Extracts from the papers of
Sir Charles Wheatstone

WHEATSTONE 4: Working papers and experimental observations relating to optics including polarisation, photometry, spectra and the characteristics of light, [1840-1875]

K/PP107/4/5

[1846-1875]

Experimental and theoretical observations, chiefly concerning the polarisation of light, including experiments made with an electromagnet; striation in luminous tubes; a general description of absorption spectra; inventory of apparatus necessary to show the law of rotation of the plane of polarisation and outline description of polarising apparatus and polarimeter; consequences of the mixture of polarised light from different sources; notes on interference; criticism by Charles Wheatstone of then current theories to explain the phenomenon of aberration; experimental notes on the refraction of light through filters; proposal for a version of the telegraph able to utilise the phenomenon of optical polarisation. With equations, sketches and chromatograms.
List of apparatus by Wheatstone, stereoscopes, pseudoscopes, polar clock, and by others including a gyroscope by Friedrich Fessel (1821-1860), German mechanic and teacher, induction coil by Heinrich Daniel Ruhmkorff (1803-1877), German instrument maker, and a stereoscope by Antoine Jean Francois Claudet (1797-1867), French photographer, [1853-1875].
Experiments on the Polarization of Light to be made with the large Electromagnet.

1. Ascertian whether the effect is uniform over the entire surface of the glass, or whether it is greater when the magnetic curves are stronger.
2. Ascertian whether there is any change of effect when the position of the plane of polarization is different to the magnetic curves.
3. Ascertian the effect of paper or cloth being wound or right hand circularly placed through the glass.
4. The above experiments are to be made with the ordinary analyzer.
5. Examine the transmitted ray with the analyzer.
5. Place a polaroid plate in various positions with respect to the magnetic source, and examine the reflected polarisation.

6. Is the polarization circular or elliptical?
According to Brewster, the maximum polarizing angle of silver is 75°, and no complete polarizing ray is produced when the plane of polarization is inclined to the plane of incidence.

On the reflection of a polarized ray, when the plane of polarization is at the plane of incidence and the reflected ray is at 60°, the ray from the glass passes through the metallic surface.

From this, it can be observed that when the plane of polarization is at an angle of about 55°, the ray emerges at an angle of 45° to the incident plane, and the reflected ray is parallel to the plane of incidence. (See Brewster.)

Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 1.
Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 2.
Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 3.
Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 4.
Notes on 'means of accurately determining the plane of polarization,' [1846-1875].
Circular Polarization.

When a circularly polarized ray is transmitted perpendicularly through a plate of rock crystal cut perpendicularly to the axis, the ripples are no longer concentric circles, but in spirals. They develop.

When the plane of reflection is 1 (the plane of polarization being 1), the spirals are those when the plane of reflection is L the spirals are

that is, in both cases the spirals are in the same direction and they commence at different angles. From observations were made when the plane of the incident was at right angles to that of the polarizer, when they commenced the spirals are those in the same direction though they appear left-handed.

Forming the analyzer to the right the ripples move because the wavelength, forming it to left because the rays; whether the plane of reflection be L or
Notes and diagrams on 'successive polarization of crystals', [1846-1875], page 1.
With a plate of calcite and perpendicular to a lens limiting the view, were the following appearances observed?

Inside the angle 4 6 the limits of the hands of a watch, the rays A and B of the upper figure come close to the latter D while the rays C and D of the lower figure come towards the right.
Circular Polarization

The column of liquid being maintained constant, the rotation by itself may be affected by a prism of such crystals, of two similar prisms of such crystals one right hand and the other left hand. Thus

...
A new and very sensible Polariscope.

A doubly reflecting prism, images widely separated, a plane of which is the principal section 45° to the line joining the two images.

A three strip of white paper fixed about 8 or 10 inches before the plane, in the part of to the line joining the two images.

Directing this polarscope to any part of the sky, and turning the variable of the sky is polarized, the white images unite to become white, while into the change when the line corresponds with the plane of polarization.

Irregularly on a piece of paper with a consider aperture against which a strip of which is fixed may be employed.
Notes describing an alternative way of forming a prism by Augustin-Jean Fresnel (1788-1827), French engineer and physicist, [1846-1875].
Notes on the direction of the quickest and slowest transmission in a crystallized film, [1846-1875].
The explanation given by Prof. Helmholz and others of the phenomenon of aberration is entirely erroneous. It must oblige us to admit that the position of objects are not solely determined by the point of the retina on which they fall, but also on the motion in which the eye falls in the same point of the retina.

Wheatstone in his explanation denies that light in its passage from a common point is entirely modified by the motion of the retina through which it passes. So that light moves at a given point, not in a straight line but in a straight line of its own plane moving in the direction of its own motion, not in a straight line perpendicular to the plane of motion, but in an inclined line. Thus, if we could have a means of determining the common point in a third room on an underground level 5 ft. from the ground in the centre of the earth rather large about 20°, and 61 units from the top of the radiator, then a point in the path of light to the center would be connected with the earth at different distances, all 61 units away and in the same plane, and the light would not change, however, there are two in which there was a difference of 18°, and in the other it is changed, the earth.
The maximons arise when the idea of the figthtr.

Both it is more probable, contrary to the other

riewrs of the state, that the figthtr propagated in

the undulated atmosphere, or to one of the

air. In this case the air is only the figure

in the light of the lines and not in light

origin, within the undulated atmosphere.

If there be an either it is connected in the air as

very much, but you would be, and is therefore carried

with it.

If the experiment is made, and that figure

from the undulated atmosphere, it would

result in the air. The other views, however,

are it must be supposed that the other

character of light would be influenced by one

mutual and not by the other.

If this air has a medium in space,

there must be an alternative conversion

air. But do any alternative phenomena

indeed be it use here? If there there do

the other alternative to the generative

but of youth (in you, the other, the amount

medium) it with the doctrine.

K/PP107/4/5/34
Criticism by Wheatstone of theories to explain the phenomenon of aberration, [1846-1875], pages 2 and 3.
List of new and experimental apparatus in the study of polarization and polarized light, including wave machine and polar clock, [1846-1875].
Notes and diagram on experiments undertaken at King's College on the polarisation of light through rock crystals using a Nicol prism [William Nicol (1770-1851), geologist], Faraday's heavy glass [Michael Faraday (1791-1867), natural philosopher] and Fresnel's rhomb [Augustin-Jean Fresnel (1788-1827), French engineer and physicist], 1846 Feb 14, page 1.
Notes and diagram on experiments undertaken at King's College on the polarisation of light through rock crystals using a Nicol prism [William Nicol (1770-1851), geologist], Faraday's heavy glass [Michael Faraday (1791-1867), natural philosopher] and Fresnel's rhomb [Augustin-Jean Fresnel (1788-1827), French engineer and physicist], 1846 Feb 14, page 2.
Description of a ‘polarimeter’, an apparatus to measure the angle of rotation of the plane of polarisation, [1846-1875].
Description of a cyanometer, an instrument to measure the intensity of blue, particularly of the sky, using a prism by William Nicol (1770-1851), geologist, [1846-1875].
Measure of the Absorption of Light.

A ready method of measuring the absorption of light by different colored substances might be of great use in chemical researches. So it might be the means of detecting the absolute purity of colored chemical substances in solutions containing analytes.

Construct a trough with some lateral sides of glass capable of accommodating to or nearing, from each other, and filled with the colored liquid to be examined. Let this be placed immediately before a sensitive spectrometer, and a number of colored filters, through one prism. The edge of which is in contact with another, and the other edge in contact with the edge of the prism while the latter has been turned by a Nicol prism while the former being turned through the prism, and before the glass, the prism, is placed an analyzing prism. Then the prism will show the prismatic or analyzing coulour, when the prism is passed through the spectrometer.
of the spectrum will be. Connect this
the way homogeneous may it not be added
be to be enough in this if, but this
in this may be employed by burning
the same type. The angular direction with the
the following formula give the intensity of
the beam of the way.

\[ A = \frac{\theta}{\beta} \]

If the angle is set to 35° by which
the quantity of the beam may be
 confined one half, and the plates of the
though the beam so that the homogeneous
can be examined what is except in the
with rays, so there must be the
whether it is where the.

of this thing may be measured for
again weight of the beam is the
between the of the relation of a quantity of
different substances, in the different homogeneous
since, we might obtain some curious laws.

\[ A = \frac{\theta}{\beta} \]

Some relations might be found to exist
between the of atomic weight and the
lengths.
The most convincing proof that the opinion that the optics of our present currents is not correct, is that by inspecting the notes found by a microscope, the theory could not be compatible with the phenomena, it is not doubted.

A note found these and put on this in the middle blank.

But on found this end.

It appears that each gas has its maximum power of conducting electricity at a certain density, when this density is reached, the gas becomes a new conductor. It would be very important to define some means for obtaining accurate measures of this property.

With a perpendicular gas, it might be said, if to write, they contain all the electric current as well. This was to say that the strain comes from a permanent distribution of strain in the tube.
On account of the great distance of the sun from the earth it may be inferred that its rays after passing through the particles of the atmosphere contained in the hemisphere present events it.

As they follow on every point of the atmosphere as reflected in every direction from it, but is more completely polarised in the direction which makes a right angle with the path of the rays.

The following are consequences of this phenomenon:

When the sun is in the zenith, the maximum value of light polarisation occurs in the horizontal circle, the reflected rays being at 90 degrees to the center and the plane of reflection being vertical. Approaching towards the zenith, the angle of reflection makes progressively a greater angle with the incident ray and its polarisation consequently diminishes. In the limiting case of the rays on the eye of the observer it is perpendicular to the rays.
Notes on the path of rays from the sun and their polarisation, [1846-1875], page 2.
The superposition of films presents numerous singular phenomena, but we wish to present a more immediate view. The frame presented when the object's middle plane is superposed.

**Notes and Diagrams**

1. Case: Principal meridian perpendicular to each other.

   - The analyzer is here, and white appears when the plane of the analyzer and analyzer coincide, and black when they are perpendicular. But in intermediate positions of the analyzer, color appears. The image is the position of the analyzer, having the point in the right or left, which gives a spectrum where the green becomes a faint color at 180°; faint blue red appears which becomes yellow and green at 90°. Black appears when red is observed in each separate film, and white when the green is at its maximum.

   ![Diagram](image)

   At 90°, the spectrum of the superposed and unsuperposed portions meet. It is the same.

The superposition of films, before the superposed film, in its certain planes, shows all colors in the superposed films, but of the plate 100° and with the analyzer they combine to appear. This shows that the different colors of the two colors are superposed in different planes.
Superposition of Entoptic films, one showing a uniform colour, the other coloured bands.

The coloured bands may be either straight or circular.

When the principal sections of the two films are parallel, the bands instead of commencing with the shade or black of the first order (according to the position of the analyser) commence with the shade corresponding on the scale of the second for the point in the line where the point of the head of the film continues; and the four shades of black and grey diminish less than those shown by the superimposed films alone.

When the principal sections of the two films are perpendicular, the bands (in which case the bands on the corresponding to the first order of the two heads) the bands are arranged in reverse order to the right and left of the central shade or black, similar rays being at equal distances from the central head.

By such superimposition the precise order of any head may be easily determined.
Draft paper on the 'superposition of Entoptic films, one showing a uniform colour, the other coloured bands', [1846-1875], pages 2 and 3.
Letter from Haggard, Hale and Pixley, stockbrokers, regarding investments including the Dunaberg and Witepsk railway in Russia, 1870 Apr 27.
Cover sheet for a bundle of papers on 'Experiments on the Successive Polarization of Light, with the Description of a new Polarizing Apparatus', the title of a paper published in the Proceedings of the Royal Society, 1871.
The Papers of Charles Wheatstone
K/PP107/4/5 - Papers relating to optics

enough so that its principal section (i.e. the section containing the axis) shall be 65° to the left of the plane of reflection, on turning the analyzer from left to right instead of the alternation of the complementary colours at each quadrant, which appears in the ordinary polarizing apparatus, the phenomena of successive polarization exactly similar to those exhibited in the ordinary apparatus by a plate of neatly cut perpendicular to the axes will be exhibited; the colours will follow in the order R O Y G B V, or, in other words, will ascend as in the case of a right-handed plate of neatly cut perpendicular to the axes. If the former be now inverted, or turned in its own plane 90°, so that the principal section shall be 65° to the right of the plane of reflection, the superposition of the colours will be reversed, while the analyzer moves in the same direction as before, presenting the same phenomena as a left-handed plate of neatly cut perpendicular to the axes.

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K/PP107/4/5/132

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K/PP107/4/5 - Papers relating to optics

If a plane be placed on the diagonal with its principal section inclined 45° to the plane of reflection, the successive polarization is right handed. The ray therefore polarized in the section which contains the optic axis is the one transmitted with the greatest velocity. Fig. 3 represents a section of Nicol with the vertices of the section in which no incident polarized ray is visible.

Films of uncurved crystals, whether positive or negative, are of biaxal crystals, all agree therefore in this respect: that if the plane of polarization of the quickest ray is to the left of the plane of reflection, the successive polarization is right handed when the analyzer moves from left to right, and if it is to the right of the plane of reflection, the phenomenon remaining the same, the successive polarization is left handed.

It must be taken into consideration that the principal section of the film is inverted in the reflected light.
image, so that if the plane of polarization of the quickest ray were the plane to the left of the plane of reflection, it is to the right of that plane in the reflected image.

§4

Al may not be uninteresting to state a few obvious consequences of this successive polarization in double-refracting media, right hand and left hand, according to the position of the plane of polarization of the quickest ray. They are very interesting as experimental results and will serve to improve the facts more vividly on the memory.

1. A film of uniform thickness being placed on the compensator with its principal section on either side the plane of reflection, when the analyser is at 0° or 90° the colour of the film remains unaltered, whether the film be turned in its own plane 90°, or be turned over so that the back shall
become the final surface; but if the analyser be fixed at 65°, 135°, 225°, or 315°, complementary colours will appear when the film is turned from back to front, or rotated in the same 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 will be formed which, when placed in the diaphragm, will exhibit simultaneously both right-handed and left-handed successive polarizations. When the analyser is at 0° or 90° the colour of the entire film will be uniform, as it is turned round the plane of one portion will ascend while those of the other will descend, and when the analyser is at 45° or 135° they will 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
the... 

is well known that such a film placed between a polarizer 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 those two planes, a series of parallel colored bands, the order of these circles on each hand from the thicker towards the thinner edge being that of their respective colors or ROY G. B. V. The tum y seen when the planes are perpendicular are intermediate in positions to those seen when the planes are parallel, in turning round the analyser these two systems of bands alternately appear all on one quadrant, while in the intermediate positions they entirely disappear. Now let us attend to the appearance of these bands when the wedge, from which the film is placed on the instrument fig. 1. As the analyser is moved round the bands advance towards or recede from the thinner edge of the wedge without any changes occurring in the colors or intensities.
of the light, the same unit occupying the same place at every half resolution of the analyzer. If the bands advance towards the thin edge of the wedge, the successive polarization of each point is left hand, and if they recede from it, the succession of colours is right hand, occurring, conversely, therefore, that with respect to an uniform fine changes right hand into left handed successive polarization in a wedge of the same substance transforms reading into advancing bands, and vice versa.

These phenomena are also beautifully shown by concave or convex films of calcite 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 picture formed by cementing laminae of sulphate of lime of different thicknesses (ranging from 0.0100 to 0.0010 of an inch) between

Two plates of glass, invisible under ordinary circumstances, being exhibited, when examined in the usual polarizing apparatus, the most brilliant colours which are complementary to each other in the two rectangular positions of the analyser. Required in the instrument fig. 1, the appearance are white 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 directions of the principal sections of each laminia, 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 polarization and behaves exactly as an ordinary crystallized film through which right-linear polarized light is transmitted.

6. A thick plate of anomalous naphtha undergoes a series of regular transformations the principal phases of which are shown fig 5.
The phenomena of conjugate or rotating polarization... admit of a very simple explanation.

The polarized light incident on the crystalline plate is resolved into two portions of equal intensity. The polarized at right angles to each other, one in the plane of section, the other perpendicular thereto. These resolved portions when they fall on the silver plate have their planes of polarization each at an angle of 45°, one to the right, the other to the left of the plane of reflection. They are, in consequence, of the unequal rotation, which in either is an angle...
What has been previously stated is true only in the supposition that the light polarized in the plane of reflection of the silver plate is that to polarize it right away. Thanks to equal intensity, but this is not the case, the experiments of James have shown.
By means of the phenomenon of successive polarization it is easy to determine which is the thickest of two films of the same crystalline substance. Place one of the films on the densitogram of the instrument fig. in the position to show any right-handed polarization, then coat it with the other film; if the former be the thickest, the successive polarization will be still right-handed; if both be equal there will be no polarization, and if the coated film be the thickest the successive polarization will be left-handed. In this manner a series of films may be readily arranged in their proper order on the scale of thickness.
In the experiments I have recently described the planes of reflection of the polarizing mirror and of the silver plate were coincident, some of the results obtained when the azimuth of the plane of reflection of the silver plate was changed are interesting. I shall confine my attention two to what takes place when the plane of reflection of the silver plate is 45° from that of the polarizing reflector.

When the principal sections of the film are parallel and perpendicular to the plane of reflection of the polarizing mirror, as the whole of the polarizing light passes through one of the sections no interference can take place, and no colors will be seen whatever be the position of the analyzer.

When the principal sections of the film are parallel and perpendicular...
If a thin crystalline plate be placed between two parallel prisms of glass and a right angle, one each of which contains light previously polarized, and you observe the reflected light in the mean of the angles, at first before the entrance of the plate (which is supposed perpendicular to the rays) and subsequently after its entrance and if the plate is thin so that the rays make an angle of 90° with the base plane of double reflection, this will cause the optical properties of plates of each crystal proper to the waves of light which cause polarized light, when the principal section of the crystal is parallel to the axes of the crystal and the crys is analyzed. The two images will generally change colour with a varying depth of their hues, as occur in the ordinary case of their ordinary planes. Outside, the nature of the axes of the two images vary only on the rotation in which of the principal planes of polarized light.
the principal sections of the beam, that is, in any of the two common planes of polarization, then, when the angle remains constant, the system of the 

It does not appear that Fresnel, in any of his published memoirs, has given any further modifications of his experiments; the importance of which has been almost entirely overlooked in elementary treatises on Light. The above seems to have remarked that similar phenomena of successive polarization are exhibited when the light incident on the crystallized plate is plane polarized, nor that the order of the succession of the colors depends on the position of the principal section with respect to the plane of polarization. These circumstances are indeed necessarily included in the beautiful theory established by this eminent philosopher; but I am not aware that they have hitherto been specifically noticed or experimentally shown.
The apparatus fig. 1 affords also
the means of obtaining large
surface of uniform or almost
light in every state of polarization,
rectilinear, elliptical or circular.
It is for this purpose much more
convenient than a Fresnel's hand,
with which but a very small
field of view can be obtained.
It must however be borne in mind
that the circular and elliptical
polarizations are inverted in the
twow methods: in the former case,
they undergo only a single, in
the latter case, a double reflection.

For the experiments which follow
the crystal plate must be placed
on the diagonal E between the
silver plate and the analyzer, and
both mirrors must have the same
inclinations as before.
By means of a movable ring
in the graduated circle D, the other
plate is caused to move round the
reflected ray, so that, while the
plane of polarization of the ray
remains always in the plane of
reflection of the glass plate, it may
assume every azimuth position with
respect to the plane of reflection of
the other plate.

In the normal position of the
instrument the ray polarized by the
mirror is reflected undisturbed by the
other plate. But when the ring is
brought to 15°, 135°, 225°, or 315° the plane of
polarization of the ray facing 45° on one
side of the plane of reflection of the
glass plate and the ray is reflected into
the other plate, respectively in the
plane of reflection and the perpendicular
plane, one of which is retained on the
other by a quarter of an undulation, and
consequently gives rise to a circular
ray, which is right handed or left hand.
according as the ring is turned 15° and 225° or 135° and 315°. When the ring is turned so as to place the plane of polarization 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 the two rectangular components.

Turning the ring of the graduated despistroscope from left to right, when the crystalline film is between the silver plate and the analyzer, occurs the same succession of colours for the same angular rotation as rotating the analyzer from right to left when the instrument is in its normal position and the film is between the polarizer and the silver plate.
§ 40

To arrange the apparatus for the ordinary experiments of plane-polarized light, without the intervention of the silver plate, all that is necessary is to remove the silver plate from the frame $F$, and to substitute for it a plate of black glass which must be fixed at the proper polarizing angle.

To convert it into a Nicol's apparatus a sheet of mill must be laid horizontal at $H$, and the instrument strengthened so that a line perpendicular to the mill shall coincide with the line of sight. The silver plate must be removed from the frame $F$ and a plate of transparent glass substituted for it, which must be so inclined that the light falling upon it shall be reflected at the polarizing angle perpendicularly towards the horizontal mirror. The eye will receive the polarized ray.
Notes proposing a telegraph able to utilise the phenomenon of optical polarisation, 1846 Feb, page 1.
Notes proposing a telegraph able to utilise the phenomenon of optical polarisation, 1846 Feb, page 2.
Notes on partially polarised light, [1846-1875], page 1.
Notes on partially polarised light, [1846-1875], page 2.

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