Were there any such laws of elevation and subsidence as Mr. Howorth maintains, the respective regions of elevation and of subsidence would have continued the same since the consolidation of the earth: but this is contradicted by the commonest facts of stratification, which show that elevation and subsidence have everywhere alternated with each other.

JOSEPH JOHN MURPHY

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The Use of Terms in Cryptogamic Botany

As no specialist in Algology has replied to the inquiry of your correspondent "D. R.," in NATURE for January 15, I may be permitted to quote for his information the following from the article "Nucleus," in the "Treasury of Botany" from the pen of the author of the "Introduction to Cryptogamic Botany":—"In Algæ the term is applied to the fructifying mass of the Rhodosperms, whether contained in a single cell or in a compound cyst or conceptacle, the word *nucleoli* being used when there is a group of nuclei." The instance alluded to by your correspondent is, unfortunately, not the only one in which the terminology of cryptogams is in a state of most perplexing confusion.

ALFRED W. BENNETT

A Lecture Experiment

THE condensation of liquid in the form of vapour into minute globules, and the production of a shower of rain, may be very well illustrated for class purposes in the following manner:—

Place about an ounce of Canada balsam in a Florence flask, and let it boil. At the top of the flask clouds of globules of turpentine will be seen hovering about, altering in shape very much like sky-clouds, and the globules are large enough to be visible by the naked eye. If a cold glass rod be gradually introduced into the flask, these clouds may be made to descend in showers. By the adaptation of a lime-light the whole process could be shown on a screen.

LAWSON TAIT

TODHUNTER ON EXPERIMENTAL ILLUSTRATIONS

Segnius irritant animos demissa per aurem,
quam quæ sunt oculis subjecta fidelibus, et quæ
ipse sibi tradit spectator.

THE following is, as nearly as I can recollect, the substance of a few remarks which I felt myself compelled to make to my class in a recent lecture. I had exhibited and described Hope's apparatus for showing the maximum density point of water, and proceeded to say:—

Now that the freezing mixture has been applied, my assistant will from time to time record on the black-board the simultaneous indications of the two thermometers, and will recall our attention to the experiment as the critical period approaches. You must, however, in this form of experiment take for granted his fidelity and accuracy in reading and recording. By means of a somewhat cumbrous application of optical processes, it would be easy to project upon a screen images of the thermometers, in such a way that each of you might see for himself the course of the phenomenon. But the thermo-electric method, whose principle I have already explained to you, is at once far easier of application, and in its indications more directly expressive. This I will show on another occasion. For the present you must rely on the observations to be made for you by my assistant. Yet I have no doubt that all of you will allow that the exhibition of the experiment, even in this imperfect manner, wonderfully assists you in understanding its nature.

This leads me to mention that a very decided opinion against the use of experimental illustration has been recently pronounced by one of the most erudite and voluminous of British mathematicians; my own former tutor, Mr. Todhunter, whose name and many of whose works must be familiar to most of you. Such a man speaks, deservedly with authority, on many points; and therefore his dicta upon a point with which he shows himself to be totally unacquainted are especially dangerous. And I feel that it is my duty to point out to you, and warn you against, errors or absurdities connected with physics, whenever they come from one whose statements are, on other grounds, worthy of attention. I shall not trouble you with the whole passage I refer to in Mr. Todhunter's "Conflict of Studies," but merely read to you a sentence or two of the most astounding part of it. I premise that though he is speaking of the teaching of physical science in schools, his observations apply (if they have any basis whatever) to science-teaching in general.

"It may be said that the fact makes a stronger impression on the boy through the medium of his sight, that he believes it the more confidently. I say that this ought not to be the case. If he does not believe the statements of his tutor—probably a clergyman of mature knowledge, recognised ability, and blameless character—his suspicion is irrational, and manifests a want of the power of appreciating evidence, a want fatal to his success in that branch of science which he is supposed to be cultivating."

Verbal comment on this would be altogether superfluous, and the only practical comment I am disposed now to make is to proceed at once to farther *experimental* illustrations of the subject before us.

P. G. TAIT

POLARISATION OF LIGHT *

V.

THE conversion of plane into circularly polarised light may also be effected by total reflexion. If plane-polarised light traversing glass be incident upon the inner side of the limiting surface at any angle at which total reflexion takes place, it may be considered as resolved into two plane-polarised rays, the vibrations of one being parallel and those of the other perpendicular to the plane of reflexion; and there is reason to believe that in every such case a difference of phase is brought about which for a particular angle in each substance (in St. Gobain glass it is 54° 30′) it has a maximum value of one-eighth of a wave-length. And if the original plane of vibration be inclined at an angle of 45° to that of reflexion the amplitudes of the two vibrations, into which the reflected vibrations are supposed to be resolved, will be equal. A full discussion of the mechanical causes which may be considered to effect this difference of phase would carry us deeper into the more difficult parts of the Wave Theory than would be suitable in this place. But if we accept the fact that the above-mentioned effects result, when polarised light (whose plane of vibration is inclined at 45° to that of reflexion) is reflected at a proper angle; then the following construction will be readily understood. Take a rhomb of glass, *a*, *b*, *c*, *d*, Fig. 14, whose acute angles are 54° 30′; a ray incident perpendicularly to either end will undergo two total internal reflexions at the sides, say at *p* and *s*, and will emerge perpendicularly to the other end. These two reflexions will together produce a retardation, as described above, of one-fourth of a wave-length. And if the ray be originally polarised and its plane of vibration be inclined

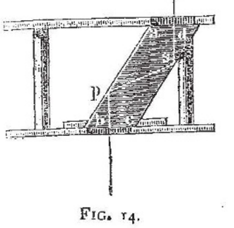

FIG. 14.

* Continued from p. 285.

at an angle of 45° to that of reflexion (that of the paper in the figure) the amplitudes of the two vibrations will be equal; and all the conditions will be fulfilled for the production of circular polarisation. Such an instrument was invented by Fresnel, and is called in consequence Fresnel's rhomb. On account of its length and its displacement of the ray, it is not so convenient as a quarter-undulation plate; but on the other hand it affects rays of all wave-lengths equally, while the quarter-undulation plate can strictly be adapted to rays of only one wave-length.

If either of these instruments be introduced and suitably placed between a selenite plate and the analyser, the chromatic effects will be similar to those due to a plate of quartz cut perpendicularly to the axis.

Another important property of these instruments consists in their effect upon circularly polarised light. Such light may be considered to arise from two plane-polarised rays whose vibrations are perpendicular to one another, and which present a difference of phase equal to a quarter of a wave-length. If, therefore, either a quarter-undulation plate or a Fresnel's rhomb be suitably placed, it will either increase or diminish the difference of phase by a quarter of a wave-length. In the one case the difference of phase will amount to a half wave-length, in the other it will vanish. And in either case the vibration will be converted into a rectilinear one; but the directions of vibration in the two cases will be perpendicular to one another.

Reflexion from a metallic surface may also be employed for converting plane into circular polarisation. If a ray of plane-polarised light fall upon a metallic reflector it is divided into two, whose vibrations are respectively parallel and perpendicular to the reflector; and the latter is retarded behind the former by a difference of phase depending upon the angle of incidence. If the plane of vibration of the incident ray be inclined to the plane of incidence at an angle (nearly 45°) which varies with the metal employed, but which is perfectly definite, the intensities become equal. And further, if the angle of incidence have a particular value dependent upon the nature of the metal (for silver 72°) the retardation will amount to a quarter of a wave-length. And the result will be a circularly polarised ray as in the case of total reflexion.

The apparatus (Fig. 15) best adapted for experiments based upon this principle is a modification of Norremberg's polariscope, suggested by Sir Charles Wheatsone, from whom the following description is quoted:—

"A plate of black glass, G, is fixed at an angle of 3° to the horizon. The film to be examined is to be placed on a diaphram, D, so that the light reflected at the polarising-angle from the glass plate shall pass through it at right angles, and, after reflexion at an angle of 18° from the surface of a polished silver plate S, shall proceed vertically upwards. N is a Nicol's prism, or any other analyser, placed in the path of the second reflexion. The diaphragm is furnished with a ring, moveable in its own plane, by which the crystallised plate to be examined may be placed in any azimuth. C is a small moveable stand, by means of which the film to be examined may be placed in any azimuth and at any inclination; for the usual experiments this is removed.

"If a lamina of quartz cut parallel to the axis, and sufficiently thin to show the colours of polarised light, be placed upon the diaphragm so that its principal section (*i.e.* the section containing the axis) shall be 45° to the *left* of the plane of reflexion, on turning the analyser from left to right, instead of the alternation of two complementary colours at each quadrant, which appear in the ordinary polarising apparatus, the phenomena of successive polarisation, exactly similar to those exhibited in the ordinary apparatus by a plate of quartz cut perpendicularly to the axis, will be exhibited; the colours follow in the order R, O, Y, G, B, P, V, or, in other words, ascend as in the case of a right-handed plate of quartz cut perpendicularly to the axis. If the lamina be now either inverted, or turned in its own plane 90°, so that the principal section shall be 45° to the right of the plane of reflexion, the succession of the colours will be reversed, while the analyser moves in the same direction as before, presenting the same phenomena as a left-handed plate of quartz cut perpendicularly to the axis. Quartz is a positive doubly refracting crystal; and in it consequently the ordinary index of refraction is smaller than the extraordinary index. But if we take lamina of a negative crystal, in which the extraordinary index is the least, as a film of Iceland spar split parallel to one of its natural cleavages, the phenomena are the reverse of those exhibited by quartz: when the principal section is on the *left* of the plane of reflexion the colours descend, and when it is on the *right* of the same plane the colours ascend, the analyser being turned from left to right.

"It has been determined that the ordinary ray, both in positive and negative crystals, is polarised in the principal section,* while the extraordinary ray is polarised in the section perpendicular thereto. It is also established that the index of refraction is inversely as the velocity of transmission. It follows from the above experimental results, therefore, that when the resolved ray whose plane of polarisation is to the left of the plane of reflexion is the quickest, the successive polarisation is right-handed, and when it is the slowest, the successive polarisation is left-handed—in the order R, O, Y, G, B, P, V and in the second case in the reverse order.

"The rule thus determined is equally applicable to laminæ of bi-axal crystals.

"As selenite (sulphate of lime) is an easily procurable crystal and readily cleavable into thin laminæ capable of showing the colours of polarised light, it is most frequently employed in experiments on chromatic polarisation. The laminæ into which this substance most readily splits contain in their planes the two optic axes; polarised light transmitted through such laminæ is resolved in two rectangular directions, which respectively bisect the angles formed by the two optic axes; the line which bisects the smallest angle is called the intermediate section; and the line perpendicular thereto which bisects the supplementary angle is called the supplementary section. These definitions being premised, if a film of selenite is placed on the diaphragm with its intermediate section to the left of the plane of reflexion, the successive polarisation is direct or right-handed; if, on the contrary, it is placed to the right of that plane, the successive polarisation is left-handed. The ray polarised in the intermediate section is therefore the most retarded; and as that section is considered to be equivalent to a single optic axis, the crystal is positive.

"In one kind of mica the optic axes are in a plane perpendicular to the laminæ. They are inclined 22½° on each side the perpendicular within the crystal, but, owing to the refraction, are seen respectively at an angle of 35°·3 therefrom. The principal section is that which contains the two optic axes. If the film is placed on the diaphragm with its principal section inclined 45° to the left of the plane of reflexion, the successive polarisation is right-handed. The ray, therefore, polarised in the section which contains the optic axes is the one transmitted with the greatest velocity.

"Films of uni-axal crystals, whether positive or negative, and of bi-axal crystals, all agree therefore in this respect:—that if the plane of polarisation of the quickest ray is to the left of the plane of reflexion, the successive polarisation is right-handed when the analyser moves from left to right; and if it is to the right of the plane of reflexion, other circumstances remaining the same, the successive polarisation is left-handed.

* The plane of polarisation is, throughout these pages, taken to be perpendicular to that of vibration.

"It must be taken into consideration that the principal section of the film is inverted in the reflected image; so that if the plane of polarisation of the quickest ray in the film is to the left of the plane of reflexion, it is to the right of that plane in the reflected image.

"It may not be uninteresting to state a few obvious consequences of this successive polarisation in doubly refracting laminæ, right-handed and left-handed according to the position of the plane of polarisation of the quickest ray. They are very striking as experimental results, and will serve to impress the facts more vividly on the memory.

"1. A film of uniform thickness being placed on the diaphragm with its principal section 45° on either side the plane of reflexion, when the analyser is at 0° or 90° the colour of the film remains unchanged, whether the film be turned in its own plane 90°, or be turned over so that the back shall become the front surface; but if the analyser be fixed at 45°, 135°, 225°, or 315°, complementary colours will appear when the film is inverted from back to front, or rotated in its own plane either way 90°.

"2. If a uniform film be cut across and the divided portions be again placed together, after inverting one of them, a compound film is formed, which, when placed on the diaphragm, exhibits simultaneously both right-handed and left-handed successive polarisation. When the analyser is at 0° or 90° the colour of the entire film is uniform; as it is turned round the tints of one portion ascend, while those of the other descend; and when the analyser is at 45° or $n90° + 45°$, they exhibit complementary colours.

"3. A film increasing in thickness from one edge to the other is well suited to exhibit at one glance the phenomena due to films of various thicknesses. It is well known that such a film placed between a polariser and an analyser will show, when the two planes are parallel or perpendicular to each other and the principal section of the film is intermediate to these two planes, a series of parallel coloured bands, the order of the colours in each band from the thick towards the thin edge being that of their refrangibilities, or R, O, Y, G, B, P, V. The bands seen when the planes are perpendicular are intermediate in position to those seen when the planes are parallel; on turning round the analyser these two systems of bands alternately appear at each quadrant, while in the intermediate positions they entirely disappear.

"Now let us attend to the appearances of these bands when the wedge-form film is placed on the diaphragm of the instrument, Fig. 15. As the analyser is moved round, the bands advance toward or recede from the thin edge of the wedge without any changes occurring in the colours or intensity of the light, the same tint occupying the same place at every half revolution of the analyser. If the bands advance toward the thin edge of the wedge, the successive polarisation of each point is left-handed; and if they recede from it the succession of colours is right-handed: every circumstance, therefore, that with respect to a uniform film changes right-handed into left-handed successive polarisation, in a wedge of the same substance transforms receding into advancing bands, and *vice versâ*. These phenomena are also beautifully shown by concave or convex films of selenite or rock-crystal, which exhibit concentric rings contracting or expanding in accordance with the conditions previously explained.

"4. Few experiments in physical optics are so beautiful and striking as the elegant pictures formed by cementing laminæ of selenite of different thicknesses (varying from $\frac{1}{2000}$ to $\frac{1}{50}$ of an inch) between two plates of glass. Invisible under ordinary circumstances, they exhibit, when examined in the usual polarising-apparatus, the most brilliant colours, which are complementary to each other in the two rectangular positions of the analyser. Regarded in the instrument, Fig. 13, the appearances are still more beautiful; for, instead of a single transition, each colour in the picture is successively replaced by every other colour. In preparing such pictures it is necessary to pay attention to the direction of the principal section of each lamina when different pieces of the same thickness are to be combined together to form a surface having the same uniform tint; otherwise in the intermediate transitions the colours will be irregularly disposed.

"5. A plate of rock-crystal cut perpendicular to the axis loses its successive polarisation, and behaves exactly as an ordinary crystallised film through which rectilinear polarised light is transmitted.

"By means of the phenomena of successive polarisation it is easy to determine which is the thicker of two films of the same crystalline substance. Place one of the films on the diaphragm E of the instrument (Fig. 15) in the position to show, say, right-handed polarisation, then cross it with the other film; if the former be the thicker, the successive polarisation will be still right-handed; if both be equal, there will be no polarisation; and if the cross film be the thicker, the successive polarisation will be left-handed. In this manner a series of films may be readily arranged in their proper order in the scale of tints.

"In the experiments I have previously described the planes of reflexion of the polarising mirror and of the silver plate were coincident; some of the results obtained when the azimuth of the plane of reflexion of the silver plate is changed are interesting.

"I will confine my attention here to what takes place when the plane of reflexion of the silver plate is 45° from that of the polarising reflector.

"When the principal sections of the film are parallel and perpendicular to the plane of reflexion of the polarising mirror, as the whole of the polarised light passes through one of the sections, no interference can take place, and no colour will be seen, whatever be the position of the analyser.

"When the principal sections of the film are parallel and perpendicular to the plane of reflexion on the silver plate, they are 45° from the plane of reflexion of the polarising mirror.

"The polarised ray is then resolved into two components polarised at right angles to each other; one component is polarised in the plane of reflexion of the silver plate, the other perpendicular thereto; and one is retarded upon the other by a quarter of an undulation.

"When the analyser is at 0° or 90° no colours are seen because there is no interference; but when it is placed at 45° or 135°, interference takes place, and the same colour is seen as if light circularly polarised had been passed through the film. The bisected and inverted film shows simultaneously the two complementary colours.

"But when the film is placed with one of its principal sections $22\frac{1}{2}°$ from the plane of reflexion of the polarising mirror, on turning round the analyser the appearances of successive polarisation are reproduced exactly as when the planes of reflexion of the silver plate and of the polarising mirror coincide. In this case the components of the light oppositely polarised in the two sections are unequal, being as $\cos 22\frac{1}{2}°$ to $\sin 22\frac{1}{2}°$; these components respectively fall $22\frac{1}{2}°$ from the plane of reflexion of the silver plate and from the perpendicular plane, and are each resolved in the same proportion in these two planes. The weak component of the first, and the strong component of the second, are resolved into the normal plane, while the strong component of the first and the weak component of the second are resolved into the perpendicular plane.

"The apparatus (Fig. 15) affords also the means of obtaining large surfaces of uncoloured or coloured light in every state of polarisation—rectilinear, elliptical, or circular.

"It is for this purpose much more convenient than a Fresnel's rhomb, with which but a very small field of view can be obtained. It must, however, be borne in mind that the circular and elliptical undulations are inverted in the two methods: in the former case they undergo only a single, in the latter case a double reflexion.

"For the experiments which follow, the crystallised plate must be placed on the diaphragm E, between the silver plate and the analyser, instead of, as in the preceding experiments, between the polariser and the silver plate.

FIG. 15.—Wheatstone's modification of Norremberg's Polariscope.

"By means of a moving ring within the graduated circle D, the silver plate is caused to turn round the reflected ray, so that, while the plane of polarisation of the ray remains always in the plane of reflexion of the glass plate, it may assume every azithumal position with respect to the plane of reflexion of the silver plate. The film to be examined and the analyser move consentaneously with the silver plate, while the polarising mirror remains fixed.

"In the normal position of the instrument the ray polarised by the mirror is reflected unaltered by the silver plate; but when the ring is turned to 45°, 135°, 225°, or 315°, the plane of polarisation of the ray falls 45° on one side of the plane of reflexion of the silver plate, and the ray is resolved into two others, polarised respectively in the plane of reflexion and the perpendicular plane, one of which is retarded on the other by a quarter of an undulation, and consequently gives rise to a circular ray, which is right-handed or left-handed according to whether the ring is turned 45° and 225°, or 135° and 315°. When the ring is turned so as to place the plane of polarisation in any intermediate position between those producing rectilinear and circular light, elliptical light is obtained, on account of the unequal resolution of the ray into its two rectangular components.

"Turning the ring of the graduated diaphragm from left to right, when the crystallised film is between the silver plate and the analyser, occasions the same succession of colours for the same angular rotation as rotating the analyser from right to left when the instrument is in its normal position and the film is between the polariser and the silver plate."

The same principles apply to the case of bi-axal crystals cut parallel to a plane containing the two optic axes. A ray of plane-polarised light transmitted through such a plate is divided into two, whose vibrations respectively bisect the angles formed by the two axes. As mentioned above, the line which bisects the smallest angle is called the intermediate section, and the line perpendicular to it the supplementary section; and the order of the colours depends upon the relative velocity of the two rays. In selenite, the ray whose vibrations lie in the supplementary section is the slowest; in mica it is the swiftest. Hence these two crystals, all other circumstances being alike, give the colours in opposite orders, and may be regarded as positive and negative, like quartz and Iceland spar. And a test similar to that indicated for uni-axal may be applied to bi-axal crystals.

Some interesting and varied experiments may be made by using two circularly polarising instruments, *e.g.*, two quarter undulation plates (say the plates A and B), one between the polariser proper and the crystal (C) under examination, the other between the crystal and the analyser. The light then undergoes the following processes. If the plate A be placed so that its axis is at 45° on one side or other of the original plane of vibration, and the plate B with its axis parallel or perpendicular to that of A, then on turning the analyser we shall have the phenomena of circular polarisation described above. Again, if, the plates A and B retaining the positions before indicated, the crystal C be turned round in its own plane; then, since the light emerging from A and B is circularly polarised, it has lost all trace of direction with reference to the positions of polariser and analyser, and consequently no change will be observed.

Again, if the plates A and B have their axes directed at 45° on either side of the axis of C, and the three plates be turned round as one piece, the colour will remain unchanged, while if the analyser be turned, the colours will follow in the regular order. If the plates A and B have their axes directed at 45° on the same side of the axis of C, and the pieces be turned round bodily as before, the colours change in the same order as above, and go through their cycle once in every right angle of rotation; and if the analyser be turned in the same direction, the colours change, but in the reverse order. The explanation of this is to be found in the fact that when the plates A and B are crossed, the retardation due to A is compensated by that due to B; so that the only effective retardation is that due to the crystal C. But upon the latter depends the rotation of the plane of vibration; if, therefore, the polariser and analyser remain fixed, the colour will remain unaltered. When the plates A and B have their axes parallel, there is no compensation, and the colour will consequently change. It should be added that the rotation of the plane of vibration, and consequently the sequence of colours, does not follow exactly the same law in these cases as in quartz.

W. SPOTTISWOODE

(To be continued.)