## RECENT PROGRESS IN SPECTROSCOPIC METHODS.[1]

AN observer who for the first time views the light of the sun through a prism cannot fail to express his wonder and delight at the gorgeous display of colours into which the white light is separated; and if the observation is made under the same conditions as in the celebrated experiment of Newton, 1666, there is, in truth, nothing else which he could observe. You will remember that he allowed a beam of sunlight to stream through a round opening in a shutter of his window, falling on a glass prism, which bent the sun-rays by different amounts depending on their colour, thus spreading out the white round sunlit spot on the opposite wall into a coloured band—the spectrum—which he rather arbitrarily divided into seven colours—red, orange, yellow, green, blue, indigo, and violet. (If the division were made to-day I doubt if indigo would be included.) There is, in fact, no definite demarcation between these, and they shade insensibly into each other, and if the solar spectrum were always produced under these conditions we should say it was continuous; indeed, if it were not the sun, but an argand burner or an incandescent lamp, which served as source, it would really be so.

But even if the source consisted of isolated (but sufficiently numerous) separate colours, the fact would be disguised by the overlapping of the successive images. In other words, the spectrum is not pure. In order to prevent this overlapping, two important modifications must be made in Newton's arrangement. First, the light must be allowed to pass through a very *narrow* aperture, and, secondly, a sharp *image* of this aperture must be formed by a lens or mirror.

The first improvement was introduced by Wollaston in 1802, who writes:—"If a beam of daylight be admitted into a dark room by a *crevice* one-twentieth of an inch broad, and received by the eye at a distance of 10 or 12 feet through a prism of flint glass held near the eye, the beam is seen to be separated into the four colours only—red, yellowish-green, blue, and violet. . . . The *line* that bounds the red side of the spectrum is somewhat confused. . . . The *line* between the red and green . . . is perfectly distinct; so also are the two limits of the violet. There are other distinct lines (in the green and blue . . . )."

The second improvement was effected by Fraunhofer, 1814, and by observing the light which fell from such a narrow aperture upon a prism by means of a *telescope* he discovered upwards of 750 *dark* lines in the solar spectrum, and mapped their position and general character.

In recognition of the enormous importance of this discovery, these lines are always known as the Fraunhofer lines.

A minor inconvenience in Fraunhofer's arrangement lay in the fact that the slit source had to be at a considerable distance from the telescope; and this was obviated in the apparatus of Bunsen and Kirchhoff, 1860, which is essentially the same as the modern spectroscope of to-day, consisting of a slit and collimator, prism, and observing (or photographic) telescope.

On this beautifully simple device rests practically the whole science of spectroscopy, with all its wonderful applications and all the astonishing revelations of the structure and motions of the sidereal universe and of the constitution of the atoms of matter of which it consists—nay, even of the electrons of which these atoms are built!

Without the telescope it is evident that the science of spectroscopy would be as limited in its field as was the science of astronomy without the telescope. It is interesting, indeed, to compare the progress of the two sciences as dependent on the successive improvements in the two instruments.

Without the telescope nothing could be discovered concerning the heavenly bodies (with the exception of a few of the more evident features of the sun, the moon, and the comets) except the brightness and places of the stars and the motion of the planets, and even these could, at best, be very roughly determined (say, to within one part in five thousand, or something over a half-minute of arc). Without the telescope spectroscopy would also have been limited to observations of general differences in character of radiations and absorptions, and a rough determination of the position of the spectral lines, with a probable error of this same order of magnitude.

In fact, the *resolving power* of the eye is measured by the number of light waves in its diameter, about 5000, and if a double star (or a double spectral line) presents a smaller angle than 1/5000 it is not "resolved." The resolving power of a telescope with a 1-inch objective would be about 100,000, so that details of the solar and lunar surfaces, and of planets, nebulæ, and of double stars and star groups can be distinguished the angular distance of which is of the order of 1/100,000. The discs of the planets, the rings of Saturn, the moons of Jupiter, and some star groups and clusters, begin to be distinguishable. Our largest telescopes have a resolving power as high as 2,000,000, corresponding to a limit of separation of one-tenth of a second.

But in order to realise the full benefit of the telescope when used with a prism, the latter must be so large that the light which falls upon it entirely fills the object glass. The efficiency of the prism then depends on its size and on its dispersive power.

In order to form an idea of the separating or resolving power in spectroscopic observations it will be convenient to consider the Fraunhofer line D of the solar spectrum or the brilliant yellow line corresponding to the radiation given out by a salted alcohol flame. This Fraunhofer recognised as a double line, and the length of the light-waves of the components are approximately 0·0005890 mm. and 0·0005896 mm. respectively. The difference is, then, 6/5893 of the whole, or about 1/1000, requiring a prism of resolving power of 1000 to separate them. If the prism were made of flint glass with a base of 25 mm. it would just suffice to show that the line was double.

Now we know of groups of spectral lines the components of which are much closer than those of sodium. For instance, the green radiation emitted by incandescent mercury vapour consists of at least six components, some of which are only a hundredth of this distance apart, and requiring, therefore, a resolving power of 100,000 to separate them. This means a glass prism of 100 inches, the construction of which would present formidable difficulties. These may be partially obviated by using twenty prisms of 5 inches each; but owing to optical imperfections of surfaces and of the glass, as well as the necessary loss of light by the twenty transmissions and forty reflections, such a high resolving power has not yet been realised.

The parallelism of the problems which are attacked in astronomy and in spectroscopy is illustrated in the following table. It is interesting to observe how intimately these are connected and how their solution depends on almost exactly the same kind of improvement in the observing instruments, particularly on their *resolving power*; so that not only are the older problems facilitated and their solution correspondingly accurate, but new problems, before thought to be utterly beyond reach, are now the subject of daily investigation.

| *Astronomical.* | *Spectroscopic.* |
|---|---|
| (1) Discovery of new stars, nebulæ, and comets. | Discovery of new elements. |
| (2) Star positions. | Wave-length of spectral lines. |
| (3) Double stars and star clusters. | Double lines, groups, and bands. |
| (4) Shape and size of planets and nebulæ.<br>(?) Star discs. | Distribution of light in spectral "lines." |
| (5) Star motions (normal to line of sight).<br>Resolution of doubles.<br>Solar vortices.<br>Protuberances, &c. | Star motions (parallel with line of sight).<br>Resolution of doubles.<br>Solar vortices.<br>Protuberances, &c. |
| (6) | Changes of character and position of lines with temperature, pressure, and magnetic field. |

(7) Spectroheliograph.
(Combination of telescope and spectroscope.)

[1] Address of Dr. A. A. Michelson, retiring president of the American Association for the Advancement of Science, delivered at the Washington meeting of the Association on December 27, 1911.

We must especially note that the newer problems require an enormous resolving power. In the telescope this has been accomplished partly by the construction of giant refractors and partly by enormous reflectors: and, curiously enough, the same double path is open to spectroscopy; for we may employ the analogous dispersive power of refracting media or the diffractive power of reflecting media. The increasing cost and difficulty of producing large transparent and homogeneous blocks of glass have tended to limit the size and efficiency of lenses and of prisms, and these have been more or less successfully replaced, the former by mirrors and the latter by *diffraction gratings.*

These are made by ruling very fine lines very close together on a glass or a metal surface. The effect on the incident light is to alter its direction by an amount which varies with the wave-length—that is, with the colour; and a spectrum is produced which may be observed to best advantage by precisely the same form of spectrometer, with a substitution of a grating for the prism.

The dispersion of a diffraction grating depends upon the closeness of the rulings; but the resolving power is measured by the total number of lines. It is important, therefore, to make this number as large as possible.

The first gratings made by Fraunhofer, 1821, contained but a few thousand lines, and had a correspondingly low resolving power—quite sufficient, however, to separate the sodium doublet. A considerable improvement was effected by Nobert, whose gratings were used as test objects for microscopes; but these were still very imperfect as spectroscopic instruments, and it was not until Rutherford, of New York, 1879, constructed a ruling engine with a fairly accurate screw that gratings were furnished which compared favourably with the best prisms in existence.

With 30,000 lines (covering more than 40 mm.) the theoretical resolving power would be 30,000; practically about 15,000—sufficient to separate doublets the components of which were only one-fifteenth as far apart as those of the sodium doublet.

An immense improvement was effected by Rowland, 1881, whose gratings have been practically the only ones in service for the last thirty years. Some of them have a ruled surface of 150 mm. × 60 mm., with about 100,000 lines, and can separate doublets the distance of which is only 1/100 of that of the sodium doublet in the spectrum of the first order. In the fourth order it should resolve lines the distance of which is only one-fourth as great.

Practically, however, it is doubtful if the actual resolving power is more than 100,000, the difference between the theoretical and the actual performance being due to the defect in uniformity in the spacing of the grating furrows.[1]

The splendid results obtained by Rowland enabled him to produce the magnificent atlas and tables of wave-lengths of the solar spectrum which are incomparably superior in accuracy and wealth of detail to any previous work; so that until the last decade this work has been the universally accepted standard. With these powerful aids it was possible not only to map the positions of the spectral lines with marvellous accuracy, but many lines before supposed simple were shown to be doublets or groups; and a systematic record is given of the characteristics of the individual lines, for example, whether they are intense or faint, nebulous or sharp, narrow or broad, symmetrical or unsymmetrical, reversed, &c.—characteristics which we recognise to-day as of the highest importance, as giving indications of the structure and motions of the atoms the vibrations of which produce these radiations.

One of the most difficult and delicate problems of modern astronomy is the measurement of the displacement of spectral lines in consequence of the apparent change of wave-length due to "radial velocity" or motion in line of sight. This is known as the Doppler effect, and had been well established for sound waves (a locomotive whistle appears of higher pitch when approaching and lower when receding); but it was only confirmed for light by Huggins and by Vogel in 1871, by the observation of displacements of the solar and stellar spectral lines.

It may be worth while to indicate the accuracy necessary in such measurements. The velocity of rotation of the sun's equator is approximately 2 kilometres per second, while the velocity of light is 300,000 kilometres per second. According to Doppler's principle, the corresponding change in wave-length should be 1 : 150,000—a quantity too small to be "resolved" by any prism or grating then in existence. But by a sufficient number of careful micrometer measurements of the position of the middle of a given spectral line, the mean values of two such sets of measurements would show the required shift. It is clear, however, that if such radial velocities are to be determined with any considerable degree of accuracy, nothing short of the highest resolving power of the most powerful gratings should be employed.

Another extremely important application of spectroscopy to solar physics is that which, in the hands of Hale and Deslandres, has given us such an enormous extension of our knowledge of the tremendous activities of our central luminary.

The spectroheliograph, devised by Hale in 1889, consists of a grating spectroscope provided with two movable slits, the first in its usual position in the focus of the collimator, and the second just inside the focus of the photographic lens. A uniform motion is given to the two slits so that the former passes across the image of the solar disc, while the other exposes continually fresh portions of the photographic plate.

If the spectroscope is so adjusted that light of the wave-length of a particular bright line in a solar prominence (say, one of the hydrogen or the calcium lines) passes through the instrument, then a photograph of the prominences, or sun-spots, or faculæ, &c., appears on the plate. But the character of this photograph depends on the portion of the bright spectral "line" which is effective, and as the entire range of light in such a line may be only a thirtieth part of the distance between the sodium lines, it would require a resolving power of at least 100,000 to sift out the efficient radiations so that they do not overlap.

As another illustration of importance of high resolving power in attacking new problems, let us consider the beautiful results of the investigations of Zeemann on radiation in a magnetic field. The effect we know is a separation of an originally simple radiation into three or more, with components polarised at right angles to each other. This is one of the very few cases where it is possible actually to alter the vibrations of an atom (electron), and the fact that the effect is directly calculable, as was first shown by Lorentz, has given us a very important clue to the structure and motions of the atoms themselves.

The experiment is made by placing the source of radiation (any incandescent gas or vapour) between the poles of a powerful electromagnet and examining the light spectroscopically. Now this experiment had been tried long before by Faraday, but the spectroscopic appliances at his disposal were entirely inadequate for the purpose.

Even in the original discovery of Zeemann only a broadening of the spectral line was observed, but no actual separation. In fact, the distance between components which had to be observed was of the order of a hundredth of the distance between the sodium lines, and in order to effect a clear separation, and still more to make precise measurements of its amount, requires a higher resolving power than was furnished by the most powerful gratings then in existence.

As a final illustration, let us consider the structure of the spectral "lines" themselves. Rowland's exquisite maps had shown many of these, which were then thought simple, to be double, triple, or multiple, and there are clear indications that even the simpler lines showed differences in width, in sharpness, and in symmetry. But the general problem of the distribution of light within spectral lines had scarcely been touched. Here, also, the total "width" of the line is of the order of 1/100 of the distance between the sodium lines, and it is evident that without more powerful appliances further progress in this direction was hopeless.

Enough has been said to show clearly that these modern problems were such as to tax to the utmost the powers of the best spectroscopes and the experimental skill of the most experienced investigators.

Some twenty years ago a method was devised which, though somewhat laborious and indirect, gave promise of

[1] This applies to all the Rowland gratings which have come under my notice, with the exception of one which I had the opportunity of testing at the Physical Laboratory, University, Göttingen. The resolving power of this grating was about 200,000.

furnishing a method of attack for all these problems far more powerful than that of the diffraction grating.

Essentially, the extremely simple apparatus which is called the *interferometer* consists of two plane glass plates. These can be made accurately parallel, and their distance apart can be varied at will. When light is reflected from the surfaces which face each other, the two reflected beams of light waves "interfere" in such a way as to add to each other, giving bright maxima, or to annul each other's effect, producing dark spaces between.

The alternations of light and darkness which occur when the eye observes in the direction of the normal are very marked so long as the plates are very near together; but as this distance increases the interferences become less and less distinct, until at a distance, *which depends on the character of the incident light*, they vanish completely. A perfectly definite relation holds between the "visibility curve" and the character of the radiation, so that the one can be deduced from the other.

Now the "resolving power" of such an apparatus is measured by the number of light waves in the doubled distance between the surfaces. This is about 100,000 for a distance of 1 inch; but the distance is, in fact, *unlimited*, and as the instrument itself is practically free from errors of any sort, its resolving power is practically unlimited.

The use of this method of light-wave analysis is attended with certain difficulties, and the results obtained are not always free from uncertainties; but in view of the fact that at this time no other methods of this power had been devised, it has amply proved its usefulness. Among the results achieved by it may be mentioned the resolution of many lines supposed single into doublets, quadruplets, &c.; the measurement of their distances apart; the distribution of light in the components; the measurement of their width and the changes produced in them by temperature, pressure, and presence of a magnetic field.

Among the radiations thus examined, one proved to be so nearly homogeneous that more than 200,000 interference bands could still be observed. Otherwise expressed, the exact number of light waves in a given distance, say 10 cm., could always be determined, and by a comparison with the standard meter the absolute wave-length of this radiation could be measured and made to serve as a basis for all wave-lengths.

The standard of length itself, the standard metre, is defined as the distance between two lines on a metal bar; and notwithstanding all the care taken in its manufacture and preservation, there is no assurance that it is not undergoing a constant slow change, doubtless very small, but perhaps appreciable by the refinements of modern metrological methods if there were any fundamental unchangeable standard with which it could be compared. The earth's circumference was supposed to be such a standard, and the metre was originally defined as the millionth part of an earth-quadrant; but the various measurements of this quadrant varied so much that the idea was abandoned. The attempt to base the standard on the length of a seconds-pendulum was no more successful.

But we have now the means of comparing the standard metre with the length of a light wave (the standard metre contains 1,553,163 waves of the red radiation from cadmium vapour), so that should the present standard be lost or destroyed, or should it vary in length in the course of years, its original value can be recovered so accurately that no microscope could detect the difference. True it is that in the course of millions of years the properties of the atoms which emit these radiations and the medium which propagates them may change—but probably by that time the human race will have lost interest in the problem.

The difficulties in the application of the interferometer method of investigating the problems of spectroscopy, it must be admitted, were so serious that it was highly desirable that other instruments should be devised in which these difficulties were avoided. This need was supplied by the "echelon," an instrument based on the same principle as the diffraction grating, but consisting of a pile of glass plates of exactly equal thickness and forming a kind of stairs, whence its name.

The grating acts by assembling light-waves the successive wave trains of which are retarded by some *small* whole number of waves (usually less than six, the distance between the grating spaces being about six light waves), whereas this retardation in the echelon is many thousand.

But the resolving power depends on the *total* retardation of the extreme rays, and this may be made very large either by having an enormous number of elements with small retardations, or by a comparatively small number of elements with large retardations. For example, an echelon of thirty plates of glass 1 inch thick, each producing a retardation of 25,000 waves, would have a resolving power 750,000, about seven times that of the grating; and this high value has actually been realised in practice.

Simultaneously, Perot and Fabry showed that by the repeated reflections between two silvered surfaces[1] a very high resolving power is obtained, and a few years later Lummer devised the plate interferometer, which embodies practically the same idea.

The resolving power of all of these newer devices is clearly many times as great as that of the grating; but all equally share the objection which holds (but to a far less extent) for the grating—that the different succeeding spectra overlap. It is true that this difficulty may be overcome (though with some loss of simplicity and considerable loss of light) by employing auxiliary prisms, gratings, echelons, &c., and in this form all these modern instruments have contributed results of far-reaching importance, which would have been impossible with the older instruments.

The diffraction grating possesses so many advantages in simplicity and convenience of manipulation that it is even now used in preference to these modern instruments, except for such refinements as require an exceptionally high resolving power. But has the resolving power of the grating been pushed to the limit? We have seen that this depends on the number of rulings; and it is certainly possible to increase this number. But the theoretical value is only reached if the rulings are very accurately spaced; for instance, the resolving power of the Rowland grating is only one-third of its theoretical value. This is a direct consequence of inaccuracies in the spacing of the lines. If a grating could be constructed of, say, 250,000 lines with exact spacing, the resolving power would be equal to that of the most powerful echelon. The problem of the construction of such gratings has occupied my attention for some years; and while it has met with some formidable difficulties, it has had a fair measure of success, and gives promise of still better results in the near future.

The essential organ in all ruling engines in actual use is the screw, which moves the optical surface to be ruled through equal places of the order of a 500th to 1000th of a millimetre at each stroke; and the principal difficulty in the construction of the machine is to make the screw and its mounting so accurate that the errors are small compared with a thousandth of a millimetre.

This is accomplished by a long and tedious process of grinding and testing, which is the more difficult the longer the screw. A screw long enough to rule a 2-inch grating could be prepared in a few weeks. Rowland's screw, which rules 6-inch gratings, required two years or more; and a screw which is to rule a grating 15 inches wide should be expected to take a much longer time, and, in fact, some ten years have been thus occupied.[2]

I may be permitted to state a few of the difficulties encountered in this work, some of which would doubtless have been diminished if my predecessors in the field had been more communicative.

First is the exasperating slowness of the process of grinding and testing the screw. This cannot be hurried, either by grinding at greater speed or by using any but the very finest grade of grinding material. The former would cause unequal expansions of the screw by heating, and the latter would soon wear down the threads until nothing is left of the original form.

Secondly, in ruling a large grating, which may take

1 Boulouch, 1893, had observed that Na rings were doubled both by reflection (grazing incidence) and transmission (normal incidence) with a light silver film.

2 A method of ruling gratings accurately, which is independent of any mechanical device, is now in process of trial, in which the spacing is regulated by direct comparison with the light waves from some homogeneous source such as the red radiations of cadmium.

eight to ten days, the ruling diamond (which must be selected and mounted with great care) has to trace a furrow several miles long on a surface as hard as steel, and often breaks down when the grating is half finished. The work cannot be continued with a new diamond, and must be rejected and a new grating begun.

Thirdly, the slightest yielding or lost motion in any of the parts—screw, nut, carriage, or grating—or of the mechanism for moving the ruling diamond, is at once evidenced by a corresponding defect in the grating. When, after weeks, or sometimes months, of preparation all seems in readiness to begin ruling, the diamond point gives way, and as much time may have to be spent in trying out a new diamond.

When the accumulation of difficulties seems to be insurmountable, a perfect grating is produced, the problem is considered solved, and the event celebrated with much rejoicing, only to find the next trial a failure. In fact, more time has been lost through such premature exhibitions of docility than in all the frank declarations of stubborn opposition!

One comes to regard the machine as having a personality—I had almost said a feminine personality—requiring humouring, coaxing, cajoling, even threatening! But finally one realises that the personality is that of an alert and skilful player in an intricate but fascinating game who will take immediate advantage of the mistakes of his opponent, who "springs" the most disconcerting surprises, who never leaves any result to chance, but who nevertheless plays fair, in strict accordance with the rules of the game. These rules he knows, and makes no allowance if you do not. When *you* learn them, and play accordingly, the game progresses as it should.

As an illustration of the measure of success attained in this work, I would direct attention to a recent comparison by Messrs. Gale and Lemon of the performance of a grating of 6½-inch ruled surface with that of the echelon, the Perot and Fabry interferometer, &c. The test object is the green radiation from incandescent mercury vapour. The spectrum of this radiation had been supposed a simple line until the interferometer showed it to be made up of five or more components. The whole group occupies a space about one-fifteenth of that which separates the sodium lines.

The grating clearly separates six components, while the more recently devised instruments give from six to nine. Two of these components are at a distance apart of only 1/150 of the distance between the sodium lines, and these are so widely separated by the grating that it would be possible to distinguish doublets of one-half to one-third this value, so that the actual resolving power is from 300,000 to 400,000—of the same order, therefore, as that of the echelon.

It may well be asked, why is it necessary to go any further? The same question was put some twenty years ago when Rowland first astonished the scientific world with resolving powers of 100,000, and it was his belief that the width of the spectral lines themselves was so great that no further "resolution" was possible. But it has been abundantly shown that this estimate proved in error, and we now know that there are problems the solution of which depends on the use of resolving powers of at least a million, and others are in sight which will require ten million for their accurate solution, and it is safe to say that the supply will meet the demand.

To return to our comparison of the telescope and the spectroscope; while the progress of investigation of the stellar universe will be ever furthered by increased size and resolving power of the telescope, this is very seriously hampered by the turbulence of the many miles of atmosphere through which the observations must be made. But there is no corresponding limit to the effective power of spectroscopes, and the solution of the corresponding problems of the subatomic structures and motions of this ultramicroscopic universe may be confidently awaited in the near future.

The messages we receive from the depth of the stellar firmament or from the electric arcs of our laboratories, come they in a millionth of a second or in hundreds of light-years, are faithful records of events of profound significance to the race. They come to us in cypher—in a language we are only beginning to understand.

Our present duty is to make it possible to receive and to record such messages. When the time comes for a Kepler and a Newton to translate them we may expect marvels which will require the utmost powers of our intellect to grasp

## THE CARBONISATION OF COAL.[1]

### I.

BEFORE it is possible to explain the highly complex actions taking place in the destructive distillation of coal, it is important to have some definite idea of the nature of the raw material with which we have to deal; and although many attempts have been made to gain an insight into the composition of coal, the wide variations in its characteristics, the difficulties attending any attempt to separate its constituents, and the ease with which the products of its decomposition undergo secondary changes at the temperatures employed in breaking it up, have prevented any very satisfactory solution of the problem being arrived at.

The one thing generally admitted is that coal is the fossil remains of a vegetation that flourished in the carboniferous period of the world's history, and that it has passed through successive stages of checked decay; the action of time, temperature, and pressure, generally out of contact with air, resulting in the conversion of these into the tertiary coals (such as brown coals or lignites), and probably by a continuance of the action yielding eventually the true coal.

All the plants of which we have fossilised record in our coal measures consisted of sedges and reeds, tree ferns, club mosses or lycopodia, and trees akin to the pine; but in those prehistoric days the conditions of growth—warmth, moisture, and carbon dioxide—were such that these plants grew with a succulent freedom and rapidity unknown in latter days, and which rendered their tissues an easy prey to decay and fermentation—actions which left only the more resistant unchanged. The work of Morris, Carruthers, Fleming, and Huxley has shown us that the bituminous matter in coal is largely derived from the spores of fossil mosses akin to the lycopodia. If we take the club mosses of to-day, we find their spores give us the body known as lycopodium—a substance so resinous in its nature that it resists the action of water, and is used to coat pills, while the same resinous characteristics render it so inflammable that a little blown through a flame provides the theatrical world with its artificial lightning. Spores of this character, from the giant growths of the carboniferous period, together with the more resinous portion of plants akin to the pine, are the substances which have best resisted the actions taking place during the ages that have elapsed in the formation of coal.

Starting with the fibre of the original plants, we find two well-defined bodies—cellulose, as represented by cotton fibre, and lignose, as represented by jute fibre. In the former, the percentage of carbon is 44, in the latter 47—each giving distinctive reactions with dilute acids at 70° C., with anilin sulphate, with Schultze solution, and with mixtures of sulphuric and nitric acids. In the cellular tissue, we find starch; and besides these bodies, there are present the extractive and mineral matters of the sap.

Among the extractive matter we find gums—such as those exuding from the acacia and cherry, but also present in the juice of many plants—mucilage, vegetable jelly (which gives many juices their power of gelatinising), resins, essential oils, and other well-defined bodies. With some forms of vegetation, the essential oils undergo oxidation and form resins; and these, being more resistant to change, accumulate in masses of decaying vegetable matter, so that large quantities of them are found in lignite beds in a fossilised, but little changed, state.

The changes in the carbohydrates and extractive matters depend largely upon the conditions of decay. Given moisture and air, they become converted into carbon dioxide and water; check the decay by cutting off free access of

[1] From a course of Cantor Lectures given at the Royal Society of Arts in November and December, 1911, by Prof. Vivian B. Lewes.