonia contain the embryo of the plant itself. The fructification of the Lycopods is the highest of which the Cryptogamia are capable, and brings them into a singular analogy with the flowering class. For in the ovule, or seed-vessel of the flower-bearing race, a large cell is formed, containing mucilaginous matter, which, soon after fructification, is converted into a mass of cellular tissue, which gives rise to the cell containing the embryo, just as the prothallus of a Lycopod gives rise to the archegonium containing the embryo of the plant. The linear leaves of existing Lycopods and the cones of their fossil allies, are similar to the leaves and cones of the Coniferæ: there is no affinity, but an analogy existing between these two groups sufficient to make them form links between the two great divisions of the vegetable kingdom. The Lycopodiaceæ probably may be regarded as the highest of the Cryptogamia, and Coniferæ as the lowest of the flower-bearing class.

SECTION XII.

GENERAL STRUCTURE OF FLOWERING PLANTS.

In some of the Cryptogamic families fertilization takes place before the plant itself is developed. In the two highest classes, those containing the great groups of Flowering Plants, on the contrary, it is the ultimate result of the inflorescence, which consists of calyx, corolla, stamens, and pistils, all which are the later expansions of the cellular tissues and groups of vessels which have in earlier stages of development formed the leaves. They contain the same materials, and in fact they are leaves modified in form, structure, and function.

Although the almost innumerable diversities in the form of leaves must produce corresponding diversities in the inflorescence, yet the general characteristics are the same or similar in both of the great botanical classes. The structure of the calyx and corolla which form the floral envelope of the fructification, is similar to that of leaves. The calyx consists, in its early stage, of several parts called sepals, which have all the characters of leaves; subsequently they are sometimes united by their edges, so as to form a tube, or are otherwise modified. The corolla only differs from a leaf by greater delicacy of organization; it has fewer stomates or breathing pores, and the veins have less woody fibre and sometimes many spiral vessels; the veins in the petals of chickweed and some other plants are entirely composed of spiral vessels. The calyx and corolla protect the fructifying organs consisting of stamens with their anthers, and the pistil or pistils.

The stamens are formed of very fine filaments, and the anthers, when young and still enclosed in the unexpanded flower, are full of a liquid which is afterwards changed into a delicate homogeneous, cellular tissue. Then the internal part of that tissue becomes divided into two kinds of cells, one of which goes to form the walls of two lateral and parallel chambers or loculi, separated by a part more or less continuous with the filament. The other kind of cells are developed into pollen grains within the chambers. They gradually form a cylindrical assemblage of mother cells. Within each of these, four cells are ultimately formed, each containing a single pollen cell. In all plants, except the aquatic, the pollen cells are soon clothed by the deposition of one or more layers of cells, which form the outer membrane, on which are impressed figures or markings peculiar to each species of plant, such as slits, points, papillæ, sharply defined circles, pores, &c. The colour of the external layer is generally yellow, rarely green, blue, or red; the thread is usually white, except in the fuchsia and some others. When the pollen is ripe the chambers dehisce to emit it. The opening is usually a slit between the valves which close the chambers. The length of the slit is variable, and the form of the pollen grains is equally so; they are commonly ellipsoidal, and attenuated at the extremities; but in all cases they are beautiful microscopic objects.

The contents of the pollen grains consist of a liquid containing mucilaginous granules, which is in circulation. The granules increase in number towards the period of maturation, mingled with oil globules, and frequently starch. The circulation of the fluid ceases long before maturation in all cases, except the Zostera; but the granules of the contents exhibit an active molecular motion often within the pollen cell, and always after expulsion even in pollen taken from dried specimens. After the liquid ceases to circulate, it becomes concentrated and contracted; and when the pollen is only enclosed in one delicate membrane, it simply bursts the vesicle; but, as most pollen grains have a double coat, they burst open at the slits, or pores, on their surface, and through these the internal membrane, in the form of a tube, is protruded, and emits its contents; but it may be projected to a considerable distance without bursting.

The pistil in a very young state is a greenish concave body scarcely to be distinguished from a nascent leaf; it becomes more concave; and finally the borders meet and unite, so that a hollow body is formed, which ultimately becomes a perfect pistil consisting of three parts, the apex or stigma, the style, and the ovary, in which the ovules, or unripe seeds, are formed and fertilized, the latter afterwards becoming the fruit.

The ovary is composed of an outward skin containing cellular tissue and vascular bundles of spiral vessels, which, running upwards, converge towards the style; they vary in number, and are sometimes ramified. A single ovule, which is an unripe seed, may be produced within the ovary, or the ovary may be divided into two or more compartments, in each of which an ovule may be formed and attached to the ovary by a mass of cellular tissue, and not unfrequently by a single thread.

The style, when examined with a microscope, is a hollow tube, or canal, extending from the cavity of the ovary to the stigma. It consists of cellular tissue with vascular bundles near the circumference, which pass upwards in straight lines, and end below the summit. In certain cases the canal is open; in others it is obstructed by lax cellular tissue having many gaps. The stigma is an expansion of that lax tissue at the point where the canal opens externally. At the time of fructification, the canal of the style is occupied by soft humid elongated cells mixed with a viscous fluid, which exudes upon the surface of the stigma, rendering it moist and glutinous. When the pollen grains adhere to that humid substance, the tubular extension of their inner lining, with its contents, passes down the style and fertilizes the unripe seeds.

After fructification the anthers, stigma, and conducting tissues wither, yet, in many fruits, additions are made to the ovary and its contents by the remains of some of the other parts of the inflorescence. In the apple, which is a simple fruit, the skin of the calyx forms the skin of the apple, and the flesh or edible part is developed out of the ovary and the remainder of the calyx, while the inner layer of the ovary forms the horny cells containing the ripe seeds. In the strawberry, which is a compound fruit, the pulp is the enlarged fleshy receptacle bearing the simple fruit on its surface. In the orange, the membranous partitions of its segments are the linings of the ovary, and the pulp is formed of lax large-celled cellular tissue developed within it.[4] All fruits have the mark of the style; it is very evident in the apple and orange. Simple fruits are formed by a single flower; multiple fruits, like the ananas, or pine-apple, and fir cone, are formed of masses of inflorescence in a state of adhesion.

Spiral vessels are frequently found passing from the fleshy part of fruits into the seeds; they are very numerous in the seeds of the Collomia grandiflora and others, coiled up and compressed by the outer skin; but they start to their full length as soon as released. The coats of the seeds of various plants, when seen through a microscope, are beautifully marked. That of the Big-

[4] Inflorescence and fructification are fully explained, and applied to a vast number of plants, in 'Structural and Physiological Botany,' by Arthur Henfrey, Esq.,—a work of great research and merit.

nonia is surrounded by a fringe of elongated spiral vessels, the seed of the poppy has a reticulated surface, and many have wings like those of the ash tree, or down like the thistle, that they may be dispersed by the wind. The tendency of roots to strike downwards is so great, that seeds right themselves whichever way they may fall.

SECTION XIII.

MONOCOTYLEDONOUS, OR ENDOGENOUS PLANTS.

The structure, growth, and reproduction of the flower-bearing vegetation offer objects of the highest interest, though very different from those furnished by the flowerless class. The plants whose seeds have but one lobe form a transition from the lowest to the highest class of vegetables, and include those which furnish the principal articles of food to man and animals. They are all flower-bearing, and consist of numerous families of land and water plants. The most important are the palms, which serve for food in tropical countries, the grasses, which are cosmopolite and social, covering extensive tracts of country with rich verdure, and including the Cerealia, which have been cultivated from such remote antiquity, that the grasses from whence they were derived are unknown. This monocotyledonous class includes, besides the palms and cereals already mentioned, the sugar-cane, the bamboo and other canes, together with reeds, rushes, screw pines, most garden bulbs, the singular and beautiful race of Orchids, and a multitude of other ornamental and useful plants.

The seeds of this class consist of a thin skin covering a mass of white or green matter, which, when ripe, constitutes the starch and flour in the Cerealia. Within that matter lies a fleshy lobe with the infant plant imbedded in one corner. The same general structure may be traced throughout the class, though the lobe with its embryo in the surrounding matter may be covered with a hard coat, as in the cocoa-nut, or inclosed in a shell covered with a rich fruit, as in the date. The infant plant, as it lies in its seed lobe, has a stem with a leaf bud or plumule at one end, and an embryo root at the other; and, as soon as the seed begins to germinate, it is nourished by the conversion of the starch of the surrounding matter into sugar. At first the whole young plant is of cellular tissue, but, as soon as the seed leaf appears above the soil, it decomposes the carbonic acid of the atmosphere, absorbs the oxygen, and consolidates the carbon. Then cords of fibro-vascular tissue are formed within it, which converge at its base, and unite with the radicle of the young plant to form the solid centre of the underground stem, from whence the real roots descend, like slender white cords, which supply the plant with food. The seed lobe having set the current of the cell sap in motion disappears, and the aërial or above-ground stem, which now consists of pith, sap, wood, and skin or bark, grows rapidly in length to its first node, or thickened part, where the first leaf or leaves appear, for the first leaves generally appear at the top of the stem in this class, and are annually succeeded by others rising above them from the top of the elongated stem, as in the palms and grasses.

The stem or axis of a palm is a cylinder with a graceful plume of leaves at its summit, and a cone of white roots at its base. A section of the stem perpendicular to its axis exhibits a mass of cellular tissue with a number of dark-côloured spots irregularly scattered throughout the whole with the exception of an envelope of dense cellular tissue, which forms a kind of bark. The dark spots are the sections of bundles consisting of two or three very wide and large vascular ducts enclosed in extremely fine woody fibre and spiral vessels closely pressed together. These bundles after having formed the ribs and footstalks of the leaves, enter the upper part of the stem, approach towards its centre, bend down for a short distance, then turn towards the exterior, interlace with the bundles of the previous year, which have followed a similar course, and make a circle of rough marks on the surface of the stem. The stem then increases in length, and a new plume of leaves crowns its top; the same process is repeated; and, as this goes on indefinitely, the lower part of the stem is rough, and sometimes even rugged, as that of the Palmyra palm. In consequence of this manner of growth, a perpendicular section of a stem shows a series of curves intersecting each other and originating in points gradually ascending as the palm grows in height. These curves proceed from every point of the circumference of the stem, present their convexities to the centre, and bend round, and enter the leaves, which are long, lanceolate, and often pinnate with veins running through them longitudinally. In some palms the greater part of the centre of the trunk is altogether cellular tissue, but each species has an arrangement of its own. Some palms, as the date palm, are diœcious, one plant bearing male, the other female flowers. In these cases, the pollen is carried from one tree to the other by the wind or by insects, and, as much is lost in the transit, there is always more produced than is required to fertilize the female flowers.

The Graminaceæ are very numerous, but the general structure is virtually the same, whether it be a simple herbaceous grass, a sugar cane, or a bamboo. The stem of the grasses is jointed, and furnished with long lanceolate leaves, springing alternately to the right and left of each successive joint, and the parts of the stem between the joints are embraced and nearly surrounded, as by a sheath, with the expanded bases of the leaves; for, in this class of plants, one growth always springs from the interior of that which precedes it. In youth the stems of the grasses are solid, and the bundles of woody tissue which surround the pith are parallel to one another and to the axis of the stem; but, at the joints, they are turned aside and are condensed into a node or joint, where they enter into a new arrangement, and pass into the lanceolate leaf, to form its longitudinal ribs. The compression of the fibro-vascular tissue is so great as to form a septum across the interior of the stem at the node. This is the case in all the grasses; for the pith, which is of moist green cellular tissue when they are young, soon disappears, so that a full grown grass is a hollow stem articulated at intervals by solid joints, from whence the long narrow leaves spring alternately, and as the bases of the leaves are continuous with the stem, they do not fall off when they wither.

In the majority of cases, the inflorescence of the Graminaceæ consists of a pistil and three anthers; but in the Anthoxanthum odoratum, or sweet-scented vernal grass, and some others, there are but two anthers, while some few species have more than three. In general, the flowers are hermaphrodite; but in certain genera they are monœcious, as in Zea and Zizania; and in others they are polygamous, as in Andropogon and Sorghum. The grasses are, for the most part, low and herbaceous; but the Arundo Donax of Southern Europe, and the sugar cane and bamboo of the tropics are lofty strong-growing plants, the latter reaching as much as 50 or 60 feet in height. The stems and leaves of the grass family are strengthened by silex; many of them are so entirely coated with it, that their leaves are as sharp as the edge of a knife. It gives hardness to the beards of wheat and barley, and is often found in concrete masses, called tabasheer, in the joints of bamboos, which in the Indian jungles have been set on fire by the friction of their silicious coats during a gale of wind. As no solid matter can enter the roots of a plant, the silex must be absorbed in a state of solution; and, as it coats the surface, which is full of pores, the liquid is removed by perspiration, and the silex is consolidated. The whole of this family abounds in sugar, and its farinaceous products are too well known to require any notice.

The grasses seem to have been the means of revealing the earliest dawn of plant life, for the Hon. Sidney Osborne discovered that the colourless protoplasm, or organizable liquid extracted from the roots of young wheat, produced spontaneously and simultaneously double ovate vesicles, or cells, such as are found in the roots themselves; and in that liquid, though hermetically sealed in glass tubes, the formation of these vesicles or cells was as active after six months as in the liquid freshly taken from the young plant. Mr. Osborne believed these vesicles to be the earliest organisms of plant life, and that this is the direct and prevailing mode of production of the embryo. This accords with the observations of Messrs. Wenham and Devey.

Many other very remarkable plants belonging to the Monocotyledons might be mentioned, as the Dracæna Draco, or Dragon tree of Teneriffe, one of the most ancient trees existing; the Pandanus, or screw pine, with its aërial roots, indigenous in the islands of Oceania; and the Zostera, or sea wrack, the only flower-bearing plant except one that inhabits the ocean; their flowers are minute and bisexual, are rarely produced, but they cover large areas with long grassy leaves. Bulbous plants, and the Orchidaceæ, the most splendid ornaments of our gardens and hothouses, are members of this class. Of the former, the snowdrop, crocus, colchicum, arum, hyacinth, narcissus, tulip, and lily form a group of singular beauty.

A bulb is merely a subterranean stem remaining permanently in the condition of a bud. It consists of a disc, or conical plate, which is the point of growth whence the flower-bearing stem and the leaves spring. These are surrounded by leafy scales of a fleshy character overlapping one another. The Liliaceæ and the Amaryllidaceæ contain many of the most remarkable and beautiful bulbous plants known in gardens. To the former order belong the hyacinth, tulip, and onion, in which the growing point is surrounded by a series of fleshy tunics, each of which encloses its predecessor; as also the lily itself, in the bulb of which the growing point is enclosed in fleshy scales imbricated in rows one above the other. One or two circles of roots descend from the circumference of the disc in the form of slender, soft, white cords or threads, with a spongy termination of cellular tissue to imbibe water and other liquids for the nourishment of the plant. These bulbs are reproduced by buds, or offsets, developed in the axils of the fleshy scales, which fall off either the first or second year of growth. Offsets are also produced by the arum, crocus, and meadow saffron or colchicum, whose bulbs form a solid mass, and are called corms. These offsets merely reproduce a *facsimile* of the parent. In these and all flowering plants fructification must take place before a new form or variety can be expected.

The Orchids surpass every plant in the vegetable world, for the variety of means employed by nature to continue the race. The blossoms are, for the most part, at once both male and female, though some plants are diœcious, but, except in rare instances, as in that of the Bee Orchis, not a blossom can be fertilized without the aid of insects. The flowers of the Orchideæ are constructed upon a fixed plan, which can be traced through the innumerable variety of beautiful, singular, and often grotesque forms which they assume. A corresponding variety is exhibited in the admirable contrivances and adaptations which enable insects to detach the pollen from one blossom, and carry it to fertilize another blossom.

The British Orchideæ belong mainly to three natural groups: the Ophreæ, which comprise the Orchis, Ophrys, and other common Orchids; the Neotteæ, comprising Epipactis, Neottia, Spiranthes, &c.; and the Malaxeæ, represented by Malaxis. Orchids have white, fibrous roots, and many of them a pair of fleshy tubercles.

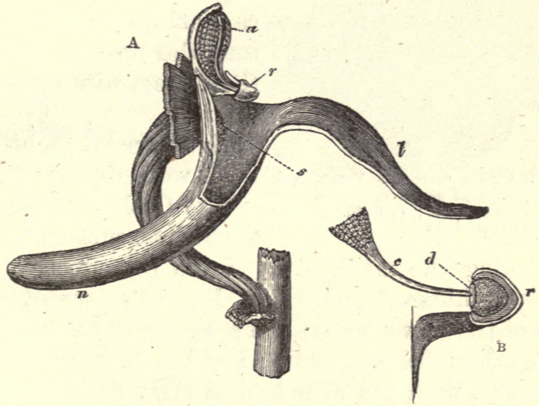


Fig. 72. Orchis mascula:—A, side view of flower, with a portion cut away; B, section through one side of rostellum, with included disc and caudicle of pollinium; *a*, anther; *r*, rostellum; *d*, disc.

From thence a straight stem springs up, ending in a spike of blossoms, each of which is attached to the stem by a twisted stalk, containing the ovarium, as represented in fig. 72. Ribbed lanceolate leaves rise from the roots, and some are attached sparingly to alternate sides of the stem. The calyx is formed of three pointed sepals, one perpendicular, the others horizontal. Instead of being green they are usually coloured. Sometimes the whole plant is green. One petal (fig. 72) is much larger than the others, occasionally assuming the most extraordinary forms. It is called the labellum, or lower lip; it secretes nectar, a sweet juice, to attract insects, and is often produced into a long, hollow, spur-like nectary, as in fig. 72 *n*. On that side of the spur which is opposite to the labellum, the organs of reproduction are so placed, that an insect alighting upon the labellum cannot insert its proboscis into the nectary tube to eat the honey, without touching them.

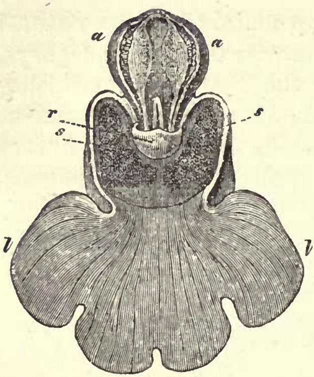


Fig. 73. Orchis mascula:—Front view of flower, with sepals and petals removed; *a*, anther; *r*, rostellum; *s*, stigma; *l*, labellum.

Mr. Darwin, in his admirable work on the 'Fertilization of Orchids,' assumes the Orchis mascula as a type for explaining the mechanism of the reproductive organs of the Orchidaceæ generally. Fig. 73 represents a front view of the flower with all the sepals and petals cut off, except the labellum, or lip; and fig. 72 is a side view of the same, with the near half of the labellum cut away, as well as the upper portion of the near side of the nectary, or spur.

In all common Orchids there is only one stamen, which is confluent with the three pistils, to form what is called the column. The edges of the labellum are attached to the sides of the column, leaving a space known as the chamber or mouth of the nectary, and thus the mouth has the column on one side, and the labellum on the other. Although the three pistils are united into one, the three stigmas are not; for the stigma of the upper pistil is transformed into a pouch-shaped viscous mass (*r*, fig. 73), called the rostellum, bearing no resemblance whatever to a stigma, while the other two stigmas form a bilobed confluent mass or stigma below it, through which the pollen grains fertilize the ovary, which latter forms the apparently twisted stalk, by which the blossom is attached to the stem. In fact, the rostellum (*r*) projects into the mouth of the nectary, and overhangs the confluent stigmas (*s s*). The lowest and narrowest part of a hood-shaped anther (fig. 73 *a a*,) is attached to the back of the rostellum, and consists of two rather widely separated oblong cells, which open longitudinally in front. Each cell contains a pollen-mass, or pollinium. Fig. 74 represents one with its club-shaped mass of pollen grains, its stalk, and viscid disc. These objects are

Fig. 74. Pollinium of Orchis mascula:—*p*, pollinium; *c*, caudicle; *d*, disc.

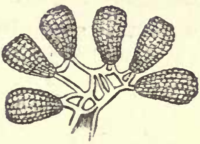


Fig. 75. Pollen grains of Orchis mascula.

seen in situ in fig. 73. A pollinium consists of a number of wedge-shaped packets of pollen grains held together by exceedingly elastic fine threads, as in fig. 75; the packets unite into the club-shaped head, and the threads form the stem; the viscid discs are formed by the rostellum.

At an early period of growth the rostellum consists of a mass of polygonal cells full of brownish matter, which soon resolve themselves into two balls of an extremely viscid semifluid substance void of structure. These two discs are flat on the top, and rounded below. They lie quite free within the rostellum, except at the back, where each viscid disc firmly adheres to a small portion of the exterior membrane of the rostellum. The ends of the two stalks of the pollinia, or granular masses, are strongly attached to these little discs, or balls.

At first the membrane forming the exterior surface of the rostellum is continuous; but as soon as the flower opens, the slightest touch causes it to rupture in such a manner as to set free from it, and from one another, the little discs, while at the same time the anther cells themselves split in a longitudinal direction from top to bottom. In this state none of the organs are changed; they are merely set free, and ready for change, yet maintaining their normal positions. The labellum, which is the largest petal of the flower, lies on one side of the nectary tube, and the rostellum projects into it on the other; hence, if an insect alights on the labellum, and pushes its head into the tube, in order to reach the honey in the nectary with its proboscis, it cannot fail to touch and depress the rostellum (see fig. 76), so that one or both of the viscid discs carrying the pollinia will stick to it, and as the anther cells are open in front, when the insect withdraws its head, one or both of the pollinia are drawn out of their cells, and stick upright on it like horns. In that position they never could fertilize any blossom which the insect might afterwards visit; but Mr. Darwin has shown that their position is changed by a contrivance that is not surpassed in beauty in the whole vegetable world. While a pollinium is upright on the head of the insect, the little viscid disc which supports it contracts on being exposed to the air, so as to cause the pollinium to sweep through ninety degrees towards the apex of the insect's proboscis, and this is accomplished in about thirty seconds, the time an insect would take to fly to another flower. The pollinium in this position

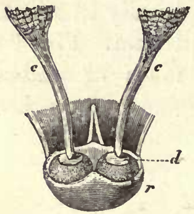


Fig. 76. Pollinia of Orchis mascula, showing front view of the discs and caudicles within the rostellum:—*r*, rostellum; *c*, caudicle; *d*, disc.

would exactly strike the surface of the stigma when the insect inserts its proboscis into the nectary of a flower.

It was long ago noticed by Robert Brown, that the stigma is very viscid, but not so viscid as when touched to pull the whole pollinium off the insect's head, yet sufficiently viscid to break the elastic threads by which the packets of pollen grains are tied together, and leave some of them on the stigma. Hence a pollinium attached to an insect can be applied to many stigmas, and fertilize them all. Mr. Darwin mentions having seen the pollinium of Orchis pyramidalis adhering to the proboscis of a moth with the stalks alone left, all the packets of pollen having been left glued to the stigma of the flowers successively visited. It appears that insects, for the most part, only remove one pollinium at a time, and that the rostellum returns to its normal position to prevent the viscid matter of the discs of the remaining pollinia from being exposed to the air.

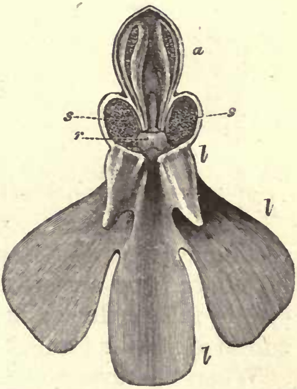


Fig. 77. Orchis pyramidalis:—Front view of flower with upper sepal and petals removed; *a*, anther; *s*, stigma; *r*, rostellum; *l*, labellum.

The Orchis pyramidalis is considered by Mr. Darwin to be the most highly organized species of the British Orchids he has examined. It has sharp leaves, and a close pyramid of white or rose-coloured blossoms. The upper sepal and the two upper petals form a hood, protecting the anther and stigmatic surfaces from the weather. In fig. 77, a front view of a blossom, these are cut off as well as in fig. 78 *a*, which represents a side view of the same blossom deprived of half the labellum, and the upper part of the nectary, or spur. The labellum is long, with three equal entire lobes, and is produced into an awl-shaped spur, or nectary. It has a small ridge on each side of its narrow base to guide the proboscides of insects to the mouth of the nectary, which, besides being small, is partially closed by the pouch-shaped rostellum, which is placed very low in this species, and is flanked on each side by a distinct stigmatic rounded surface (fig. 77 *s s*). The rostellum (*r*) is hollowed out on its under-side in the middle, and is filled with a fluid. Instead of two little viscid discs or balls, as in the Orchis mascula, there is but one which is saddle-shaped (figs. 78, 79), carrying on its nearly flat top or seat, the two stalks of the pollinia, of which the two truncated ends firmly adhere to its upper-surface. Before the membrane of the rostellum ruptures, the saddle-shaped disc forms part of its continuous surface. The upper membrane of the disc is rather thick; it is lined with a layer of highly adhesive matter formed within the rostellum.

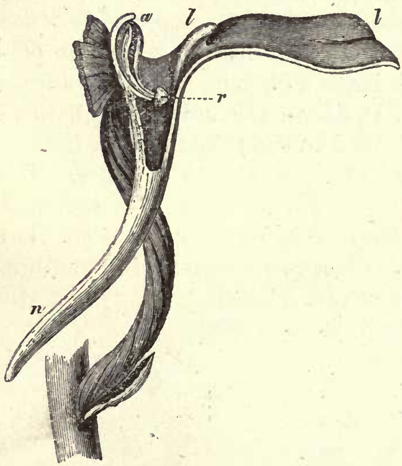


Fig. 78. Orchis pyramidalis:—Side view of flower, with a portion cut away; *a*, anther; *r*, rostellum; *l*, labellum; *n*, nectary.

When the flower opens, the saddle-shaped disc is set free by the rupture of the membrane of the rostellum. Then the rostellum, which projects into the minute round orifice of the nectary, is easily depressed by the proboscis of a moth, and as the now naked and sticky under-surface of the saddle-shaped disc is uncovered, it adheres to the proboscis, and is withdrawn with it into the air, carrying the two pollinia (fig. 80) on its exterior surface. Almost instantly the saddle is exposed to the air, a rapid movement takes place. The two flaps curl

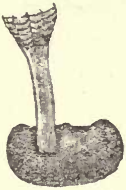


Fig. 79. Disc of Orchis pyramidalis seen from above, with one pollinium, flattened by force.

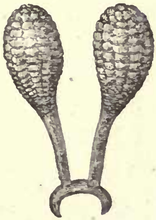


Fig. 80. Pollinia of Orchis pyramidalis, attached to saddle-shaped disc.

Fig. 81. Pollinia of Orchis pyramidalis with the disc contracted.

inwards (fig. 81), and embrace the proboscis, and the pollinia, at first parallel, become divergent. A second movement now takes place, which causes the divergent pollinia (fig. 81), which are at right angles to the proboscis, to sweep through ninety degrees towards the tip of the proboscis, so as to become depressed, and lie on each side of it. Hence, when a moth pushes its proboscis between the guiding ridges of the labellum into the nectary of another flower, the two thick ends of the pollinia will exactly strike against the two stigmas. These stigmas are so viscid that they hold and rupture the elastic threads which bind the packets of pollen grains together, and some dark green grains are seen even with the naked eye remaining on the two white stigmatic surfaces. In the Orchids, as in all other flowering plants, tubes sent out by the

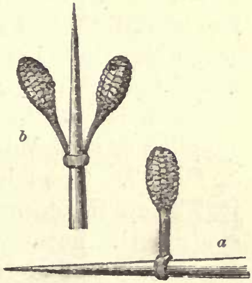


Fig. 82. Pollinia of Orchis pyramidalis :—*a*, as withdrawn by the insertion of a needle; *b*, as after the second contraction.

pollen grains penetrate through the stigmas, and fertilize the ovules in the twisted ovary. The double movement of the pollinia, while on the moth's proboscis, is owing to the rapidity with which the viscid matter contracts and dries. Both butterflies and moths frequent this Orchis. Mr. Darwin enumerates twenty-three species of these insects which he had seen with the pollinia of the Orchis pyramidalis attached to their proboscides. Many had two or three pairs; the proboscis of the Acherontia had seven, and that of the Caradium had no less than eleven of these saddles attached at regular distances from top to bottom of its proboscis. Few of the species of Orchis are visited by bees.

On account of some resemblance in form, the Ophreæ are named after insects. The Fly Ophrys differs in no material respect from the other Orchids. The stem or caudicle of the pollinium, instead of being straight, as in the Orchis mascula, is doubly and almost rectangularly bent. The upper membrane of the disc to which the stalk of the pollinium is fixed, being the summit of the rostellum, is exposed to the air, and becomes dry when the flower opens, consequently the disc, though viscid enough on its under-side to stick to an insect's head, is incapable of shrinking, and causing that depression of the pollinium, characteristic of all the species of Orchis. The labellum has no spur, but at its base, just below the stigma, there is a deep depression representing the nectary; and as the pollinia, which cannot be shaken out of their cells, or pouches, are certainly, though rarely, extracted, Mr. Darwin conceives that small insects crawl along the labellum to its base, strike against one of the pouches, extract a pollinium, and fly with it sticking on their head to another blossom, and that while bending their heads into the hollow at the base of the labellum, the pollinium, owing to its doubly bent stalk, strikes the sticky stigmatic surface, and leaves pollen grains on it. There can be no doubt that this plant is visited occasionally by insects, as it cannot be fructified without them; but it is scentless, and as no nectar has as yet been found in it, their motive for visiting it is unknown.

The fructification of the Ophrys apifera, or Bee Ophrys, is independent of insects, for the stalks of the pollinia

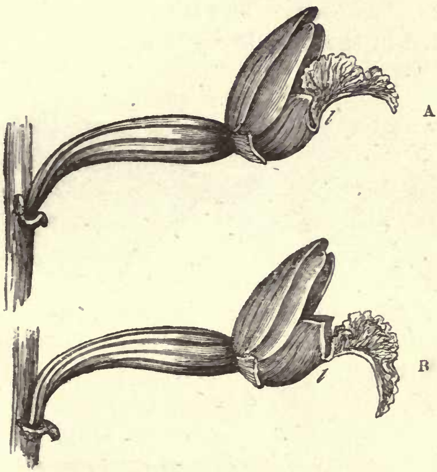


Fig. 83. Epipactis palustris:—Side views of flower, with lower sepals cut away: A, with lip in natural position; B, with lip depressed as by an insect.

are extremely long, thin, and flexible; and although their viscid discs still remain in their pouches, as soon as the flower expands, and the anther cells or pouches open, the heavy thick ends of the pollinia fall out of their cells, and hang freely down in the air exactly opposite to the stigmatic surface. A breath of air is sufficient to make them vibrate, strike the stigma with their pollen mass, and leave pollen grains on its sticky surface.

The great tribe of British Neotteæ is characterized by a free anther standing like a hood behind the stigma; the pollen grains are tied together with threads, and attached to a viscous cap lying on the top of the rostellum. The Epipactis palustris is a type of this group of orchids. Its spike is short, and the pink blossoms stand out horizontally from the stem on long ribbed footstalks, which contain the ovaries. Fig. 83 A is a side view of the flower in its natural position, with the lower sepals alone removed. The labellum, or lowest petal, is interrupted in the middle by a kind of flexible hinge:

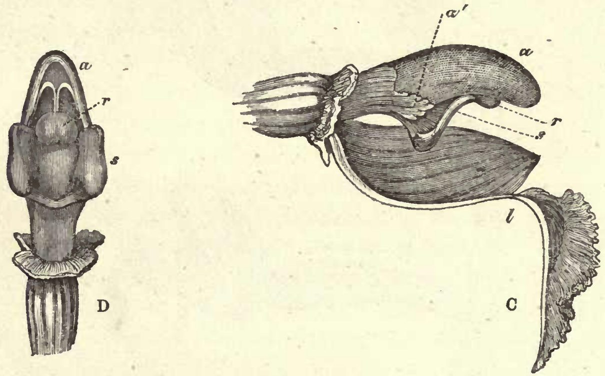


Fig. 84. Epipactis palustris:—C, side view of flower, with sepals and petals and half the labellum removed: D, front view of column: *a*, anther; *r*, rostellum; *s*, stigma; *l*, labellum.

the basal part is a cup-shaped trough, at times abounding in nectar; the extreme part is a wavy leaf (fig. 83 B). The entrance to the nectary cup is nearly closed by the hood and the large anther; but, on account of the elasticity of the hinge, the weight of an insect is sufficient to give access to the nectar; but no sooner is the labellum relieved of the weight, than it springs up into its natural position, and the insect creeps backwards and comes out at the top of the flower with the viscous cap clasped round its proboscis, and the pollen grains attached to it ready to fertilize another blossom. In fig. 84, C represents a section of the Epipactis, and D is a front view of the column.

Of all the British Orchids, the Listera ovata, or Twayblade (fig. 85), has the most curious structure. It grows in woods and pastures, has a creeping root, oval leaves, a downy stem, and yellowish green flowers. Fig. 85 represents a lateral view of a blossom, with all the sepals and petals removed, except the labellum. In this plant the rostellum (*r*) is large, thin, convex in front, concave behind, and arches over (*s*) the stigmatic surface. When the flower is full blown, the anther cells (*a*) are already open, and the naked and friable pollen grains united by a few threads, which form the pointed tips of the pollinia, rest upon the concave back of the rostellum. The labellum, which is contracted at the base, is exceedingly long, hanging down like a narrow ribbon. It is divided half-way up, and furrowed along the middle, from the bifurcation close up to the base of the stigmatic surface (*s*). The borders of the furrow are globular, and secrete much nectar. The rostellum is internally divided into a series of longitudinal cells, or

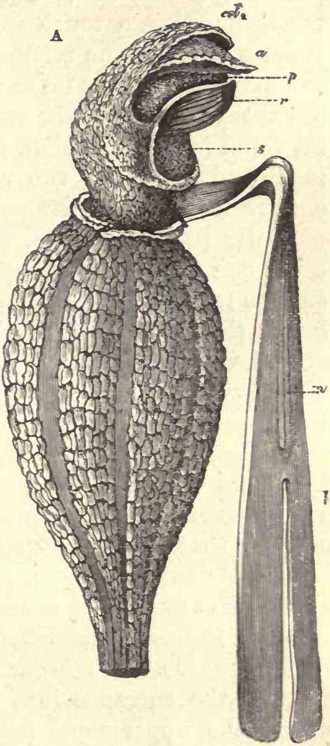


Fig. 85. Listera ovata :—Side view of flower, with sepals and petals cut away : *a*, anther ; *col.* summit of column ; *p*, pollen ; *r*, rostellum ; *s.* stigma ; *l*, labellum ; *n*, nectar-secreting furrow.

chambers, which contain and expel viscid matter with violence on the slightest touch, and the viscid matter sets hard in two or three seconds, and soon assumes a purplish brown tint. So exquisitely sensitive is the rostellum, that a touch from the thinnest human hair suffices to cause the explosion. As the pointed tops of the loose pollinia lie on the crest of the rostellum, they are always caught by the exploded drop. This never fails. So rapid is the explosion, and so viscid the fluid, that it is difficult to touch the rostellum with a needle quick enough not to catch the pollinia already attached to the partially hardened drop, and consequently the slightest touch of any small insect which enters the flower, suffices to explode the rostellum, and the pollinia which attach themselves to its proboscis are carried by it to the next flower to adhere to the viscid stigma and fertilize it. Mr. Darwin has seen two Hymenopterous insects retreat from one of these plants with bright yellow pollinia on their heads, and Mr. C. K. Sprengel saw an insect of that kind leave pollen upon a stigma. The action and structure of Neottia Nidus-avis is almost identically the same as that of Listera ovata.

The Malaxis paludosa, or Bog Malaxis, the smallest of British Orchids, is a rare plant, and differs from all of them in having its labellum turned upwards instead of downwards. Its lower margin clasps the column, making the entrance into the flower tubular. In this orchis the upper sepal and two upper petals are reflexed, to allow insects freely to visit the flower. In many orchids the labellum is properly directed upwards, but assumes its usual position as the lower lip by the twisting of the ovarium, or pedicel, of the flower. In the Malaxis paludosa, however, the twisting has been carried to such an excess, that the flower occupies the same position it would have held if the ovarium had not been twisted at all, and which the stalk ultimately assumes when ripe by the process of gradual untwisting. This little plant belongs to a genus distinguished by having a movable and deciduous anther, and is one of the British orchids that have allied forms among the exotic genera. All Dr. Lindley's vast tribes of Epidendreæ, and the still more numerous and splendid Vandeæ, have not a single British representative.

The structure of the exotic orchids is often very complicated, and they possess many properties unknown in the British genera. Their labellum, or lower lip, is so varied, and sometimes so singular, that it baffles description; besides, it often possesses peculiar motions, sometimes from structure, at other times from irritation. In the Bolbophyllum Rhizophoræ, the labellum is attached to the column by a very narrow thin strap, elastic as india rubber, which oscillates in a singular manner; while that of the B. barbigerum has a beard of fine hairs in almost constant agitation. The irritability of the labellum in many of the allied forms of the orchids is one of their remarkable properties; the slightest touch sets them into motion. The Australian genus Caleana possesses it in the highest degree; for when an insect settles on its labellum, it suddenly shuts up against the column, and encloses it, as it were, in a box.

Some of the exotic orchids have a pseudo-diœcious character. Thus some species of Catasetum have two long horns, or antennæ, attached to the rostellum, which stand over the labellum, and the pedicels of the anthers are fastened down in a curved position; so, when an insect alights upon the labellum and touches the antennæ, the excitement is conveyed by them to the rostellum, the attached edge of the disc of the anthers is ruptured, and they straighten themselves with such force, that not only do they drag the balls of pollen and anther cells from their places of attachment, but the whole pollinium is jerked forward over and beyond the tips of the horns, to the distance of two or three feet. The insect, disturbed by so sharp a blow, or after having eaten its fill, flies with the pollen adhering to it to fertilize the female plant, which differs from the male in having no antennæ. Thus the agency of insects is as requisite to fertilize these semi-diœcious as hermaphrodite orchids.

The Vanilla, which is cultivated for its aromatic pods in Tahiti, Bourbon, and the East Indies, does not bear fruit without artificial aid, which shows that the American insect, which fertilizes it in its own native home, is not indigenous in the places mentioned. It appears that many exotic orchids require a less elevated temperature than has hitherto been supposed.

The form and position of the nectary are exceedingly varied. In certain species, both of the native and tropical orchids, they are always dry; but Mr. Darwin has discovered that, in these cases, the walls of the nectaries are thick and formed of two coats, and that a liquid is contained between them, to which the insect penetrates by piercing the inner wall. The exotic orchids are, for the most part, larger, and require larger insects to fertilize them than our small ones, whose organs are generally microscopic. A curious instance, both of this and of the extraordinary form of the nectary, is found in the Angræcum sesquipedale, a Madagascar orchid, with large six-rayed flowers, like stars formed of snow-white wax. It has a green whip-like nectary, sometimes as much as a foot long, and, from the structure of the plant, it appears that the pollinia never could be withdrawn, until a large moth, with a wonderfully long proboscis, attempts to drain the last drop of nectar from the bottom of the nectary.

Notwithstanding the vast diversity in the form of the orchids, they are homologous in their general structure.

Mr. Robert Brown was the first to observe, that an orchid flower consists of fifteen organs, arranged alternately, three within three, in five whorls. This accords perfectly with a system of spiral vessels developed at an early age in all orchids. Mr. Brown and three of the greatest living botanists[5] have each traced the spirals from six bundles surrounding the ovary in the footstalk to the different organs of the flower, and have found that they consist of fifteen bundles corresponding to the fifteen organs of the flower; namely, three sepals, three petals, six anthers in two whorls (three of which are rudimentary), and three pistils, with their stigmas: these are arranged in alternate whorls, and undergo many modifications. The pistils and anthers are confluent, and form the column; the uppermost stigma becomes the rostellum; the three inner anthers are rudimentary, one forming the front of the column, and the other two forming the membranous sides of the hood which protects the pollen; and, lastly, the two lower anthers are united to the sides of the lowest petal, and form the labellum, which accounts for its great size, frequent tripartite form, and peculiar manner of attachment.

This system has been wonderfully modified to produce the varied groups of extra-tropical and brilliant forms of exotic orchids, yet it can be traced in all.

[5] Messrs. Hooker, Darwin, and Brongniart.

SECTION XIV.

DICOTYLEDONOUS, OR EXOGENOUS PLANTS.

In Endogenous plants the seeds have but one lobe, and the growth is invariably from the interior. In the Exogenous class, on the contrary, the seeds have two lobes, and the increase in growth is external: hence the botanical distinction of Exogenous plants. Although the distinctive character of the highest class of vegetables is to have seeds with two lobes, yet the structure and position of the seeds are extremely diversified. Many have horny coats, such as the pips of apples and oranges; or hard ones, as nuts, and the stones of plums and cherries. They are sometimes on the outside of the fruit, as in strawberries, but oftener within it, as in the melon, the pear, and a variety of others. These succulent substances nourish the young seeds for a time, but, when they are matured, the light and heat which ripened the fruits now combine to accelerate their decay and decomposition, in order to set the seeds free.

Whatever be the size or form of the seeds, whether large or microscopic, they invariably contain two seed lobes or primary leaves, consisting of cellular tissue, between which the miniature plant, with its radicle, stem, and terminal bud lies concealed. At the end of the first year there is little difference in the structure of a young woody plant, whether from a one or two lobed seed; the distinction begins the second year. In herbaceous plants, the stem, which is in general annual, is of loose cellular tissue, with separate bundles of fibro-vascular tissue running from the roots upwards, and passing at last into the leaves, where they form the ribs or veins. Many of the higher forms of plants have fleshy underground stems, as instances of which may be named the Corm, as seen in the crocus and colchicum, the Tuber, as in the potato, the Rhizome, as in the fleshy rootstock of Iris florentina, which yields the violet powder of the shops, and indeed most bulbs may be considered as modifications of stems, though they are more strictly analogous to buds. The edible parts of the carrot, turnip, parsnip, and radish are not stems, but highly developed succulent roots, the unusual development of which is a direct result of cultivation.

A young tree, at the end of the first year of its growth, has subterranean roots, with their branches and fibrils, and an aërial stem, often more or less branched, formed of bark, wood, and pith, with a few leaves at its extremity, all exceedingly tender. Every succeeding year a new cylinder of woody fibre and vascular tissue is formed between the wood and the bark, both in the stem and branches. It follows from this manner of growth, that the stem of a tree, consisting of bark, wood, and pith, is formed of a series of cylinders or extremely elongated concentric cones closely united, so that a transverse section exhibits a series of concentric circles or zones from the surface of the bark to the central pith. The structure of the branches is similar, but the number of zones depends upon the age. Since all the tissues that have been described are combined to form the organs of nutrition and reproduction in a full-grown tree, it affords the best general illustration of the organization of the highest class of vegetables.

Every part of a tree or plant, except the top of the stigma and extremity of the roots, is covered by an extremely delicate film of cellulose, closely pressed down upon one, two, or three layers of transparent colourless cellular tissue compressed into a tubular form, which constitutes the cuticle. These flattened cells, which are firmly united to one another by their edges, differ in shape in almost every tribe of plants. In the monocotyledons they are elongated in the direction of the parallel ribs of the leaves; in the highest class they differ little from circular discs, but they have large sinuosities in their edges, which make their junction very irregular. The upper cells of the cuticle are lined with a waxy substance, which protects the plant from damp; and in many cases it contains more or less silex.

This general covering, or cuticle, is perforated by numerous pores, especially on the under-side of the leaves, and the green tender parts of the branches; they are the organs of respiration. These pores, or stomata, are usually formed of two crescent-shaped cells, joined together by their points or horns, so as to leave an open space like a mouth, through which the plant breathes. These, however, are only the guardians: the opening between them leads into a cavity full of air, which is the antechamber to an interior cavity. The valves of the stomata open and shut according to the humidity or dryness of the atmosphere. All plants of both classes, woody or herbaceous, have stomates, except water plants, fungi, fuci, and others of the lowest class. They are generally very abundant on the under-surface of leaves. They are sometimes in vast numbers on both sides of the leaves, and are essential to the life of the plant. According to MM. Payen and Liepner, silex and azote, together with calcareous and alkaline salts, are invariably found in the cells forming the skin of the roots, stems, leaves, fruits, hairs, and spines. The strong cohesion of the skin, together with the presence of these substances, becomes a defence against the wearing effect of the weather, without diminishing the transparency of the tissues.

The bark is divided into three regions, or zones. The external coat, lying immediately under the skin, is formed of one or many layers of cubical or oblong cells, elongated horizontally. They are transparent and colourless at first, but become brown and opaque with the colouring matter of cork as they grow older. On that account it is called the suberous zone, and sometimes acquires great thickness, as in the Quercus Suber, or cork tree.

The green cellular envelope comes next to the corky layer, and consists of prismatic cells and laticiferous tubes, which form an irregular wide-meshed network, elongated in the direction of the axis of the tree, and sometimes constituting the chief thickness of the bark. This zone, as well as the succeeding, increases imperceptibly by new layers added to its interior, while the exterior coats of the bark perish annually. In some trees they are annually cast off in plates and large flakes, as in the Oriental plane, whose stem and branches look as if they had been peeled in autumn.

The liber, which is the third and innermost zone of the bark, generally consists of several layers of cellular tissue, traversed longitudinally by bundles of woody fibre and laticiferous tubes.

The generating layer of cambium, in which all the phenomena of growth takes place, is a semi-fluid mucilaginous substance, which comes between the liber and the wood. It is most abundant in the spring, and is the origin of all horizontal growth. This mucilage is really made up of a vast multitude of cells, with cell-walls as delicate as those of a soap bubble, which gradually undergo transformation into woody fibre, laticiferous ducts, spirals, &c., thence called the cambium zone. The whole of this matter spontaneously divides into two parts: one forms a new layer of liber on the interior of all those which precede it, and the other a new ring of young sap-wood, exterior to all its predecessors. A portion of the cambium, in its unchanged or liquid state, always remains between the wood and the bark, which are never in absolute contact.

As a new cylinder of wood enclosing all its predecessors is annually formed, the section of a stem perpendicular to its axis exhibits a ring of woody fibre, alternating with a ring of spotted and rayed vascular tubes, which constitute the silver grain of the wood. The rings are more and more crowded, and narrower towards the centre, and at last become impervious to the sap, which only rises through the younger part of the sap wood. In fact, a large portion of the solid fibres of most plants have ceased to take any active share in the performance of vital functions, and, like the solid heart of an oak, retain their integrity simply because they are not exposed to influences which would cause their decomposition. A vegetable tissue exposed to ordinary chemical action, can only remain entire so long as it is performing vital functions. The arrangement of the woody fibre and ducts in the different orders and genera is much varied. The breadth of the rings of wood shows the effect of good and bad seasons; and in extra-tropical latitudes, where there is alternately a period of growth and repose, their number frequently indicates the number of years' growth; so that the age of a tree may be approximately, if not exactly, learned from a critical examination of a section of its stem.

The innermost cylinder of wood is lined by the medullary canal or tube containing the pith. It is a delicate membrane, entirely formed of hollow spiral tubes. The pith, which fills the canal, is of greenish cellular tissue when young, full of sap, and occasionally, though rarely, mixed with vascular and spiral tissue. It passes uninterruptedly to the end of every branch, leaf bud, and flower. Perpendicular plates, called medullary rays, radiate from the medullary sheath and end at the bark, dividing the whole mass of the wood into triangular or wedge-shaped sections. They are thin plates of cellular tissue, stretched horizontally between the central pith and the bark. In each family of trees and shrubs they have a different arrangement, but in all they keep up a horizontal communication between the centre and the circumference, though they do not all extend throughout the whole length of the stem; some do, others do not. Thus the cellular tissue forms a horizontal system, while the fibro-vascular ducts constitute a perpendicular system of tissues. In some trees the pith is scarcely perceptible, and in others it diminishes or vanishes with age, as in the oak. In the alder and other plants it dries up, breaks into pieces, and the canal is filled with air.

In the stem and branches of the Coniferæ, there is scarcely any mixture of vessels amongst the woody fibre, the vascular system generally consisting exclusively of glandular woody tissue, except in the medullary sheath, where spiral vessels are found in small numbers.

The subterranean growth, or descending axis of trees consists of large branches, sometimes tending downwards, but more frequently spreading in extensive ramifications, not far from the surface of the earth. Their growth and structure are similar to those of the stem, but the cylinders of wood are less apparent; they have medullary rays, but no pith; they merely connect the active roots with the stem, and fix the plant firmly in the ground, for they have few or no pores, and contribute little to the nourishment of the plant, except by conveying liquids from the fibrous roots to the upper growth. The active feeding roots spring from them in the form of bunches of white fibres, like cords or threads, which sink straight down into the ground. These real roots are of cellular tissue enclosed in vascular tubes and spiral vessels, which terminate at a little distance from the extremity, leaving a point of loose spongy cellular tissue, called the spongiole, which absorbs from the ground the liquids that nourish the plant. These root fibrils are temporary organs; they die on the older parts of the subterranean branches, and are succeeded by others on the new.

The various tissues which form the stem of a tree form, in the same manner, though in diminished numbers, the complicated ramifications of the branches and the leaf-stalks, and terminate in the leaves themselves. Under the transparent film which forms the skin on the upper-surface of a leaf, there is a layer of soft thin-walled cylindrical or prismatic cells, closely pressed together, and full of green vegetable matter, or chlorophyll. Several layers of thick-walled cells follow, each more loosely aggregated than that which precedes it, and fuller of void spaces, till in the last green layer on the under-side of the leaf the cells are globular, with numerous large irregular void spaces, united in a reticulated system filled with air, and in direct communication with the atmosphere by means of the innumerable stomata, which are to be found in the under-surface of the leaves of all land plants of the higher classes, and which are their organs of respiration.

The form of the leaf is determined by the arrangement of the vascular bundles, which are in communication with those in the interior of the stem, and branch out in various directions through the green layers: these branches unite again, and form the skeleton of the leaf, which is often a delicate maze of the finest lacework of nerves. The vascular system is double, consisting of an ascending and descending portion. The ascending portion, which is continuous with the medullary sheath, becomes continuous at the apex of each nerve of the leaf with the descending portion, which is beneath and in contact with it throughout its ramifications. This descending portion at the base of the leaf-stalk, or petiole, becomes continuous with the bundles of the liber. In the upper part of the nerves of the leaf there are spotted vascular ducts, in the lower part there are laticiferous vessels. Those on the upper side carry the rising sap to the green matter, where it is elaborated and matured, and then it passes into the vessels on the under-side of the nerves or veins, which carry it down the liber.

Buds are generally formed of scales closely imbricated round the young leaves, which are variously folded and firmly packed; they contain the rudiments of the whole plant, and as in a large tree they are renewed every year, the sources of life are all but infinite.

The spines with which many plants are armed are of two kinds; one is permanent, being an excrescence from the wood, as in the blackthorn; the other proceeds from the bark, and may be stripped off, as in the rose; both contain silex, and are covered by the skin common to the whole plant.

Few plants of any kind are without hairs, which are chiefly found on the young shoots, and on the under surface of the leaves. They are either formed of a transparent elongated hollow cell, or consist of a number of transparent colourless superimposed cells, sometimes jointed, but more frequently rectilinear. When they sting, as in the nettle, they are set upon a kind of bulb composed of cells which secrete the acrid colourless liquid which causes the irritation, and when slightly pressed send it through the hair, the point of which breaks off as it enters the skin of the hand.

The hairs are so transparent that the gyration of the azotized liquid, called protoplasm they contain, has been distinctly traced, a motion so universal in some part of the structure of plants that according to the observations of Mr. Wenham, the difficulty is to find a plant, aquatic or terrestrial, in which it does not take place at some period of its growth. The gyration in any given cell preserves a uniform direction; in different cells the direction is different. It will persist in a detached part of a plant for several days or even several weeks. It is arrested by cold, and recommences its gyration when the temperature is raised.

It has been mentioned that in the primordial cell the solid coloured particles often form a nucleus in the centre of the viscid liquid called protoplasm, which is continually diminished by the increase of the watery vegetable sap. At length the protoplasm in the hairs is reduced to mere threads extending from the cell wall to the nucleus, so that the latter looks like a spider in the middle of its web. These threads are really streams of the viscid protoplasm flowing through the more liquid cell sap from the nucleus to the cell wall, where they turn and flow back again in another thread. When there are several currents in the same cell, the nucleus, which is the common point of departure and return, is the centre of the vital activity of the cell, though it does not always maintain a central position; in the cells of the leaves of the Vallisneria spiralis the nucleus even follows the protoplasm, which flows in a broad stream up one side of the cell and down the other, as in the Chara. In most plants the gyration is transitory, for the nucleus which always exists in young cells is dissolved as the cell advances in age, and the protoplasm is so much diminished in quantity, that its motion is imperceptible. There are exceptions, however, as in the hairs of the nettles and some other plants, where it is persistent.

The motion is in general very slow. The thinness and minuteness of the currents may be imagined, since they and the cells containing them are microscopic objects, and the solid particles carried by the liquid, which afford the means of tracing its course, are not more than between the three and the five thousandth part of an inch in diameter. M. Schleiden ascribes the motion to changes in the form of the cells produced by an internal vital action, while Professor Karsten believes, from observations he made on the rotation of liquids in the hairs of the common nettle, that it is a phenomenon of diffusion, depending upon the chemical changes taking place in the cells of the hairs independent of any contractibility, not referable to them.

The whole of the tissues that exist in a well-grown tree are not to be met with in each of the numerous woody and herbaceous plants of the first class; some may be wanting, and those that do exist may be, and generally are, much modified both in form and size. All the trees in the temperate zone, and most of those in the tropics, belong to the class of Exogens; but the annual rings of wood are less distinct in the latter, the periods of repose and activity depending upon the dry and wet seasons not being so decided as our winter and summer. The leaves of tropical plants have a thicker skin than in colder climates, to defend them from an ardent sun. The structure of herbaceous plants in all countries is lax and juicy, they have abundance of pith, large medullary rays, and zones of fibro-vascular tubes, which separate the pith from the bark. In fact, each herbaceous and ligneous family has a structure and properties peculiar to itself; but although there is almost an infinite diversity of form and character, the general type of the class may be traced in all.

Vegetable matter consists of carbon, hydrogen, oxygen, and nitrogen, yet no plant can combine these simple elements into organic substances; they imbibe them by their roots and leaves under the form of carbonic acid, water and ammonia: these they have the power of decomposing, and recombining their simple elements into new compounds. Carbon forms the hard part of plants, and enters extensively into their most delicate structure; but it is never found free. Combined with hydrogen and oxygen it not only constitutes the cell wall cellulose, which may be regarded as the skeleton of the vegetable world, but hundreds of compounds differing decidedly in their properties, yet consisting only of these three elements united with one another in different quantities and proportions. Proteine, a compound of all the four simple elements, is a mucilaginous substance, which lines the primordial cell, is homogeneous at first, and afterwards more or less granulated. It is present wherever the vital energy is in activity.

Although these four primary elements form the basis of vegetation, plants require other substances which they absorb from the ground in a state of solution, such as silex, or rather silicious salts having a base of potash or soda, the carbonates, sulphates, and phosphates of lime, the phosphate of manganese, and the oxides of manganese and iron, with various other metals and substances in a state of combination and solution. A few are universal constituents, as the earths and alkalies; in general each race of plants only absorbs such as are peculiar to itself. Soda abounds in the Algæ and is found in the Liliaceæ, Cruciferæ, and other plants that are indigenous on the sea-coast, or in brackish marshes. Potash exists in land plants, and cannot be replaced by soda, for however rich the soil may be in soda, they do not thrive in it. The ashes of land plants consequently contain the metal potassium, while most of the Algæ yield sodium; they also yield chlorine, iodine, and bromine in a state of combination. It is proved by spectrum analysis, that every plant, with the exception of the very lowest, contains a variety of metals in infinitesimal quantities, as lithium, rhodium, and others; but they are not essential to the welfare of the plants. Iron is the most frequent constituent in very small quantities; there are also occasional deposits of soda, lime, and a little manganese. All the various substances which enter the vegetable system, are combined in definite proportions into an infinite variety of organic compounds in different plants, and in different parts of the same plant, for the decomposed matter is carried by the ascending sap to every part even of the highest trees. Throughout the whole process the law of the division of labour prevails; to each part of a plant, and to each group of cells, its own duty is allotted.

The vegetable sap, consisting of water, carbonic acid, ammonia, and other substances, which enter the spongy extremities of the roots in a liquid state, rises in the form of a crude fluid through the whole loose texture of herbaceous plants, through both the wood and pith of trees under two years' growth, and in older trees and shrubs it rises through the sap-wood of the stem into the branches, and thence into the leaves, the limit of ascent in all plants, so that in spring, all the cells are full of sap. The vascular ducts are capillary tubes, and the cellular tissue is an assemblage of closed cells or sacs, whose wall or cell-membrane is permeable by liquids; hence the imbibition of the roots and the rise of sap in the plant are essentially due to capillary attraction acting contrary to gravitation. The ascension of the liquid is inversely as the diameter of the capillary tubes and cells in the stem and branches; the quantity raised is the same at all heights, and the velocity of ascent is inversely as the height.[6] As soon as the leaves are expanded, they evaporate a quantity of water through their stomata during the day, so that in

[6] Professor Matteucci.

a tree or any plant, an enormous extent of evaporating surface aids in raising the sap by creating a vacuum in all the upper cells and vessels, by which the force of suction and the rapidity of ascent are increased. It appears that the water evaporated by the leaves is in exact proportion to that taken up by the roots to supply its place; but as soon as the young branches are formed, the buds for the following year produced, and when the leaves are full of the chlorophyll which they have consolidated during the summer, the evaporation is less, the sap ceases to rise, the spirals and vascular ducts in the medullary canal and sap-wood are left dry, and fill with air, which they convey to every part of the plant except the bark, to assist in assimilation, that is, in the formation of organic compounds.

During the whole of this process the leaves and other green parts, which are the organs of vegetable respiration, are most active. They absorb carbonic acid gas from the atmosphere by day, and exhale oxygen. For by the direct action of solar light the carbonic acid gas and ammonia in the crude sap are decomposed, part of the oxygen is set free and exhaled, and the rest, with part of the remaining elements, combine to form chlorophyll, which is a compound of starch and a little nitrogen. The oxygen inhaled by plants during the night, combined with other elements in the sap, forms oxidized vegetable compounds.

M. Kosmann, of Strasburg, observed that both the leaves of plants and their corollas give out a ponderable quantity of ozonized oxygen, much more than that which exists in the air, and that the quantity is less in the night.

All parts of plants that are *not green* exhale carbonic acid gas, and inhale oxygen, like animals, night and day; if prevented from inhaling oxygen they lose their vital power, are soon suffocated, and the plant dies. The expiration of oxygen by the leaves is connected with the nourishment of a plant, the inspiration of that gas is connected with its life.

When the sap is completely organized by respiration, evaporation, and the chemico-vital agency of light, it descends chiefly through the cambium, lying between the liber and the wood. From this layer the sap distributes to each organ capable of increase, the requisite nutritious liquids, deposits various organic compounds, and annually renews the cambium. Part of the sap in its descent runs into the wood through the horizontal medullary rays, in the cells of which it deposits starch. The descent of the sap is no doubt due to gravitation.

The latex is a general name for those white or coloured juices peculiar to some plants. It is separated in the leaves from the descending sap, which is always colourless, and consists of a clear liquid, thickened and coloured by white, yellow, reddish-brown, or green globules floating in it; it does not turn blue under the action of iodine, therefore it does not contain starch. These proper juices differ as much in quality as in colour; some contain fatty matters, others substances of a totally different nature, as caoutchouc; a few are bland and nutritious, many acrid and poisonous; some contain alkaloids, others have none. These juices are by no means essential to the life of the plant, for sometimes they are wanting in their most essential parts, and they are found in certain species and not in others most nearly allied. Certain it is, that tropical lactescent plants which do not produce their proper juices when brought to a cold climate, still produce their milk vessels.

These vessels follow the ramifications of the veins of the leaves in the highest class, and also in some of the monocotyledons. In the stem the milk vessels belong especially to the layers of the bark, where they take the form of long reticulated perpendicular ducts, through which the proper juices descend towards the roots.

Each plant has its own system of milk vessels, and M. Lestiboudois has found that the coloured liquids have a rapid motion; the movements are very complicated, not from point to point, but in such a manner that the granules are carried by the liquid into all the ramifications of a complicated network.

The septa, or divisions between the primordial cells, exert a powerful influence upon the substances contained in the sap as it permeates through them, no doubt acting as a dialysing membrane, which separates the gelatinous from the crystalloid matter. The latex is probably separated from the sap by the septa in the cells of the leaves, and sent into the vessels peculiar to it, and then, while the sap is descending and passing through the cambium, it is likely to be dialysed by the septa between the cells of that layer, arresting the protein, and other gelatinous substances, and allowing sugar, starch, and other crystalloid matter to pass freely, and form deposits of organic compounds for the following year. For perennial plants in extra-tropical countries remain in a dormant state during the winter; their cells are then full of organic compounds under the form of protein, as well as sugar, gum, &c., but especially starch, which is converted into sugar or dextrine, when spring awakens the plants to renewed life and activity.

The composition of inorganic matter is very simple; there are comparatively few radicals, and the substances are compounded of few equivalent atoms, at most eight or ten, sometimes only two or three. Carbonic oxide is formed of one atom of carbon and one of oxygen; carbonic acid is formed of one atom of carbon and two of oxygen; and acetylene, M. Bertholet's base of synthetic compounds, contains two atoms of carbon and two of hydrogen, chemically united; but no organic compound contains less than three equivalent atoms, generally a great many more. For example, citric acid, which is lemon juice, contains 12 atoms of carbon, 5 of hydrogen, and 11 of oxygen; while strychnine contains 44 atoms of carbon, 23 of hydrogen, 4 of oxygen, and 2 of nitrogen. Experiment has proved that the powers which maintain stability among the numerous and complex constituents of organic substances decrease in energy as the number of the equivalent atoms augments; hence such compounds are in less stable equilibrium than those of inorganic bodies, and are more liable to be disturbed and changed into new and more stable forms.

As the chemical functions are not the same in all the cells, situated as they are in different parts of a plant, they elaborate different substances from the same materials. Besides, new substances are introduced with the growth of the plant, to be acted upon by the light and heat of the different seasons, so that numerous compounds may be formed out of a given number of the primary elements. For example, the ultimate elements of wheaten flour, or a grain of ripe wheat, are carbon, the three elementary gases, sulphur, phosphorus, calcium, magnesium, and silex; but during the germination and growth of the plant, its flowering, forming the seed, and ripening the grain, certain portions of these elements chemically combine in definite proportions to form cellulose, starch, sugar, gum, gluten, fibrin, albumen, casein, and fat, all of which are found in wheaten flour.

However much plants may differ in their organic products, they all agree in producing protein, which takes an active part in the formation of cells; and all produce neutral hydrates of carbon, such as cellulose, starch, sugar, gum, &c., which consist of carbon, combined with hydrogen and oxygen in the exact proportion that forms water. Many of them have precisely the same quantity of carbon, and only differ in the quantity of the aquatic element, as for example, lignin, starch, and cane-sugar, which consist of 12 parts of carbon, in a state of combination with 8, 10, and 11 parts of water respectively; indeed the affinity between many of these neutral hydrates is of a most intimate character. Some of their varieties are isomeric, that is to say, they contain the same ingredients in the same proportions, and yet they differ essentially in regard to their properties.

Next to cellulose, starch is the most universal and distinctive of vegetable productions, being a constituent of all plants, except the fungi. It abounds in the grains and other seeds, and supplies the young plant with food till it can feed itself. In both of the flowering classes it occurs in small colourless transparent grains, either floating in the sap, attached to the walls of the cells, or accumulated within them. Starch globules of very small size are imbedded, either singly or in groups, in the granules of chlorophyll, or leaf green; the manner in which the green coating takes place is unknown. Starch is an organic substance, varying from grains of inappreciable minuteness to such as are visible to the naked eye, and of such a variety of forms that it can be ascertained with tolerable certainty by what plant a grain of starch has been produced. The small grains are generally globular, but whatever the form may be, each consists of a series of superimposed layers of different densities, which exhibit coloured rings and a black cross in polarized light.

Starch is an early and transient product of young plants, which is destined to be changed into nutritious substances at a later period, but being insoluble in cold water it is unfit to travel with the sap. However a ferment called diastase produced during the incipient germination of the grains and seeds, in the tubers of potatoes, &c., being in a state of change, imparts that state to the starch, and converts it into a sweet soluble matter known as dextrine or starch-gum which is capable of being carried throughout the plant with the sap, and which is itself ultimately changed into sugar. Dextrine is an ingredient in the primordial cell. Starch, dextrine, and cellulose are isomeric: consisting of the same elements with different characters.

The woody part of trees and shrubs, the fibres of hemp, flax, of the Agave, and many other plants, are formed of cellulose, the purest form of that substance being bleached flax and linen. During the progress of vegetation, the cells of the ligneous tissue of trees, also those of woody and fibrous plants, which are transparent and colourless when young, become internally coated or filled with sclerogen, the colouring matter of wood, a substance of various hues. In extra-tropical countries it is generally some shade of brown, sometimes dark, sometimes so pale as to be almost white with a yellowish or reddish tinge; and occasionally it is beautifully marked as in the wood of the olive. In tropical countries the colours are more vivid and varied, deeper and even black, as in ebony. This colouring matter has the same quantity of oxygen as cellulose, but it contains hydrogen and more carbon, hence wood is combustible in proportion to the quantity of sclerogen it contains. In beech it forms half of the wood, in oak two thirds, and in ebony nine tenths, so it is the most highly combustible of the three. The additional carbon is obtained by increased respiration, the hydrogen by decomposition of water in the sap.

Sugar is almost as universal a constituent of the higher classes of plants as cellulose and starch, for besides the saccharine juice of innumerable plants, starch, the acids of unripe plants, and even the acrid juice of the fig and other plants, is turned into sugar as the plant advances to maturity, and the fruits ripen. Manna and other saccharine exudations from the leaves or stems of trees, as the lime tree, are probably intercepted by the dialysing septa of the cells, and exude to the exterior through the pores of the skin. The sweet juice found in the nectaries of flowers is formed in other parts of the plant, and rarely flows to the flower before it is full blown; the quantity is at its maximum during the emission of the pollen, and ceases when the fruit is formed. In diœcious plants and that singular and beautiful race the Orchideæ, it is evidently intended to attract insects for their aid in fertilization.

Vegetable oils, resins, and wax, consisting of the same simple elements as the hydrates, form a large class of inflammable organic substances in which hydrogen predominates. Olive oil is a rare instance of a fixed oil being obtained from a fruit; some laurels have that property also, but the fixed oils are chiefly found in seeds, as the walnut, hazel nut, and the almond, in which the principle of oil is in its greatest purity. It is particularly abundant in hemp seed, and in a great variety of plants the starch in the seed is changed into oil to nourish the embryo, till the seed lobes are above the ground, and the true lobes appear.

Resins, gums, and wax, being colloid substances, are dialysed and ejected from the system either through the fissures in the bark, or by pores in the leaves. The resins exude through the bark from canals that run between the cells of the plant, in solution, and are consolidated by the oxygen on coming into the air. The herbaceous zone in the bark of the fir and pine family furnish an abundant supply of resins and balsams; the camphor tribe and the Amyrids are rich in them, as frankincense, myrrh, balm of Mecca, and the Olibanum, supposed to be the frankincense of scripture.

Wax is a frequent vegetable production, especially in the torrid zone, where many of the wax-bearing plants supply the natives with light. An exudation through the pores of many plants coats their surfaces with resin or wax. Young buds are often covered with resin to protect them from cold and wet during the winter and early spring, as those of the horse-chestnut and balsam poplar. It is wax that gives the bloom to the plum, cherry, and grape, and the rain drops lie on the waxy surface of the cabbage leaf, like balls of diamond, from the total reflection of light at their point of contact. Wax protects plants from damp in a rainy climate, and prevents too strong perspiration from the fleshy leaves of the aloe, cactus, and other inhabitants of the parched and hot regions in the tropics.

The vegetable substances hitherto under consideration are neutral, but the remarkable compounds albumen, fibrin, and casein, already mentioned as constituents of wheaten flour, not only contain carbon and hydrogen with a little oxygen, but azote and small quantities of sulphur and phosphorus. Each of these three organic compounds is the same, whether derived from animal or vegetable matter. Thus albumen is chemically the same, whether obtained from wheat and other grains, from arrowroot, dahlia roots, the serum of blood, or the white of an egg. As it constitutes the film or thin coating of the primordial cell, and combines with dextrine in its internal viscid lining, it not only forms an ingredient in all vegetable organisms, but plays an important part in the growth of the whole vegetable world. Fibrin is chemically the same in the juice of plants and in blood, in which it exists as a liquid during the life of the animal, and as a fibre after death. It forms the basis of the muscular system in animals, and that extracted from the juice of plants coagulates spontaneously like blood. Casein is chemically identical, whether derived from the curd of milk, or from peas and beans. Azote is a very important principle in these substances as well as in the gelatinous substance gluten. It forms an essential part of the animal structure, and is either highly nutritious or deleterious in the vegetable, being at once one of the most valuable, contradictory and powerful agents in nature.

Chemists have formed by synthesis compounds identical with all the fixed and essential oils, for confectioners can now give the flavour of the pear, orange, quince, pine apple and other fruits by means of artificial chemical compounds. All the saccharine substances have not yet been artificially obtained, nor the albuminous substances, albumen, fibrin, and casein.

It cannot be a matter of surprise, when chemists form organic substances out of inorganic elements, that they should succeed in transforming compounds produced by living plants into new compounds, as that of changing the vegetable acids into alcohols, which is now done. But some of the acids themselves are synthetically formed out of inorganic elements; as for example the oxalic, the most common of all the vegetable acids, which is found most abundantly in the Oxalis or wood sorrel, and is a frequent constituent of the highest and lowest plants. The formic acid, which is the acrid stinging principle in ants, is also synthetically formed; it is found in the juice of the stinging nettle and in decaying pine leaves, and contains hydrogen like all the other vegetable acids. These acids result from an augmentation of oxygen during nocturnal respiration, which penetrates deeply into the vegetable structure.

Octahedral, prismatic, and stellar microscopic crystals formed by the chemical combination of the natural acids with bases imbibed by the roots, are deposited in the cells under the skin, and in all parts of plants. However, they appear most frequently as bundles of needle-shaped crystals of carbonate of lime, lying side by side in the hollow of a cell. They are known as raphides, from *raphis* a needle, and may be easily seen under the skin of the medicinal squill. Large single crystals of oxalate of lime, octahedral or prismatic, are found in the cells under the skin of the onion and other plants; and stellar crystals of the same substance abound so much in the common rhubarb that the best specimens of the dry medicinal root contain as much as thirty-five per cent. of them; while certain aged plants of the cactus tribe have their tissues so loaded with them as to become quite brittle. The calcareous base in some instances is combined with tartaric, citric, or malic acid. The crystals of some raphides are $\frac{1}{40}$th of an inch long, others are not more than the hundredth; they are brought into view by polarized light.[7] Spherical raphides between the $\frac{1}{2000}$th and $\frac{1}{4000}$th of an inch in diameter have been discovered scattered profusely through the tissues of the leaves, and those parts of plants which are modifications of the leaves; they may be seen under the skin of Pelargoniums and other plants, and it is supposed that few if any orders of plants are without them.[8]

Although azote forms 788 thousandth parts of the atmosphere, none, or at least no appreciable quantity of it, is absorbed by the vegetable world; that great principle of nourishment is entirely supplied by ammonia and nitric acid, imbibed by the roots, and decomposed by the chemico-vital power. Here it shows its capricious character by combining with other simple elements in the bark, to produce the most precious medicines in some plants, and in others the most deadly poisons, while no vegetable substance is perfectly nutritious without it.

The milk sap, when exposed to the air, coagulates into a tenacious viscid solid. The white juice is generally acrid, or narcotic, or both, and for the most part extremely poisonous, though exhibiting strong contrasts even in nearly allied species. In the order Euphorbiaceæ or Spurgeworts, comprising nearly 1,500 species, a large proportion are hurtful; but there is a gradation from mere stimulants to the most formidable poisons.

[7] Dr. Carpenter, 'Microscope.'
[8] Annals of Natural History for 1863.

This order furnishes the Ethiope and the native Brazilian with poison for their arrows. It contains the Manchineel, and Excœcaria Agallocha, the most poisonous of plants; even the smoke from the burning branches of the Excœcaria affects the eyes with insufferable pain. The white juice of the Fig, one of the Morad order, is violently poisonous; in many, as in the common fig, it is acrid and irritating. The Antiaris toxicaria, the celebrated Upas-tree of Java, which is of the Artocarpeæ or Bread-fruit order, owes its virulence to its milky juice, which contains strychnia, the most fatal of drugs. Dangerous and acrid as these orders are, the Bread-fruit, abounding in starch, supplies the inhabitants of the East Indian islands with excellent food; the milky juice of the Cow-trees, chiefly of the Bread-fruit and Fig orders, furnishes a wholesome beverage to the South Americans; and the Manihot or Cassava, a poisonous spurgewort when raw, yields when roasted nutritious food to whole nations, the heat driving off the dangerous principle. Caoutchouc, a most harmless substance, is the solid produce of many of the most acrid and virulent juices of plants belonging to the preceding orders; the poison is probably left in the liquid. The chemico-vital power is strikingly illustrated by the number of safe and excellent fruits produced by trees full of the most deleterious juices, whether milky or not. Some of the finest fruits in the Indian Archipelago are products of eminently dangerous species of the Sapindaceæ or Soapworts. The acrid juices of the leaves and branches, are so much diluted with water in the fruits, that they become innocuous, or they may be changed into sugar, as in the common fig. Nothing can surpass the virulence of the juice of the Upas-tree, yet its nuts are eaten with impunity, and the pulpy contents of the fruit of the Strychnos nux vomica is food for birds. The leaves and berries of the potato are so strongly narcotic, that an extract from them is intermediate in power between that from deadly nightshade and hemlock, yet the potato itself, like the cassava, is rendered wholesome by being boiled or roasted.

The alkaloids are alkaline substances formed in the bark and milky juices of plants, always combined with an acid during the life of the plant. The chemical structure of this class of substances is very much alike, and chemists have succeeded in forming many of them synthetically; they all contain azote, and have a great affinity for acids. The bark of the different species of Cinchoneæ, especially the Cinchona cordifolia and C. Condaminea, yield three alkaloids—namely, cinchonine, quinine, and cusconine—they are all formed of carbon, hydrogen, and azote in the same proportions; but the first has one atom of oxygen in addition, the second has two atoms in addition, and the third has three; so that in these alkaloids the carbon, hydrogen, and azote combine to form an organic radical, which is oxidized in three different degrees. Six of the alkaloids have been obtained from opium, which is the solid portion of the milk juice of the poppy; of these, morphine seems to be the narcotic principle; and the orange-coloured milk sap of the Chelidonium, a very poisonous and acrid plant of the poppy order, has furnished chelidonine. The Colchicum order, containing the meadow saffron or autumnal crocus, and Veratrum album or white hellebore, as well as many other plants, yield alkaloids, all of which are medicinal or poisonous, according to the dose.

There is scarcely a people, however savage, that has not discovered some exciting narcotic. Opium is almost universally smoked or eaten among Eastern nations; and bhang, a strong narcotic, obtained from the leaves of Indian hemp, is in equally universal use among the Brazilian savages and Hottentots, but especially among the Malays, who are excited to madness when they smoke it too freely. The same intoxicating effect is produced by a strong liquor prepared from the Datura sanguinea, a species of stramonium; and its congener tobacco, now all but a necessary of life among civilized mankind, was smoked by the natives of the American continent, before the arrival of the Europeans, as a relief from hunger.

Coffee has been long in use on account of its stimulating principle caffeine, which is now discovered to be the same with theine, the latter, however, being less exciting, unless the tea plant grows in a very hot climate. In countries where nature furnishes few narcotic principles, wine, beer, and spirits supply their place, especially in the far north, where animal heat is rapidly carried off by the cold, and carbon must be furnished to satisfy the all-devouring oxygen which we draw in at every breath.

Caffeine, the highly azotized principle of coffee, obtained from tea leaves and coffee beans, is one of the substances known as neutral crystallisable principles. Similar substances are found in asparagus, pepper, almonds, the bark on the roots of the apple, pear, plum, and cherry trees, as well as in the bark of the willow. The two last are especially analogous, and contain no azote, as the others do.

The colouring matter of flowers is a fluid contained in cells, situated immediately under the skin, which itself is perfectly transparent and colourless. The whiteness of the white Camellia, rose, lily, and other flowers, is supposed to be owing to the total reflection of light from the cells immediately below the skin, which are either full of air, or of a colourless liquid. The predominating colours are yellow, red, and blue, with the various intermediate tints. Sometimes these colours are converted one into another in the petal after fertilization, at which period the colours are brightest. The chemical nature of these liquids, the cause of their variety, and their definite arrangement in one and the same petal, do not seem as yet to be ascertained.

The parts of plants that are not green inhale oxygen from the atmosphere, and exhale carbonic acid gas exactly like animals. During the chemical combinations of the oxygen with the carbon derived from the nutriment to form the carbonic acid gas, heat is necessarily evolved, especially in the flower, the point of maximum heat varying with its expansion. The blossoms of the Aroideæ, or Arums, are remarkable for the evolution of heat. According to Saussure, a blossom of the common Arum maculatum consumes five times its volume of oxygen in twenty-four hours previous to its evolution of fruit, so it is not wonderful that the chemical combination of such a quantity of oxygen should produce a strong development of specific temperature. By M. Dutrochet's observations, the heat evolved by the Arum maculatum has a maximum in the day and a minimum in the night, and he found that it exceeded the heat of the surrounding air by between 25° and 27°. The heat of the Colocasia odorata, another Arad, was determined by several observers to be even 50° above the warmth of the air. The heat evolved by germinating seeds when in a heap is not from fermentation; it is owing to their consumption of oxygen and expiration of carbonic acid gas. The temperature of all vegetating parts of plants, the roots, leaves, young juicy shoots, &c., is far superior to that of their flowers. It arises from the nutritive process, and has a maximum at noon, and a minimum at midnight, like that of the flower. The growth of plants is most vigorous at noon; consequently there is then a greater evolution of heat.

Water in small quantities is secreted night and morning from the points of the leaves of many plants, probably to relieve them from a superabundance of liquid, which evaporation is insufficient to carry off. The arums are remarkable for the quantity they eject. It falls in drops from the points of the leaves. About half a pint is given out every night by the enormous leaves of the Caladium distillatorium, a species of Arad. In that plant, and in the Colocasia, the water flows in canals along each rib into a general duct, which runs along the border of the leaf, and terminates in an orifice upon the surface.

Since electricity is developed by chemical action in unorganized matter, it may be inferred that it is also developed within the vegetable cell where so many organic compounds are formed; but it is probably given off from the points of the leaves or by evaporation from their surfaces. Professor Fleming ascertained by actual experiment, that the sap of a leaf, and its surface, are in different electric states; he also found that the surface of the spongioles of the roots of plants and the ascending sap have opposite electricities. Both of the preceding cases the Professor ascribes, in part at least, to organic changes which take place during vegetation. Slight currents of electricity were obtained from the petioles of flowers, but fruits and tubers give powerful electrical currents due to the reaction of different vegetable juices upon one another. The tuberose is said to emit scintillations and dart small sparks of light in a hot electric evening, and gardeners have long been aware that mushroom spawn is most prolific in stormy weather.

The irritability of the tissues of plants which renders them liable to be acted upon by external causes, has occupied the attention of many celebrated botanists. From experiments by Professor Ferdinand Cohn and his pupil M. Krabsch upon the irritability of the stamens in the florets on the discs of composite flowers, more especially the Centaureas, they have come to the conclusion that susceptibility to the excitement of light, as well as to that of mechanical and probably electrical impulse, is possessed by all young vigorous tissues, and upon comparing the phenomena of these with those of animal irritability, they further conclude that the faculty of responding to external irritation by internal movements and change of form, belongs to cells, and holds good in the vegetable as in the animal kingdom. To be irritable, to change its normal form as a vessel of excitation, and to revert to the normal form after a while by its internal elasticity, are characteristics of the living cell. In plants these properties are met with only when the vital processes are in full activity, and therefore are particularly noticed during the period of flowering, when the processes are at the maximum. And it may be remarked that the stamens, in which irritability is most frequently noticed, are the only organs in which an elevation of temperature measurable by the thermometer occurs, although a certain degree of heat is generated in all plant cells by the chemical process going on within them. It is to be supposed that irritable properties belong to all parts of plants, but that they exist in an intensified degree, and for a certain epoch, in those parts where their results arrest attention, as in the stamens of the Centaurea, berberry, cactus, Cistus, nettle, &c., and in the anthers of the Stylideæ, the leaves of Dionæa muscipula, and many others, all of which are more or less affected by the external action of mechanical force and electricity; for it is scarcely possible that plants should not be under the influence of atmospheric electricity, since every shower of rain forms a perfect conductor between the clouds and the earth. The motion does not always immediately follow the excitement; plants often require to be rudely shaken before the movement begins. M. Hofmeister has observed that all young shoots and leaves become curved by mechanical shaking.

Light is the most universal and important exciting cause in the vegetable world. The mouths of the stomata are opened by the influence of light. The leaves, young shoots, and tendrils turn to the light; it regulates the sleep of plants, as well as the diurnal motions of the daisy and sunflower. The opening of blossoms and of folded leaves which had been closed in sleep during the night, shows the susceptibility of their tissues to the influence of light, an influence beautifully exhibited by the orange-coloured Eschscholtzia, which shuts its golden blossoms under every passing cloud.

All M. Cohn's experiments prove that in the Mimosa pudica, which is highly sensible to the action of light, heat, electricity, and touch, 'the propagation of the external excitement, proceeds in the same mode as in animals, and there is little doubt that the vascular tissue (which contain spiral vessels) constitute the special bundles adapted for the purpose, and that the phenomena of contractibility depend upon a muscular tissue.'[9]

From Professor Franklin's experiments it appears that 'the motions resulting from external causes are owing to vital contractibility, and that they are governed by the same laws which regulate similar action in the animal kingdom. Their energies vary with the vigour of the plant; they are exhausted by over exercise, and require rest; and like animals they are lulled and put to sleep by chloroform and narcotics.'

[9] Annals and Magazines of Natural History for 1863.

END OF THE FIRST VOLUME.

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Prob. of Iron in Sun = 10^9 p. 152
Spectrum of Stars = 155

$\frac{1}{10}$ lb per sq ft

4800 lbs

240
200
48000

15
150
2250