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.

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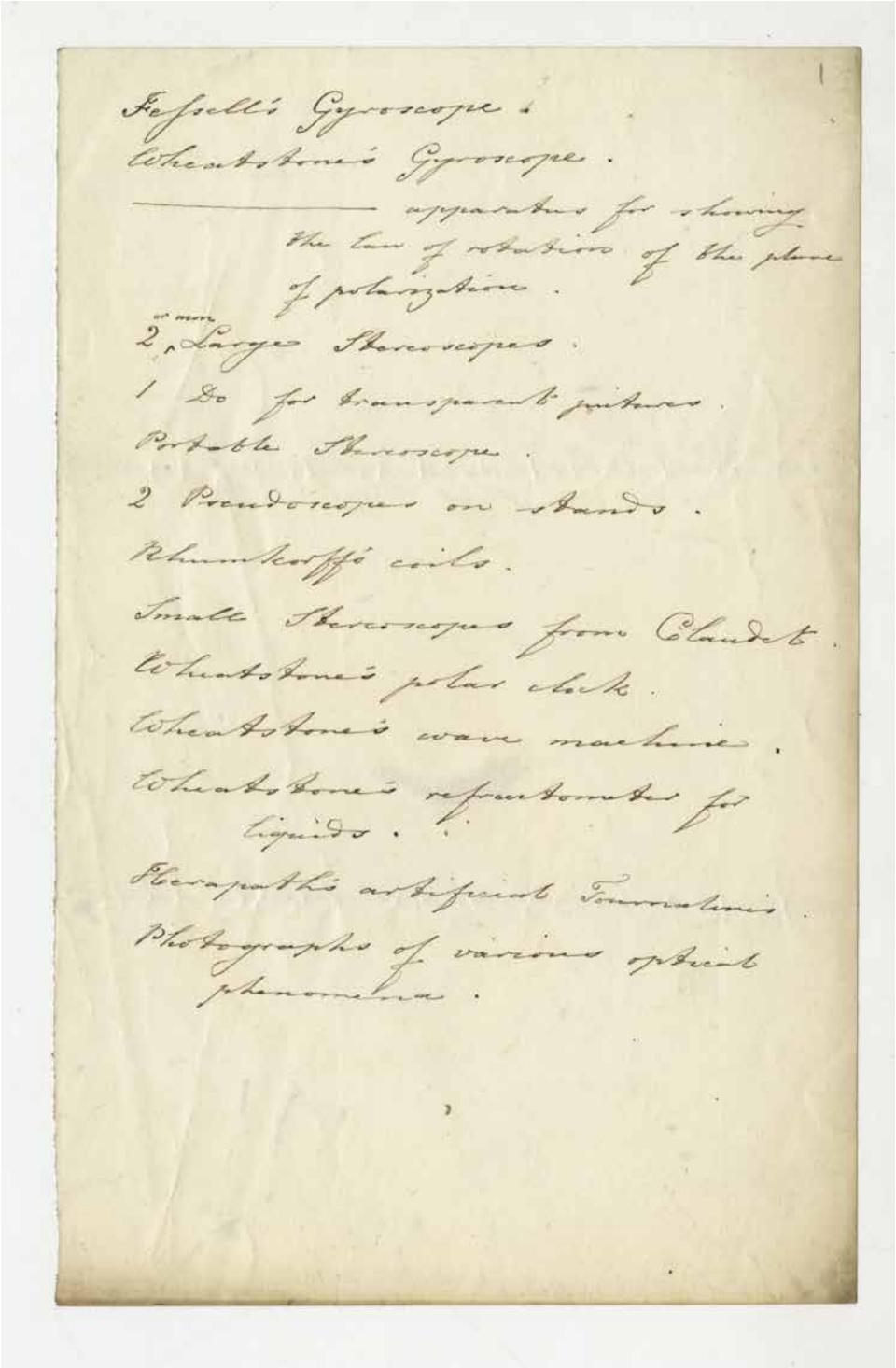

Fessell's Gyroscope.
Wheatstone's Gyroscope.
——————— apparatus for showing the law of rotation of the plane of polarization.
2 Large Stereoscopes.
1 Do for transparent pictures.
Portable Stereoscope.
2 Pseudoscopes on stands.
Rhumkorff's coils.
Small Stereoscopes from Claudet.
Wheatstone's polar clock.
Wheatstone's wave machine.
Wheatstone's refractometer for liquids.
Hierapath's artificial Tourmalines.
Photographs of various optical phenomena.

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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].

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2

Experiments on the Polarization of Light to be made with the large Electro-magnet.

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1. Ascertain whether the effect is uniform over the entire surface of the glass, or whether it is greater where the magnetic curves are strongest.

2. Ascertain whether there is any difference of effect when the primitive plane of polarization is differently inclined to the magnetic curves.

3. Ascertain the effect of passing a left hand or a right hand circularly polarized ray through the glass.

All the above experiments are to be made with the ordinary analyzer.

4. Examine the transmitted ray with my analyzer.

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Notes on 'experiments on the polarization of light to be made with the large electromagnet, [1846-1875], page 1.

5. Place a silvered plate in various directions with respect to the magnetic curves, and examine the reflected polarized ray.

6. Is the polarization circular or only elliptical?

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3

According to Brewster the maximum polarizing angle of Silver is 73°, and a circularly polarized ray is ~~pro~~ obtained when the primitive plane of polarization is inclined 45° to the plane of incidence.

In the reflection of a 'di-polarized' ray when the primitive plane of polarization is in the plane of incidence and the neutral axes are inclined 45°, there must therefore be two circularly polarized rays reflected from the metallic surface.

Fresnel separated the two pencils formed by double refraction along the axis of quartz. They differ from polarized light because when either of them is doubled by a doubly refracting crystal, the pencil or images never vanishes during the revolution of the crystal; and from common light, because when they suffer the total reflection from glass, at an angle of about 54°, the one will emerge polarized in a plane inclined 45° to the right, and the other in a plane 45° to the left, of the plane of total reflection. (See Fresnel and Brewster)

No trace of polarization when analyzed by a chain of calcareous spar — Does not give brilliant colours in thin crystallized plates — No colours when the paper through the portions on each crystal cut perpendicular to the axis.

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Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 1.

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when the planes of polarization move back to the polarizing plane of the analyser, one colour is produced; when they continue to move forward to it the complementary colour is obtained.

This rule is true whether the di-polarizing axes of the rhombs are equally or unequally inclined to the planes of polarization.

—

We will suppose the primitive plane of polarization to remain always the same.

1st case. The polarizing plane of the analyser coincident with the primitive plane

a – pp of the rhombs coincident with the other two planes; no colour, light polarized in one plane

b – pps of the rhombs 45° on each side the primitive plane: the polarized ray is shifted equally 45° on each side: the analyzing plane shifts them backwards to the same position as before

c pps of the rhombs unequally placed with respect to the primitive plane – the polarized ray is shifted unequally – colour but not so intense as when equal, and intensity as the inequality increases. The analyzing plate shifts them back to the same position as before.

2d Case .. The polarizing plane of the analyser perpendicular to the primitive plane

a – pps of the rhombs coincident with the primitive plane .. ~~[illegible]~~ – no colour but dark image of light as if the filter were not interposed.

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Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 2.

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6 – pp of the rotinite 45° on each side the primitive plane .. the complementary colour appears .. The polarized ray is shifted 45° on each side the primitive plane .. the analyzing plate shifts them forwards so that they coincide with the analyzing plane, each passing through 90°

c pp of the rotinite unequally placed with respect to the primitive plane .. the polarized ray is shifted unequally .. complement colour but not so intense as when equal .. the analyzing plate shifts them forwards until they coincide with the analyzing plane. the ray which was last shifted before is now the most and vice versa. Thus in the entire shifting is always 90°

This shifting 90° results or the gives rise to the loss of half an undulation.

3° Case .. The polarizing plane of the analyzer 45° to the primitive plane.

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Notes on an observation by Sir David Brewster (1781-1868), natural philosopher, on the maximum polarizing angle of silver, [1846-1875], page 3.

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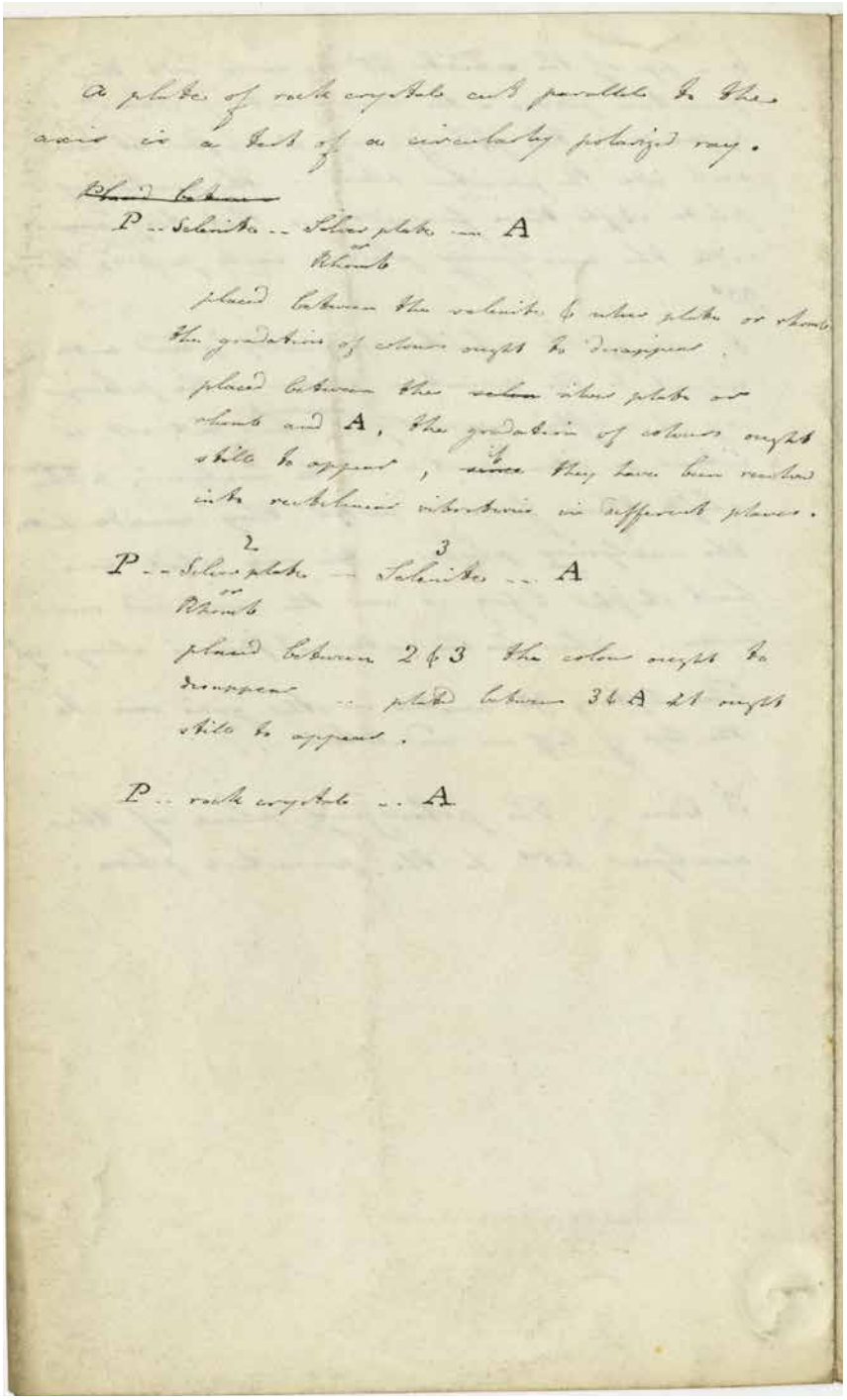

a plate of rock crystal cut parallel to the axis is a test of a circularly polarized ray.

~~Placed between~~

P -- Selenite -- Silver plate or Rhomb -- A

placed between the selenite & silver plate or rhomb the gradation of colour ought to disappear.

placed between the ~~colour~~ silver plate or rhomb and A, the gradation of colours ought still to appear, ~~since~~ they have been restored into rectilinear vibrations in different planes.

P -- Silver plate (2) or Rhomb -- Selenite (3) -- A

placed between 2 & 3 the colour ought to disappear -- placed between 3 & A it ought still to appear.

P -- rock crystal -- A

6

Means of accurately determining the plane of polarization

The luminous of sulphate of lime being held so that one of its sections is parallel with the plane of polarization, no colour appears if the plane of analysis be parallel or perpendicular to the plane of polarization. This is to be expected because according to the theory the polarized ray passes through unaltered; there is no interference by which colour can be produced. ~~For we can is~~ But colour does appear, and sometimes very strongly, when the plane of analysis is not parallel. This however is only an indication that the section is not exactly parallel to the plane of polarization.

It is easy to determine accurately the plane of pol by means of a film interposed between the pol and anal; for when either of its sections is perfectly parallel to the plane of pol, rotation of the analyzer produces no colour.

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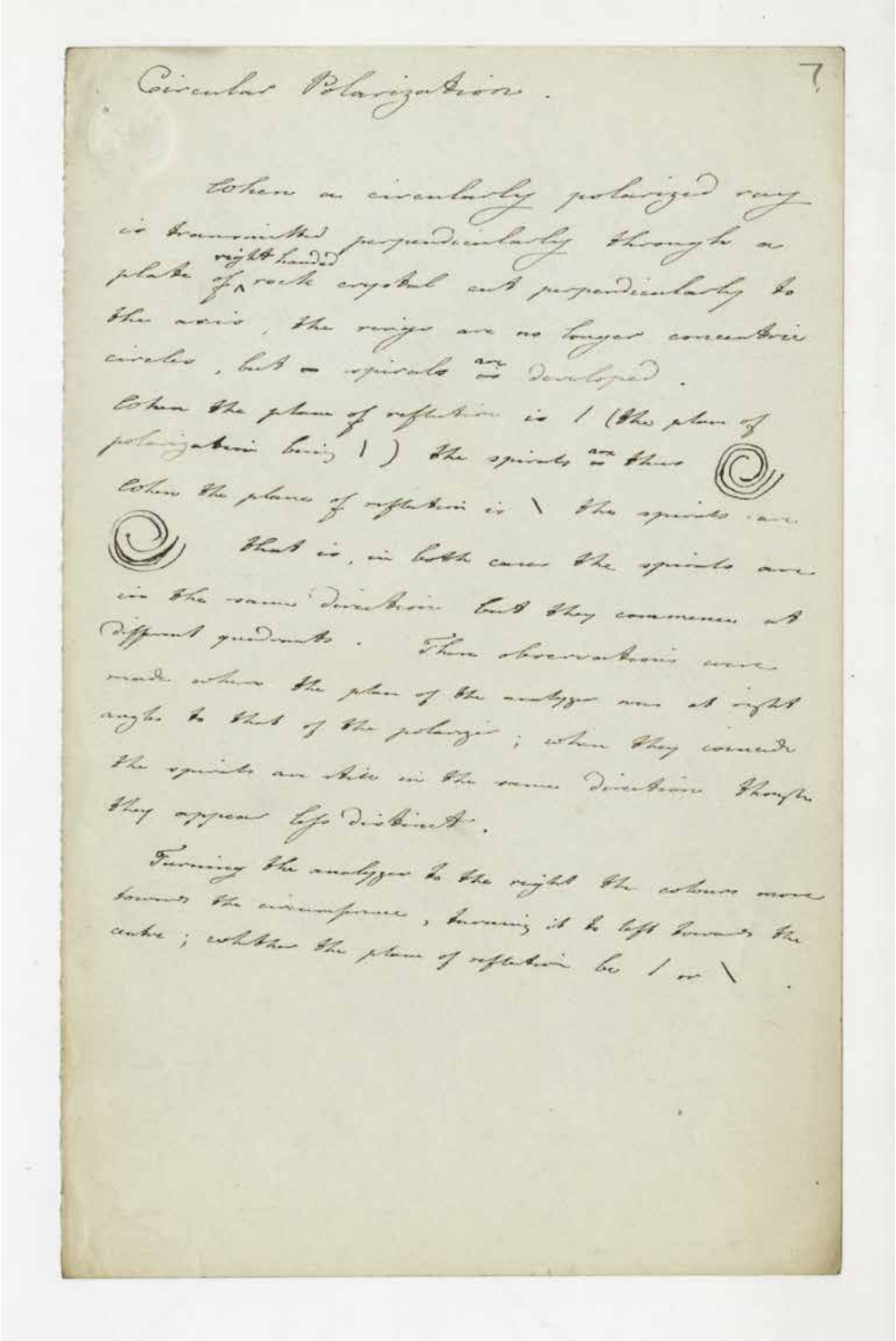

7.

Circular Polarization.

When a circularly polarized ray is transmitted perpendicularly through a plate of right handed rock crystal cut perpendicularly to the axis, the rings are no longer concentric circles, but = spirals are developed.

When the plane of reflection is / (the plane of polarization being |) the spirals are thus

When the plane of reflection is \ the spirals are

That is, in both cases the spirals are in the same direction but they commence at different quadrants. These observations were made when the plane of the analyzer was at right angles to that of the polarizer; when they coincide the spirals are also in the same direction though they appear life distinct.

Turning the analyzer to the right the colours move towards the circumference, turning it to left towards the centre; whether the plane of reflection be / or \.

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Notes on circular polarization, [1846-1875].

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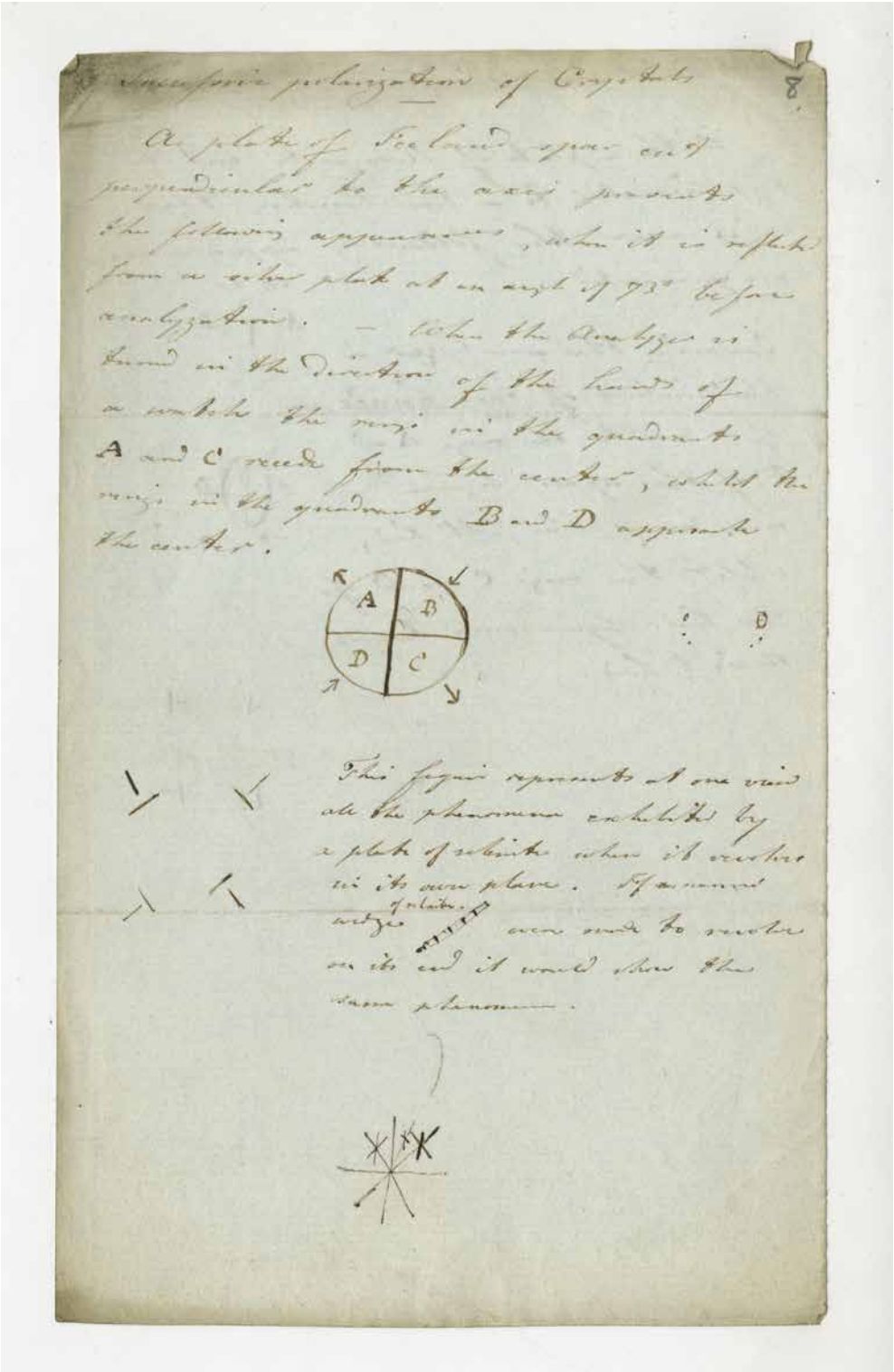

Successive polarization of Crystals

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A plate of Iceland spar cut perpendicular to the axis presents the following appearances, when it is reflected from a silver plate at an angle of 73° before analyzation. — When the analyzer is turned in the direction of the hands of a watch the rays in the quadrants A and C recede from the centre, whilst the rays in the quadrants B and D approach the centre.

This figure represents at one view all the phenomena exhibited by a plate of selenite when it rotates in its own plane. If a narrow wedge of selenite were made to rotate on its end it would show the same phenomena.

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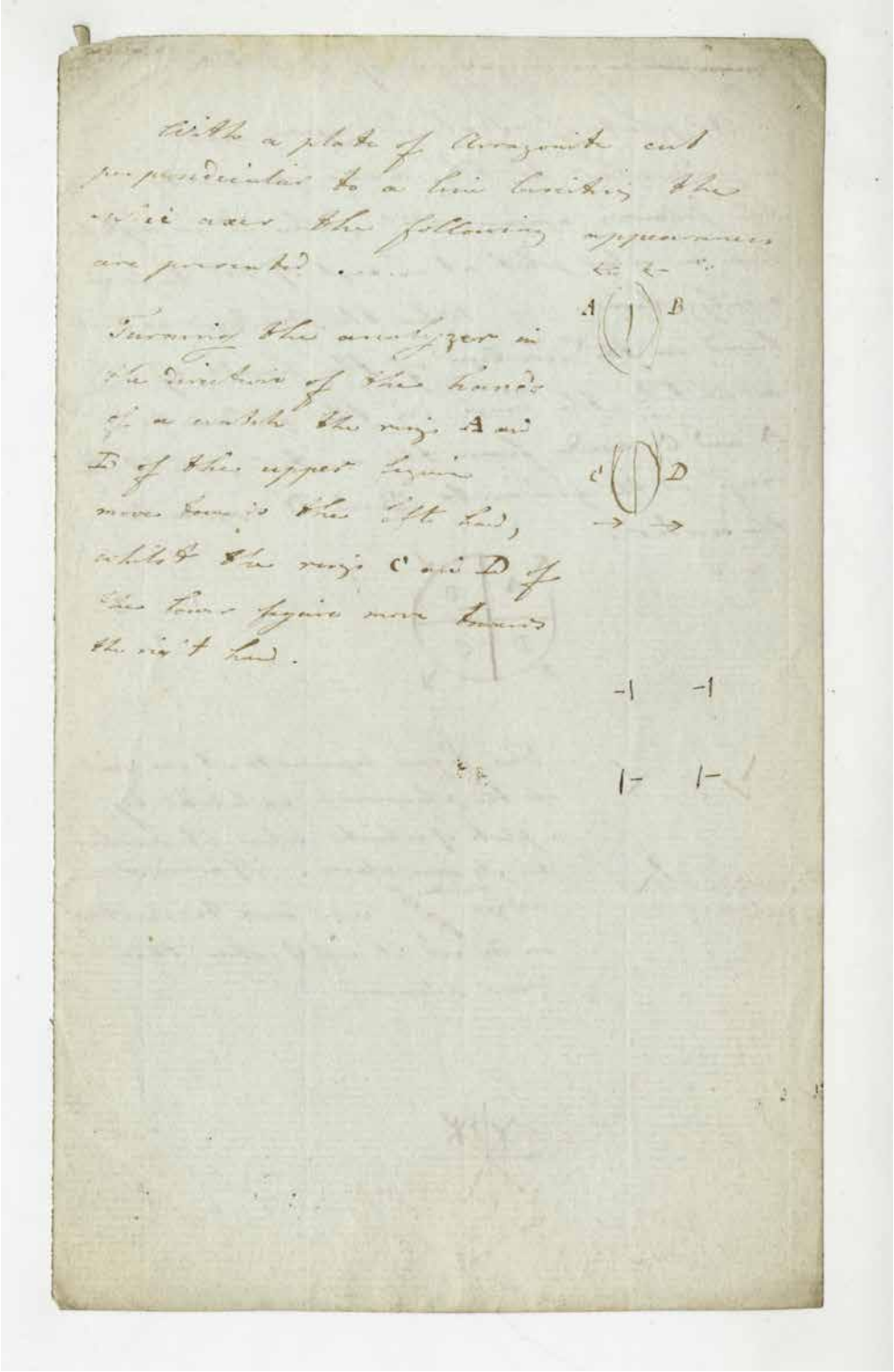

With a plate of Arragonite cut perpendicular to a line bisecting the optic axes the following appearances are presented ....

Turning the analyzer in the direction of the hands of a watch the rays A and B of the upper figure move down to the left hand, while the rays C and D of the lower figure move towards the right hand.

A B

C D

-| -|

|- |-

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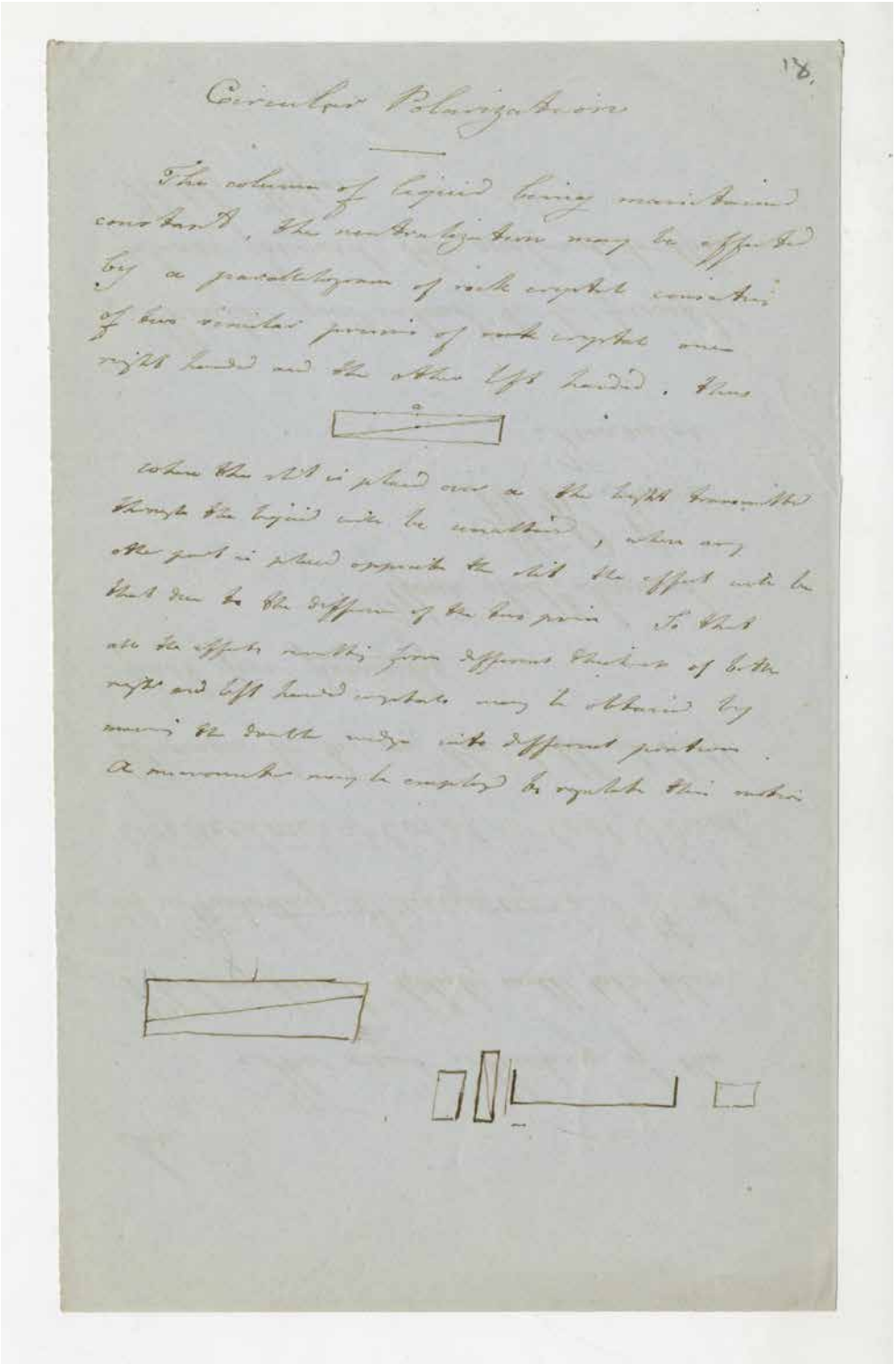

18.

Circular Polarization

The volume of liquid being maintained constant, the rotation may be effected by a parallelogram of rock crystal consisting of two similar prisms of rock crystal one right handed and the other left handed. Thus

when the slit is placed over a the light transmitted through the liquid will be unaltered, when any other part is placed opposite the slit the effect will be that due to the difference of the two prisms. So that all the effects resulting from different thickness of both right and left handed crystals may be obtained by moving the double wedge into different positions. A micrometer may be employed to regulate this motion

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Notes with diagrams describing circular polarization, [1846-1875].

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A new and very sensible Polariscope.

A doubly refracting prism, images widely separated —
a film of selenite its principal section 45° to the line joining the two images.
a thin strip of white paper fixed about 5 or 8 inches before the film ~~in the~~ parallel to the line joining the two images.
Directing this polariscope to any part of the sky, and turning it round, if the sky is polarized two colour images will be seen, white will be brought when the line corresponds with the plane of polarization.
~~Either~~ Or a piece of blackened card with a circular aperture against which a film of selenite is fixed may be employed.

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Notes describing 'a new and very sensible polariscope', [1846-1875].

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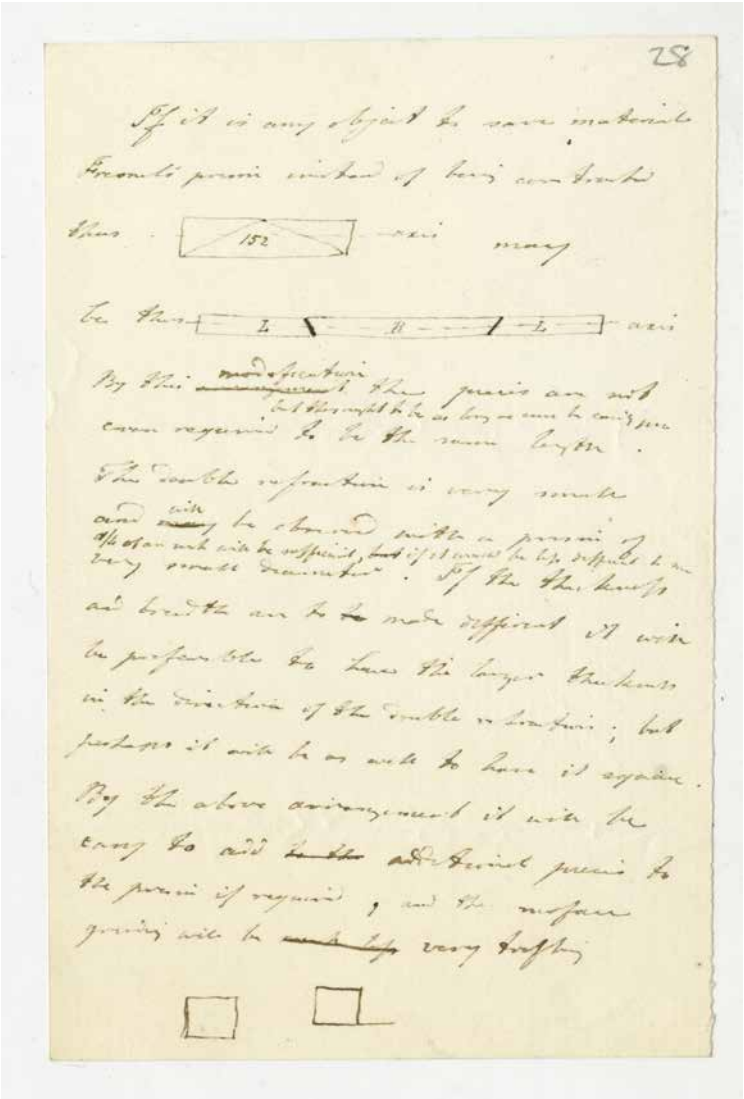

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If it is any object to save material Fresnel's prism instead of being constructed thus may be thus

By this ~~modification~~ the pieces are not but should be as long as ever be only pieces cannot required to be the same length.

The double refraction is very small and ~~may~~ will be observed with a prism of 45° or not will be sufficient, ~~but~~ if it may be by difficult to see very small deviation. By the thickness and breadth are to be made different it will be practicable to have the larger thickness in the direction of the double refraction; but perhaps it will be as well to have it equal. By the above arrangement it will be easy to add ~~another~~ additional pieces to the prism if required, and the surface grinding will be ~~much less~~ very trifling

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Notes describing an alternative way of forming a prism by Augustin-Jean Fresnel (1788-1827), French engineer and physicist, [1846-1875].

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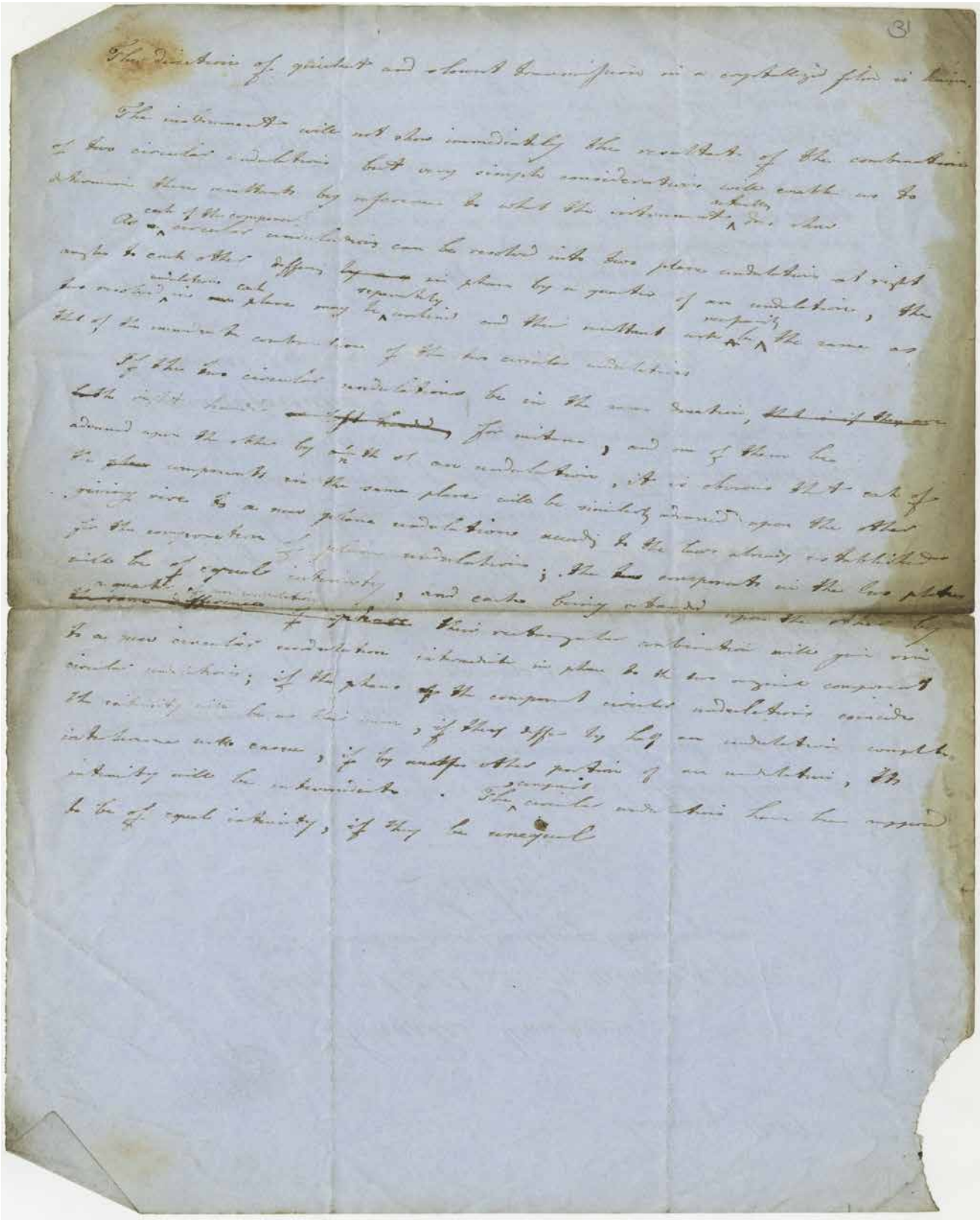

K/PP107/4/5/31

Notes on the direction of the quickest and slowest transmission in a crystallized film, [1846-1875].

The explanation given by Pontécoulant and others of the phenomenon of aberration is decidedly erroneous. It would oblige us to admit that the position of objects was not solely determined by the point of the retina on which they fell, but also on the direction in which the rays fell on the same point of the retina.

Herschel in his explanation admits that light in its passage from a luminous point is entirely unaffected by the motion of the medium through which it passes, so that we may arrive at a ~~given~~ point, ~~not~~ in a ~~straight line, but~~ given plane, moving in the direction of the earth's motion, not in a straight line perpendicular thereto, but in an inclined line. Were this so, we should have a means of ascertaining the cardinal points in a closed room or even underground; for the deviation in the direction of the earth's motion being about 20", would be in a direction perpendicular to this 0°. Were a point or vertical line of light be made to coincide with the wire at opposite sides, at 0°; and the system be turned round 90° the light would no longer appear, but on one side would have the right and on the other side would have the left.

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The maximum deviation would indicate the pole of the ecliptic.

But it is more probable, contrary to the opinion of Bessel, that light propagated in the terrestrial atmosphere partakes of its motion. In this case aberration will only be observed in the light of the stars and not in light originating within the terrestrial atmosphere. If there be an Æther it is connected with air as any material gas would be, and is therefore carried with it.

If the experiments which follow from Bessel's opinion were to succeed, it would establish a point of the utmost importance, viz that the sun has no motion in space. For it would be absurd to suppose that the aberration of light would be influenced by one motion and not by the other.

If the sun has a motion in space there must be an aberration corresponding therewith; do any astronomical phenomena indicate its existence? If this motion be slow the aberration will be imperceptible, but if quick (as quick than the annual motion) it will be observed.

The admission that the Æther has different densities in different substances, seems to be opposed to the notion that it freely permeates all matter. —

(Doppler's ideas on aberration &c are noticed in Poggendorf for 1847).

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Criticism by Wheatstone of theories to explain the phenomenon of aberration, [1846-1875], pages 2 and 3.

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A new instrument to represent to the eye the principal results of the wave theory of light.

A new polarizing apparatus presenting a broad field ~~[illegible]~~ of view of polarized light either rectilinear, elliptic or circular, and also supplying the deficiency.

A new series of experiments on coloured polarization.

Experiments on the reflection of circularly polarized rays.

Experiments on the rotatory polarization of rock crystal and certain liquids with a new apparatus to measure the ~~pla~~ rotation of the plane of polarization.

Experiments on the primitive decomposition of polarized light transmitted through crystallized films.

New apparatus for measuring the intensity of polarized light reflected from surfaces at any incidence.

New atmospheric polarimeter.

The Polar Clock.

Possible applications of polarized light for Light House Signals and Telegraphs.

On the Composition of Polarized Light and a review of Sir D. Brewster's opinion on this subject.

An instrument to combine ~~two~~ light polarized in planes inclined at any angle to each other.

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List of new and experimental apparatus in the study of polarization and polarized light, including wave machine and polar clock, [1846-1875].

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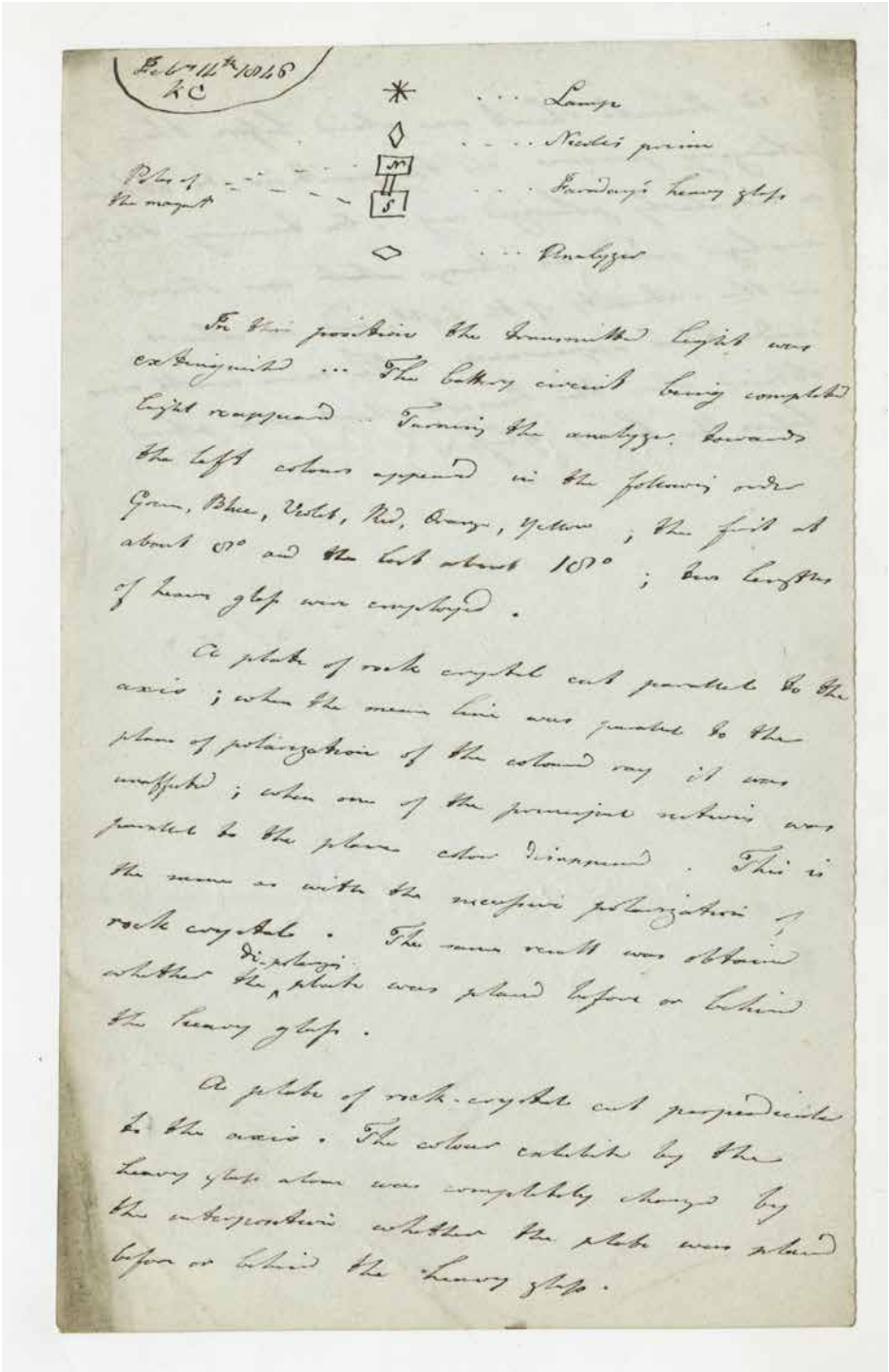

Feb 14th 1846
KC

* ... Lamp

◊ ... Nicol's prism

Place of the magnet — N S ... Faraday's heavy glass

◇ ... Analyzer

In this position the transmitted light was extinguished ... The battery circuit being completed light reappeared. Turning the analyzer towards the left colours appeared in the following order Green, Blue, Violet, Red, Orange, Yellow; the first at about 5° and the last about 180°; two lengths of heavy glass were employed.

A plate of rock crystal cut parallel to the axis; when the mean line was parallel to the plane of polarization of the coloured ray it was unaffected; when one of the principal sections was parallel to the plane colour disappeared. This is the same as with the uniaxal polarization of rock crystal. The same result was obtained whether the diplagio plate was placed before or behind the heavy glass.

A plate of rock-crystal cut perpendicular to the axis. The colour exhibited by the heavy glass alone was completely changed by the interposition whether the plate was placed before or behind the heavy glass.

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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.

A Fresnel's rhomb was placed before the polarizing prisms in the position to obtain a circularly polarized ray. On turning the analyzer round no change was observed in the intensity of the light, and no colours made their appearance. The same result was obtained when the Fresnel's rhomb was placed before the heavy glass.

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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.

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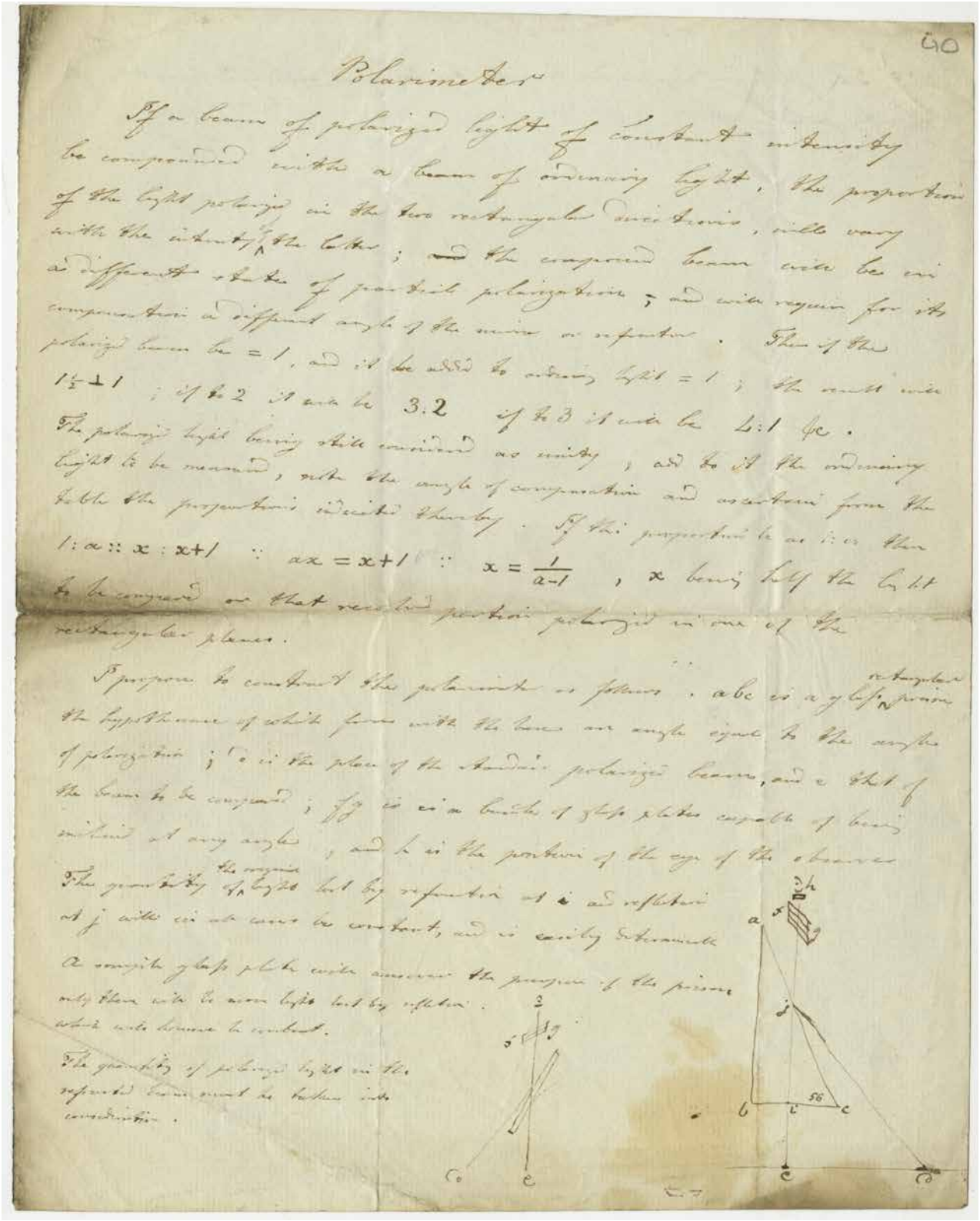

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Polarimeter

If a beam of polarized light of constant intensity be compounded with a beam of ordinary light, the proportion of the light polarized in the two rectangular directions, will vary with the intensity of the latter; the compound beam will be in a different state of partial polarization; and will require for its compensation a different angle of the mirror or reflector. Thus if the polarized beam be = 1, and it be added to ordinary light = 1; the result will be $1\frac{1}{2} \perp 1$; if to 2 it will be 3.2 if to 3 it will be 4:1 &c. The polarized light being still considered as unity, and to it the ordinary light to be measured, with the angle of compensation and ascertain from the table the proportion indicated thereby. If this proportion be as 1:a then $1 : a :: x : x+1 \therefore ax = x+1 \therefore x = \frac{1}{a-1}$, x being half the light to be compared or that resulting portion polarized in one of the rectangular planes.

I propose to construct the polarimeter as follows. abc is a glass prism the hypothenuse of which forms with the base an angle equal to the angle of polarization; d is the plane of the standard polarized beam, and e that of the beam to be compared; fg is a bundle of glass plates capable of being inclined at any angle, and h is the position of the eye of the observer. The quantity of the original light lost by refraction at i and reflection at j will in all cases be constant, and is easily determined. A simple glass plate will answer the purpose if the prism only then will be seen light lost by reflection: which will become a constant.

The quantity of polarized light in the refracted beam must be taken into consideration.

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Description of a 'polarimeter', an apparatus to measure the angle of rotation of the plane of polarisation, [1846-1875].

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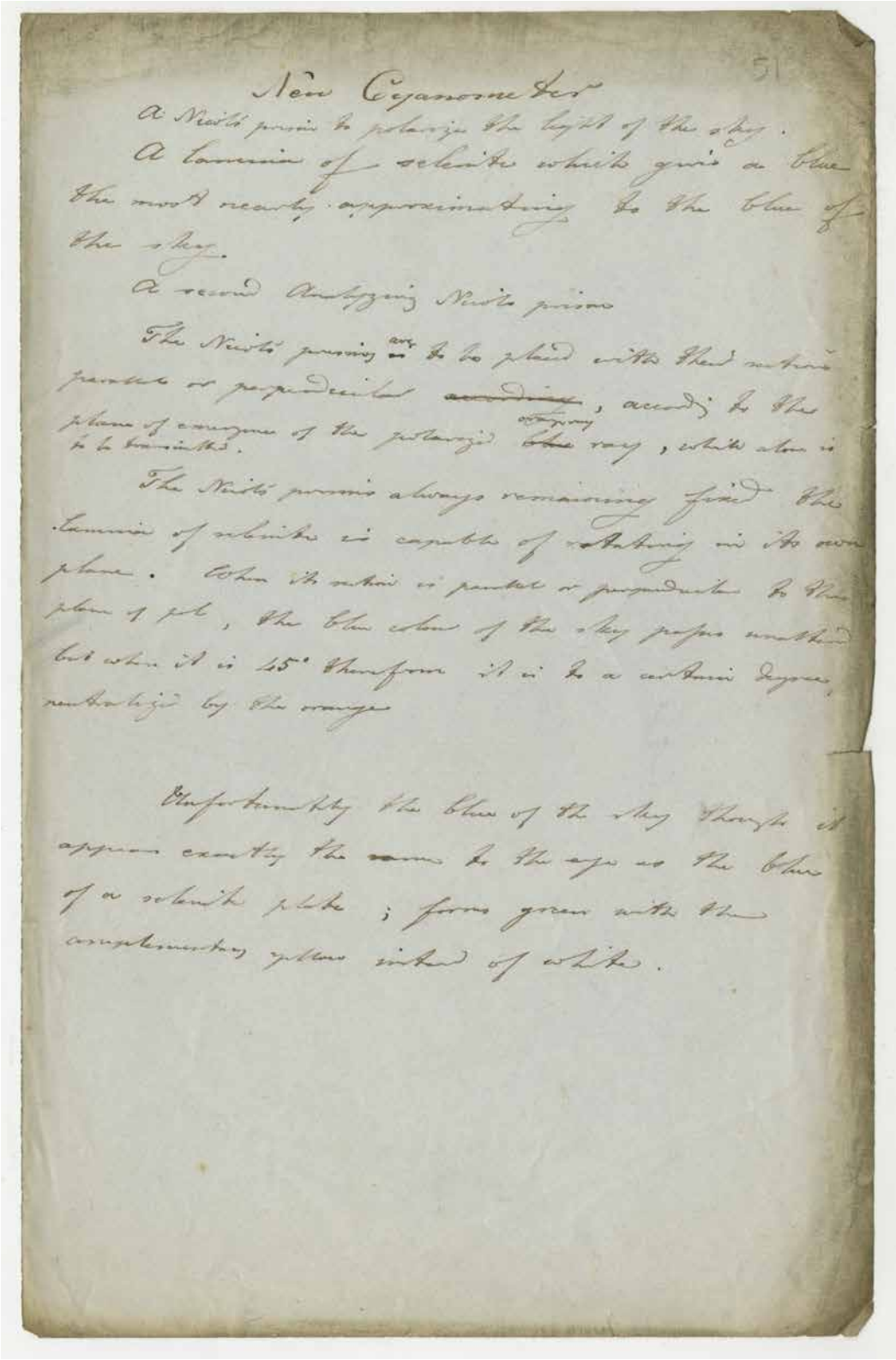

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New Cyanometer

A Nicol's prism to polarize the light of the sky.

A lamina of selenite which gives a blue the most nearly approximating to the blue of the sky.

A second analyzing Nicol's prism

The Nicol's prisms are to be placed with their natural parallel or perpendicular ~~meridian~~, according to the plane of compass of the polarized ~~blue~~ ray, which also is to be ascertained.

The Nicol's prisms always remaining fixed the lamina of selenite is capable of rotating in its own plane. When its axis is parallel or perpendicular to the plane of pol, the blue color of the sky passes unaltered but when it is 45° therefore it is to a certain degree neutralized by the orange

Unfortunately the blue of the sky though it appears exactly the same to the eye as the blue of a selenite plate; forms green with the complementary yellow instead of white.

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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].

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Measure of the Absorption of Light.

A ready method of measuring the absorption of homogeneous light by differently coloured substances might be of great use in chemical researches. For it might be the means of detecting the absolute quantities of coloured chemical substances in solution without analysis.

Construct a trough with ~~variable~~ parallel sides of glass capable of approximating to or receding from each other, and fill it with the coloured liquid to be examined. Let this trough be placed immediately before a prismatic spectrum formed by a narrow slit of solar light passing through a prism; the edges of which are placed vertically. Let the side of the liquid be so disposed that it shuts out ~~upper half~~ the lower half of the spectrum, the upper half be covered by a Nicol's prism while the lower half remains uncovered; and before the trough let there be placed an analyzing prism. When the planes of the polarized and analyzer coincide, the lower half of the spectrum will be perfectly

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of the spectrum will be unequal: ~~for any homogeneous ray~~ Confining attention to any ~~homogeneous~~ ray it will be found to be of unequal intensity; but the intensities may be equalized by turning round the analyzer. The angular deviation will by the following formulae give the intensity of the transmitted ray

$$A \cos \theta = \beta A .$$

If the analyzer be fixed to 45° by which the intensity of the direct ray will be reduced one half, and the plates of the tourmaline be chosen so that the transmitted homogeneous ray be assumed shall be equal to the direct ray, we shall ascertain that the thickness which stops one half the light.

If this thickness were measured for a given ~~weight of the solution in a certain volume~~ strength of the solution, of a variety of different substances, with different homogeneous rays, we might obtain some curious laws.

Probably if for any given colour a certain quantity ~~absorbed~~ transmitted one half $\frac{1A}{2}$, a similar quantity would transmit $\frac{A}{2^n}$.

Some relation might be found to exist between the atomic weights and the absorption.

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Draft paper on 'Measure of the Absorption of Light', [1846-1875], pages 2 and 3.

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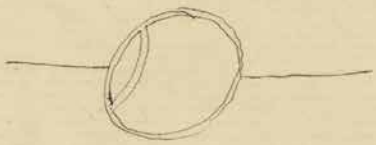
Luminous Striae

The most convincing proof that Mr Grove's opinion that the stratification of successive currents is not tenable, is that by dividing the mass formed by ~~a single tube~~ breaking the primary circuit only, it is not doubled.

A tube formed thus would present no striæ in the middle branch

But one formed thus would



It appears that each gas has its maximum power for conducting electricity at a certain density; when too dense or too much rarefied the gas becomes a non conductor. It would be very important to devise some means for obtaining accurate measures of this property.

Will a phosphorescent gas show striæ, and if so will they continue after the electric current ceases? This would be a proof that the striæ arise from a permanent distribution of density in the tube.

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Notes and diagrams on 'Luminous Striae', supporting the opinion of William Robert Grove (1811-1896), natural philosopher, relating to stratification of successive currents, [1852-1875].

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On account of the great distance of the sun from the earth it may be assumed that its rays fall ~~indefinitely~~ parallel on all the particles of the atmosphere contained in the hemisphere presented towards it.

A ray falling on any point of the atmosphere is reflected in every direction from it, but is more completely polarized in all directions which make a right angle with the path of the ray.

The following are consequences of these assumptions.

When the sun is in the zenith, the same maximum state of ~~and~~ polarization exists in the horizontal circle, the reflected rays being all in a circle of which the observer is the centre and the planes of reflection being vertical. Approaching towards the zenith the angle of reflection makes proportionally a greater angle with the incident ray and its polarization consequently diminishes. ~~For the line joining the sun and the eye of the observer the polarized rays can reach the eye~~

When the sun is in the horizon; the solar rays are all parallel to the line joining the eye or sun and the antisolar point. and the incident and reflected rays are made in the horizontal plane. At the antisolar point there is no polarization; moving the eye round the horizon the angle of reflection increases, the angle of maximum polarization occurring at 90°

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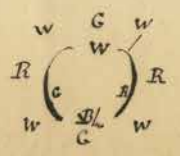
J

The superposition of films presents numerous singular phenomena; but we will at present confine ourselves to those presented when two exactly similar films are superposed.

1st Case ... Principal sections perpendicular to each other; — as the Analyzer is turned round white appears when the planes of the polarizer and analyzer correspond, and black when they are perpendicular; but in intermediate positions of the analyzer colour appears. Starting with the position for black, turning the prism to the right a rich dark green appears which becomes gradually finer till white appears at 100°; fine light red appears which becomes redder and darker till black appears. Black appears in the middle when red is shown in each single film, and white when the green is at its maximum.



at 45° the intensity and colour of the superposed and unsuperposed portions seem to be the same

The depolarizing plate B, placed before the compound film with its sections parallel, destroys all colour in the superposed films; but if this plate be moved round with the analyzer they continue to appear. This shows that the different intensities of the two colours are polarized in every different plane.

K/PP107/4/5/78

Notes and diagram on how the 'superposition of films presents numerous singular phenomena', [1846-1875].

82

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 white or black of the first order (according to the position of the analyzer) commence with the tint corresponding with that of the films of uniform thickness. The bands exhibit are therefore much fuller and less numerous than those shewn by the unequal films alone.

When the principal sections of the two films are perpendicular, ~~the bands~~ (in which case the bands are then corresponding to the difference of the two thicknesses) the bands are arranged in inverted order to the right and left of the central white or black, similar rings being at equal distances from the central band. By such superposition the proximate order of any tint may be easily determined.

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When the light emergent from these superposed films is reflected from a silver plate at 72; the bands advance or recede constantly in the same direction. The uncompensated portions at each side of the central band having their principal sections at right angles to each other, it might without consideration be thought, that the bands should simultaneously advance or recede from the central band, but it must be borne in mind that the augmentation of the uncompensated thickness increases equally on each side the central band consequence of which the bands on one side advance to the central band and those on the other recede from it, both series of bands thus advancing in the same direction.

For this experiment it is better that the bands should be as wide as possible and straight.

Though the bands on each side the central line move in the same direction, it will be observed that at equal differences of thickness on each side the central line, the tints of one side recede and those of the other advance on moving the analyzer in the same direction.

K/PP107/4/5/82

Draft paper on the 'superposition of Entoptic films, one showing a uniform colour, the other coloured bands', [1846-1875], pages 2 and 3.

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

Mr. C. Wheatstone
8. Copthall Court.
Throgmorton Street.
London. 27 April 1870
E.C.

Dear Mr Charles.

Enclosed we beg to hand you contracts for the investments made in United States 5/20 of 1867 and Spanish Stk.

The Dunaberg & Witepsk we are watching, hoping to buy on better terms than the quote We are Dear Sir

Yours truly
Haggard Hale & Pixley

K/PP107/4/5/88

Letter from Haggard, Hale and Pixley, stockbrokers, regarding investments including the Dunaberg and Witepsk railway in Russia, 1870 Apr 27.

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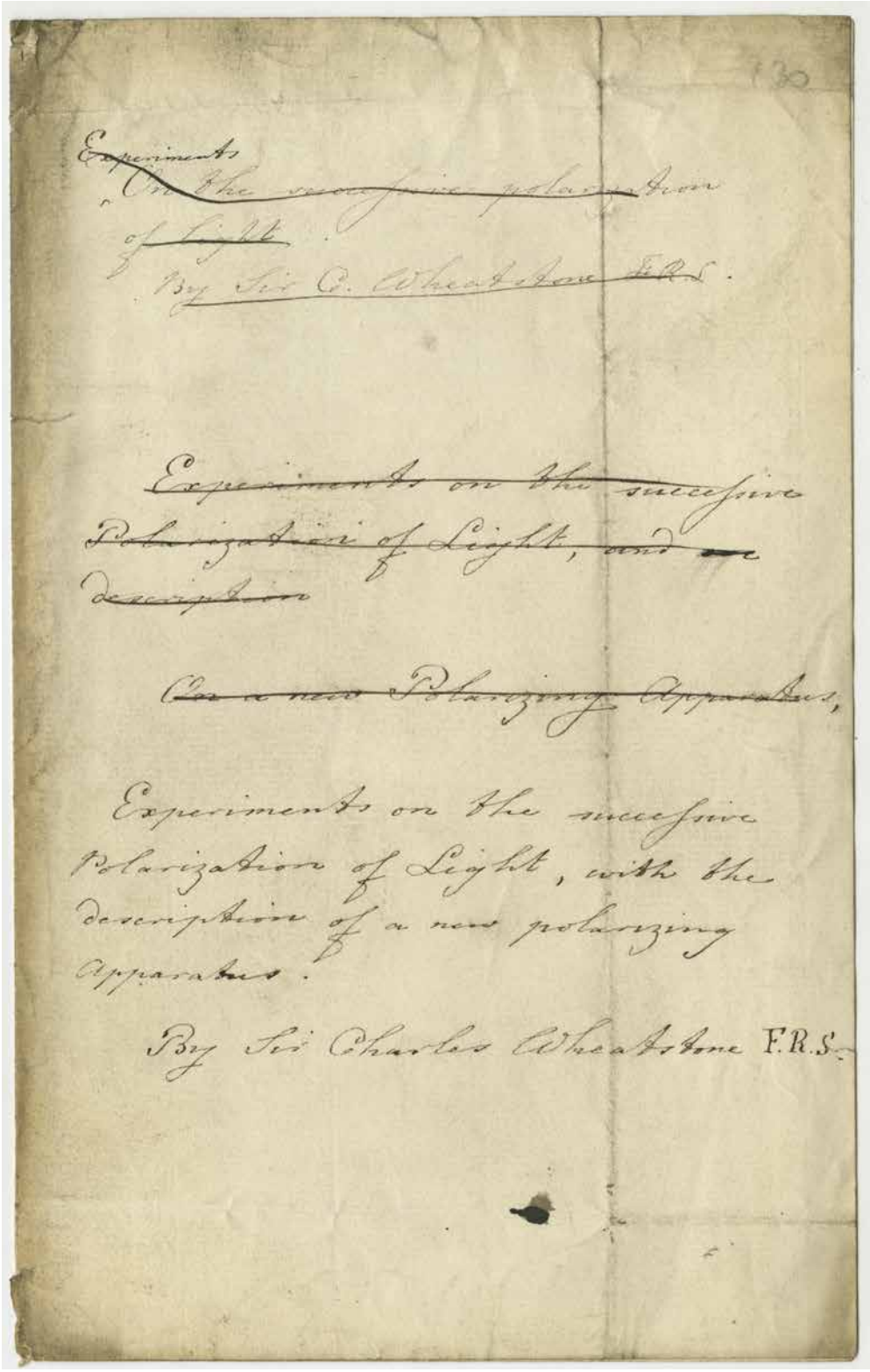

130

~~Experiments On the successive polarization of Light. By Sir C. Wheatstone F.R.S.~~

~~Experiments on the successive Polarization of Light, and the description~~

~~Of a new Polarizing Apparatus,~~

Experiments on the successive Polarization of Light, with the description of a new polarizing Apparatus.

By Sir Charles Wheatstone F.R.S.

K/PP107/4/5/130

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.

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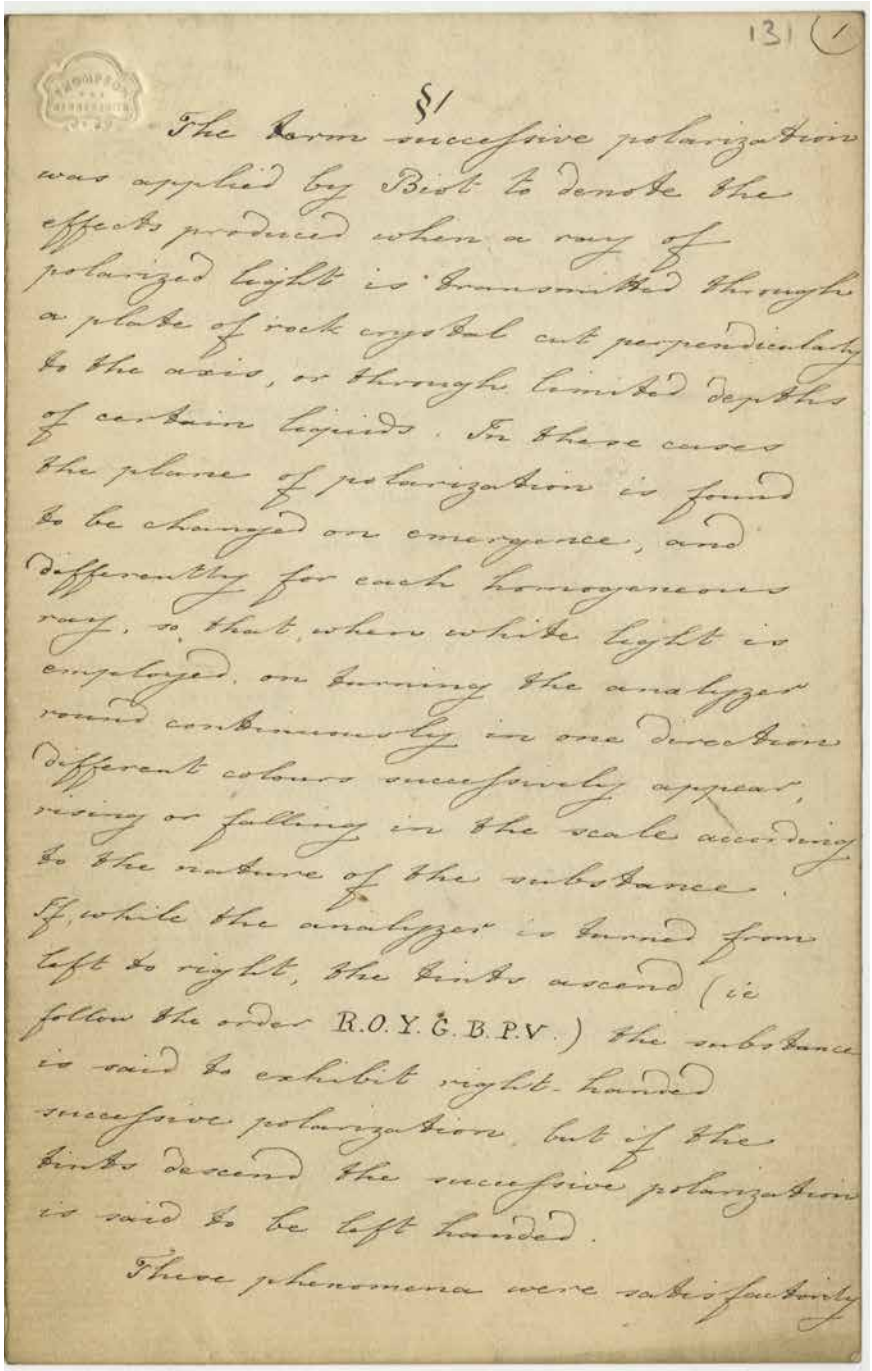


131 (1)

§1

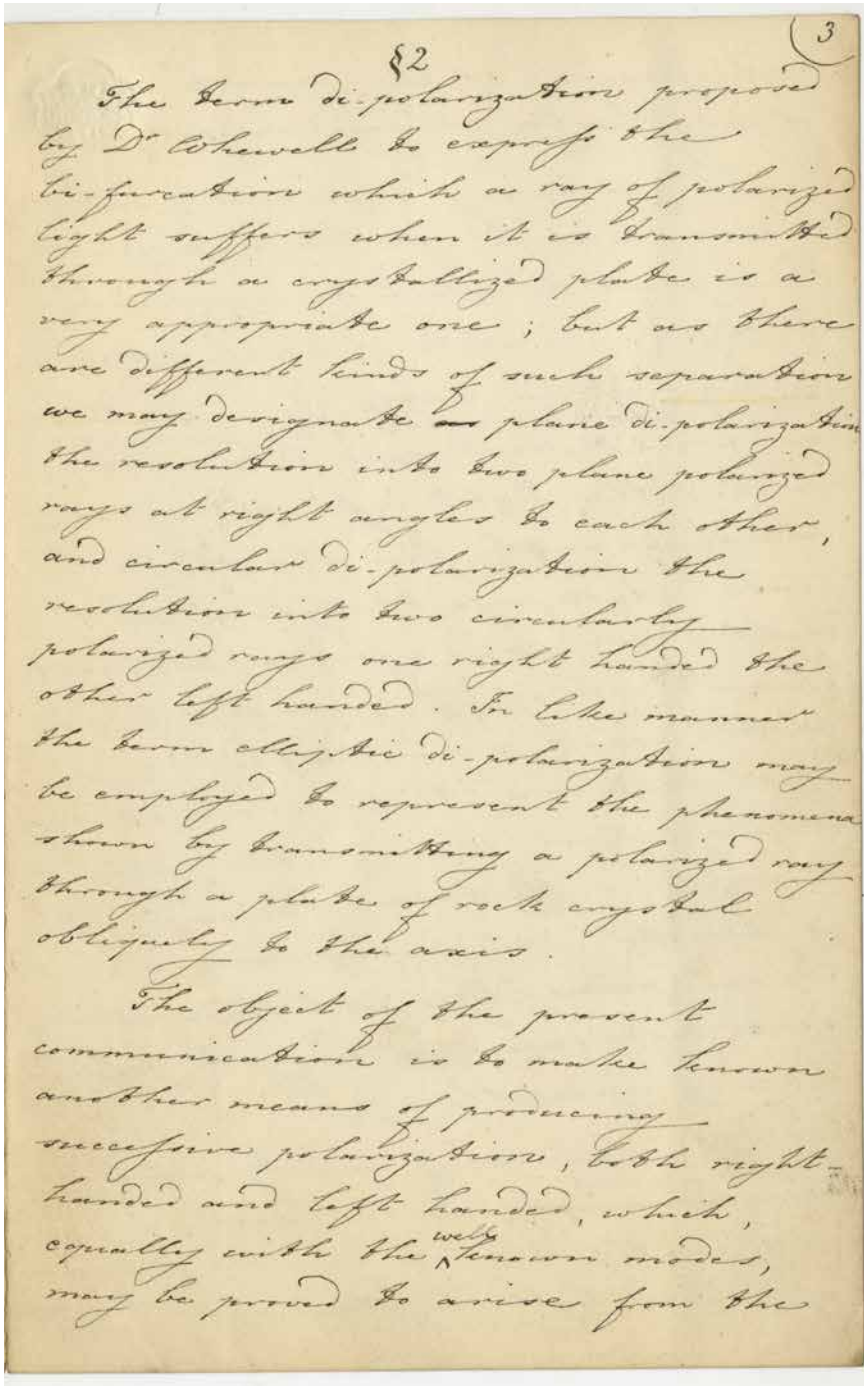
The term successive polarization was applied by Biot to denote the effects produced when a ray of polarized light is transmitted through a plate of rock crystal cut perpendicularly to the axis, or through limited depths of certain liquids. In these cases the plane of polarization is found to be changed on emergence, and differently for each homogeneous ray, so that, when white light is employed, on turning the analyzer round continuously in one direction different colours successively appear, rising or falling in the scale according to the nature of the substance. If, while the analyzer is turned from left to right, the tints ascend (ie follow the order R.O.Y.G.B.P.V.) the substance is said to exhibit right handed successive polarization, but if the tints descend the successive polarization is said to be left handed.

These phenomena were satisfactorily

K/PP107/4/5/131

Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 1.

2). explained by Fresnel in the following way. The incident polarized ~~ray~~, instead of resolving itself into two plane polarized rays at right angles to each other, as in the ordinary cases of di-polarization, resolves itself in these instances into two ~~opposite~~ circularly polarized ~~pencils~~ rays one right handed the other left handed which are transmitted with different velocities; each homogeneous ray, thus resolved into two opposite circularly polarized pencils, on emergence composes a ~~single~~ ray polarized in a single plane, the deviation of which from the primitive plane of polarization depends on the difference of phase of the two circularly polarized rays. The rotation of the planes of polarization is from left to right if the circular rays are transmitted with greater velocity than the circular rays; and it is from right to left if the contrary be the case.



(3)

§2

The term di-polarization proposed by Dr Whewell to express the bi-furcation which a ray of polarized light suffers when it is transmitted through a crystallized plate is a very appropriate one; but as there are different kinds of such separation we may designate ~~as~~ plane di-polarization the resolution into two plane polarized rays at right angles to each other, and circular di-polarization the resolution into two circularly polarized rays one right handed the other left handed. In like manner the term elliptic di-polarization may be employed to represent the phenomena shown by transmitting a polarized ray through a plate of rock crystal obliquely to the axis.

The object of the present communication is to make known another means of producing successive polarization, both right-handed and left handed, which, equally with the well known modes, may be proved to arise from the

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4)

interference of two opposite systems of circularly polarized rays.

§3

The polarizing apparatus which I have employed for the experiments I am about to detail is represented by fig 1. A plate of black glass G is fixed at an angle of 70 to the horizon. The film to be examined is to be placed on a diaphragm D ~~in place~~ so that the light reflected at the polarizing angle from the glass plate shall pass through it at right angles and after reflection, at an angle of 72°, from a silvered plate S shall proceed vertically upwards. N is a Nicol's prism, or any other analyzer, placed in the path of the second reflection. The diaphragm is furnished with a ring, moveable in its own plane, by which the crystallized plate to be examined may be placed in any azimuth. A

If a lamina of quartz cut ~~perpendicularly~~ parallel to the axis, and sufficiently thin to show the colors of polarized light, be placed upon the

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Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 4.

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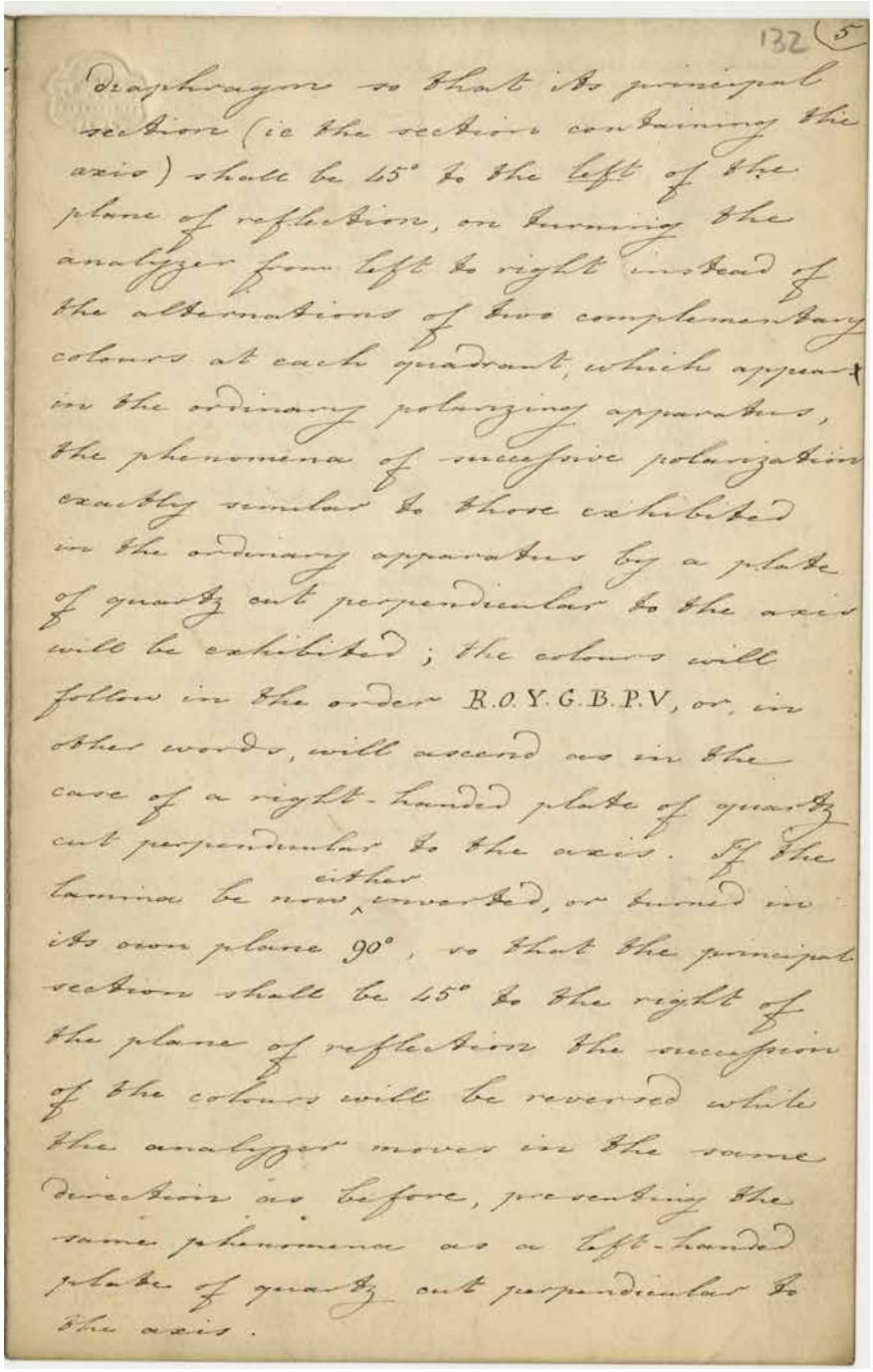

132 (5

diaphragm so that its principal section (ie the section containing the axis) shall be 45° to the left of the plane of reflection, on turning the analyzer from left to right instead of the alternations of two complementary colours at each quadrant, which appear in the ordinary polarizing apparatus, the phenomena of successive polarization exactly similar to those exhibited in the ordinary apparatus by a plate of quartz cut perpendicular to the axis will be exhibited; the colours will follow in the order R.O.Y.G.B.P.V, or, in other words, will ascend as in the case of a right-handed plate of quartz cut perpendicular 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 reflection the succession 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 quartz cut perpendicular to the axis.

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Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 5.

6)

Quartz is a positive double refracting crystal, and in it, consequently the ordinary index of refraction is smaller than the extraordinary index. But if we take a 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 reflection the colours descend, and when it is on the right of the same plane the colours ascend, the analyzer being turned from left to right.

It has been determined that the ordinary ray, both in positive and negative crystals, is polarized in the principal section; while the extraordinary ray is polarized 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 polarization is to the

left of the plane of reflection is the quickest the successive polarization is right handed, and when it is the slowest the successive polarization is left-handed; in the first case the colours follow in the order R.O.Y.G.B.P.V, and in the second case in the reversed order.

The rule thus determined is equally applicable to laminae of biaxal crystals.

As selenite (sulphate of lime) is an easily procurable crystal, and readily cleavable into thin laminae capable of showing the colours of polarized light, it is most frequently employed in experiments on chromatic polarization. The laminae into which this substance most readily splits contain in their planes the two optic axes; polarized light transmitted through such laminae 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

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Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 7.

(8)

thereto which bisects the supplementary angle is called the supplementary section. The positions of these lines, and of the optic axes, with respect to the natural edges of the film are represented fig 2. These definitions being premised, if a film of selenite be placed on the diaphragm, with its intermediate section to the left of the plane of reflection, the successive polarization is direct or right handed; if, on the contrary, it be placed to the right of that plane the successive polarization is left handed. The ray polarized 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 Mica one kind of the optic axes are in a plane perpendicular to the laminae. They are inclined 22°½ 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

133 (9

film be placed on the diaphragm with its principal section inclined 45° to the left of the plane of reflection the successive polarization is right handed. The ray therefore polarized in the section which contains the optic axes is the one transmitted with the greatest velocity. Fig 3 represents a film of Mica ~~with~~ the positions of the sections in which an incident polarized ray is resolved.

Films of uniaxal crystals, whether positive or negative, and 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, other circumstances 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

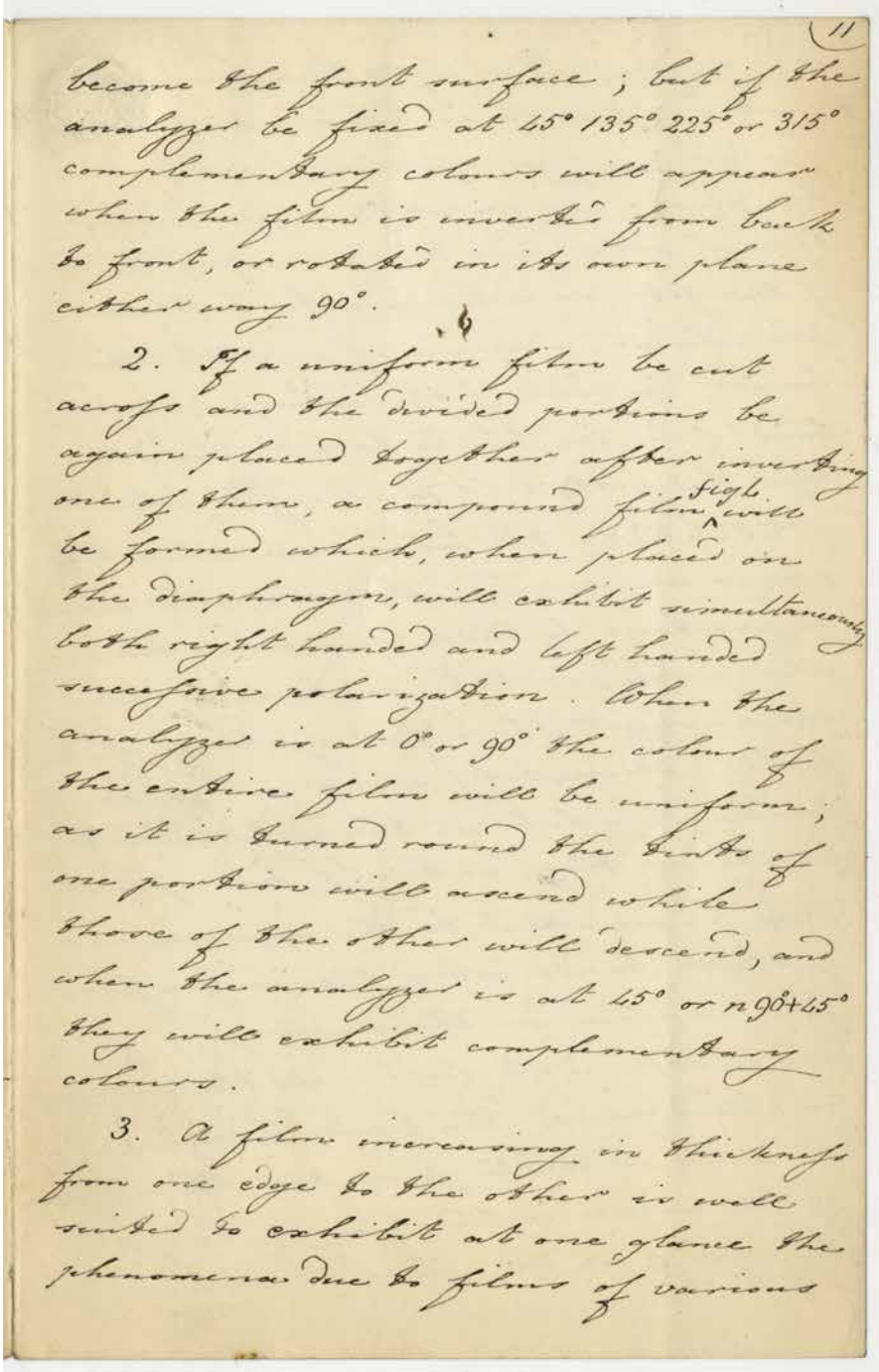
10)

image, so that if the plane of polarization of the quickest ray on the film is to the left of the plane of reflection, it is to the right of that plane in the reflected image.

§4

It may not be uninteresting to state a few obvious consequences of this successive polarization in double refracting laminae, right handed and left handed according to the position of the plane of polarization 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 reflection; when the analyzer 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



(11)

become the front surface; but if the analyzer 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 will be formed which, when placed on the diaphragm, will exhibit simultaneously both right handed and left handed successive polarization. When the analyzer is at 0° or 90° the colour of the entire film will be uniform; as it is turned round the tints of one portion will ascend while those of the other will descend, and when the analyzer is at 45° or n 90°+45° 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

12)

thicknesses. It is well known that such a film placed between a polarizer and an analyzer 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 analyzer 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 1. As the analyzer is moved round the bands advance towards or recede from the thin edge of the wedge without any changes occurring in the colours or intensity

134 (13

of the light, the same tint occupying the same place at every half revolution of the analyzer. If the bands advance towards the thin edge of the wedge the successive polarization 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 an uniform film changes right handed into left handed successive polarization, in a wedge of the same substance transforms receding into advancing bands, and vice versa. 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 laminae of sulphate of lime of different thicknesses (varying from 0.01818 to of an inch) between

14

Two plates of glass. Invisible under ordinary circumstances they exhibit, when examined in the usual polarizing apparatus, the most brilliant colours which are complementary to each other in the two rectangular positions of the analyzer. Regarded in the instrument fig 1. 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.

(15)

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 rectilinear polarized light is transmitted.

6. A thick plate of unannealed glass undergoes a series of regular transformations the principal phases of which are shown fig 5.

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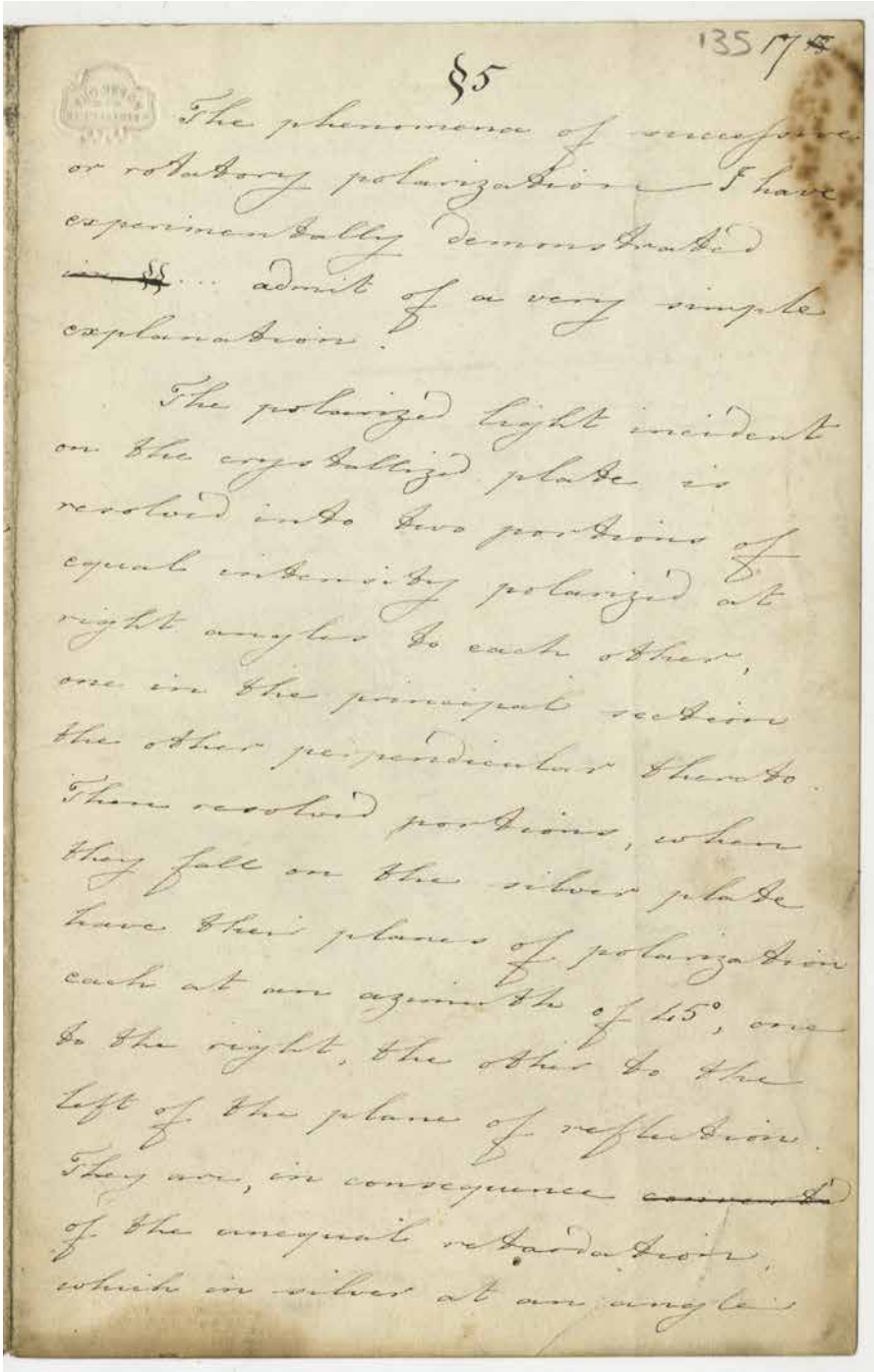
Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 15.



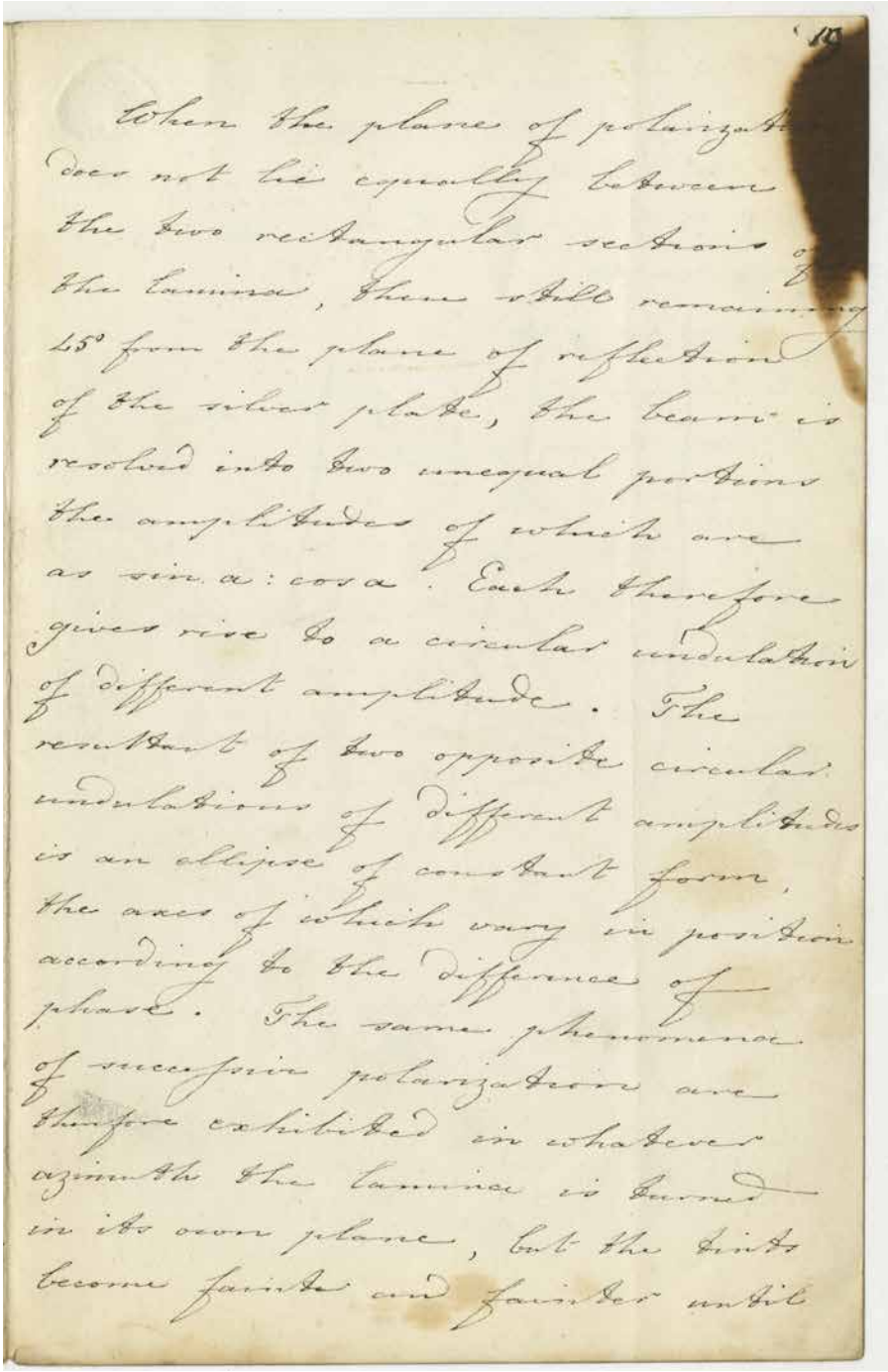
135 175

§5

The phenomena of successive or rotatory polarization I have experimentally demonstrated ~~in §§~~ admit of a very simple explanation.

The polarized light incident on the crystallized plate is resolved into two portions of equal intensity polarized at right angles to each other, one in the principal section the other perpendicular thereto. These resolved portions, when they fall on the silver plate have their planes of polarization each at an azimuth of 45°, one to the right, the other to the left of the plane of reflection. They are, in consequence ~~consequ~~ of the unequal retardation, which in silver at an angle

of 72° amounting to a quarter
of an undulation, converted
into circularly polarized beams,
one right handed, the other
left handed. The various
homogeneous ~~beams~~ rays being
~~which~~ accelerated differently in their
transmission through the two
sections of the crystallized plate
this difference is preserved after
reflection from the silver plate,
and the oppositely circularly polarized beams
are reflected with the same
difference of phase as the two
plane polarized rays are when
emerging from the crystallized
lamina. The composition of
two circular waves one right-handed
the other left handed, gives for
resultant a plane wave the azimuth
of which varies with the difference
of phase of the two components.



When the plane of polarization does not lie equally between the two rectangular sections of the lamina, then still remaining 45° from the plane of reflection of the silver plate, the beam is resolved into two unequal portions the amplitudes of which are as sin a : cos a. Each therefore gives rise to a circular undulation of different amplitude. The resultant of two opposite circular undulations of different amplitudes is an ellipse of constant form, the axes of which vary in position according to the difference of phase. The same phenomena of successive polarization are therefore exhibited in whatever azimuth the lamina is turned in its own plane, but the tints become fainter and fainter until

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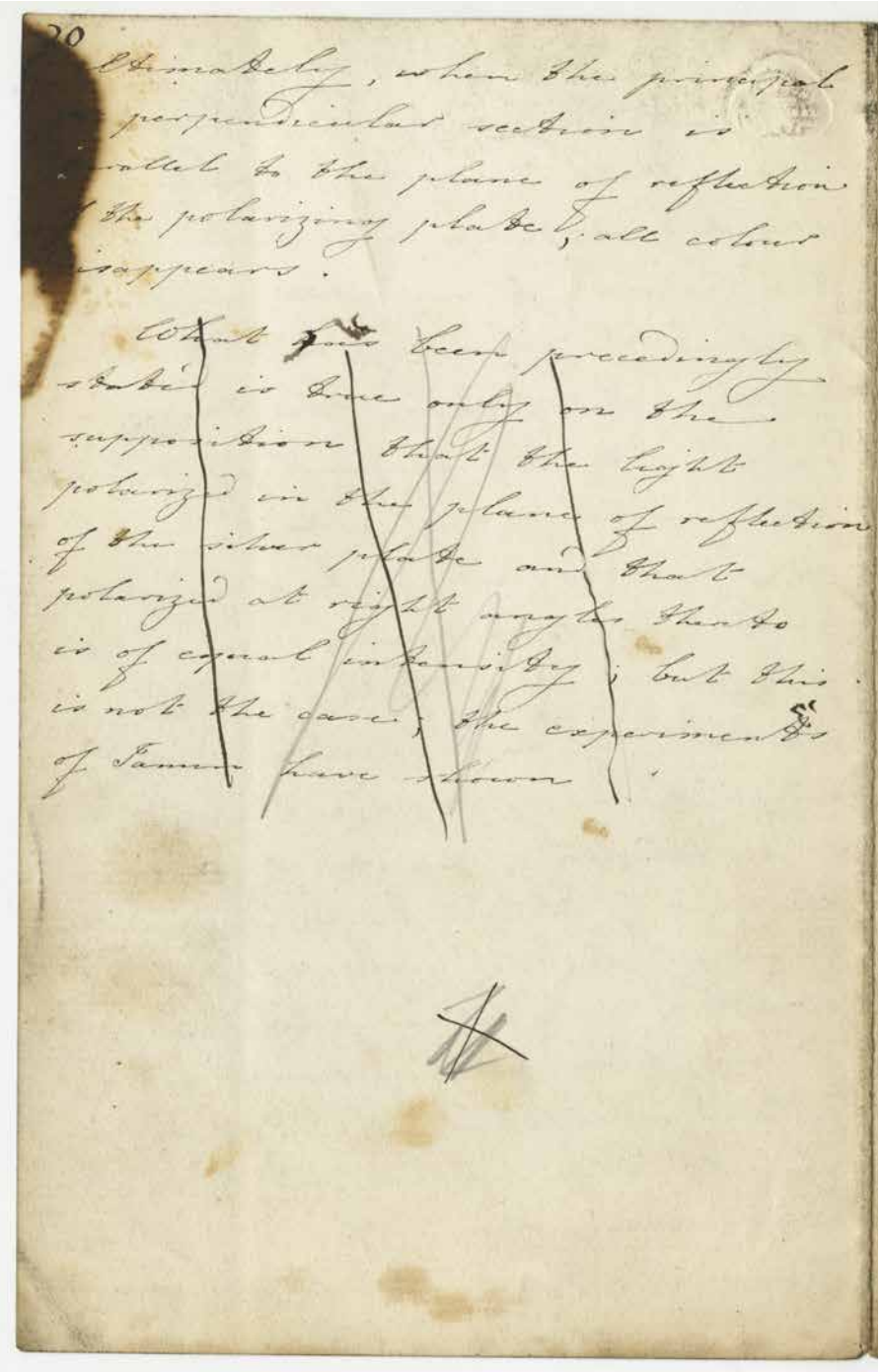


20

Ultimately, when the principal perpendicular section is parallel to the plane of reflection of the polarizing plate, all colour disappears.

~~What has been precedingly stated is true only on the supposition that the light polarized in the plane of reflection of the silver plate and that polarized at right angles thereto is of equal intensity; but this is not the case, the experiments of Fanner have shown.~~

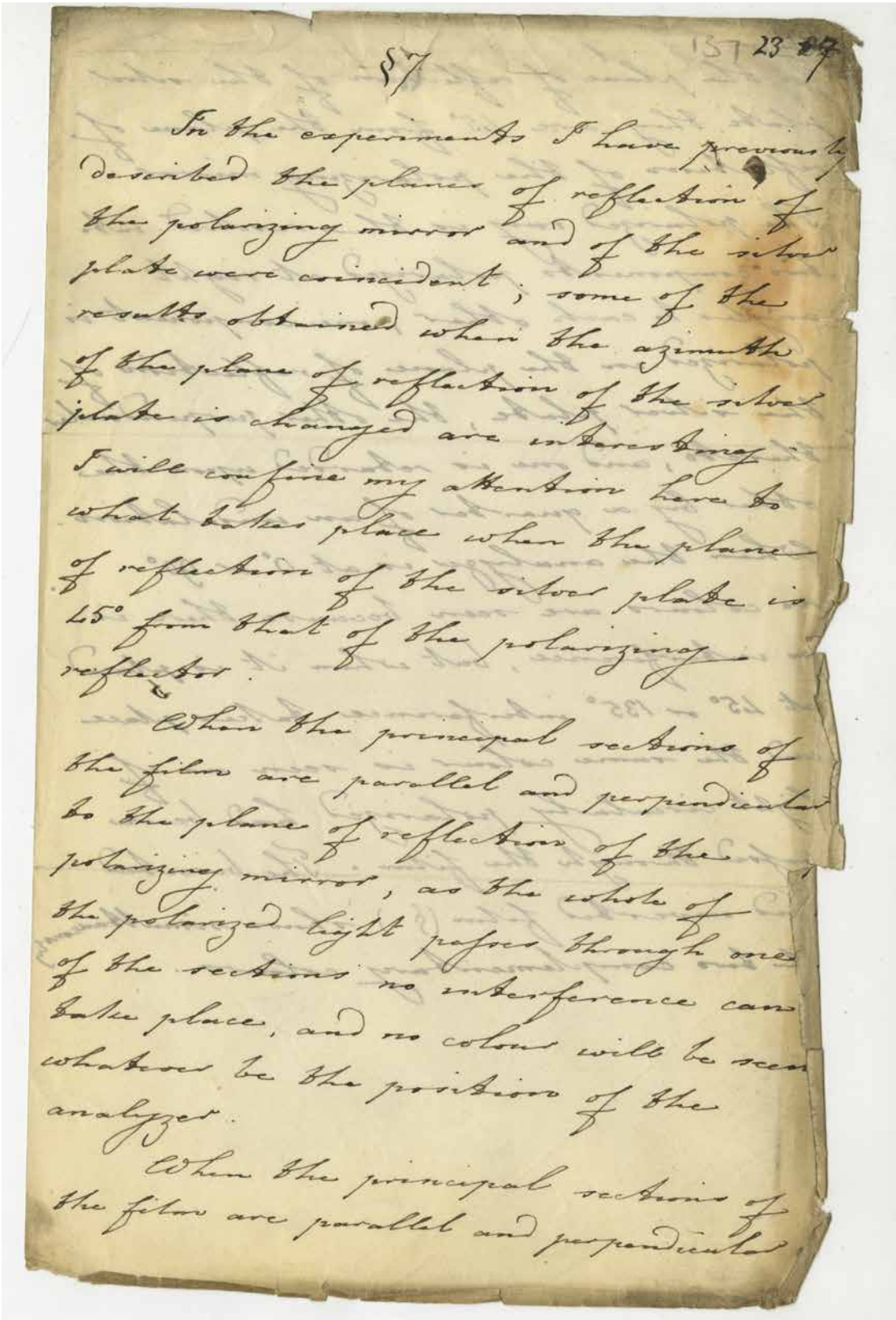
K/PP107/4/5/135

Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 20.

136 21 ~~25~~

§ 5

By means of the phenomena of successive polarization 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 of the instrument fig. in the position to show say right-handed polarization, then cross it with the other film; if the former be the thicker the successive polarization will be still right-handed; if both be equal there will be no polarization; and if the crossed film be the thicker the successive polarization will be left handed. In this manner a series of films may be readily arranged in their proper order in the scale of tints.



§7 137 23 ~~27~~

For the experiments I have previously 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 is changed are interesting. I will confine my attention here 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 films are parallel and perpendicular to the plane of reflection of the polarizing mirror, as the whole of the polarized light passes through one of the sections no interference can take place, and no colour will be seen whatever be the position of the analyzer.

When the principal sections of the films are parallel and perpendicular

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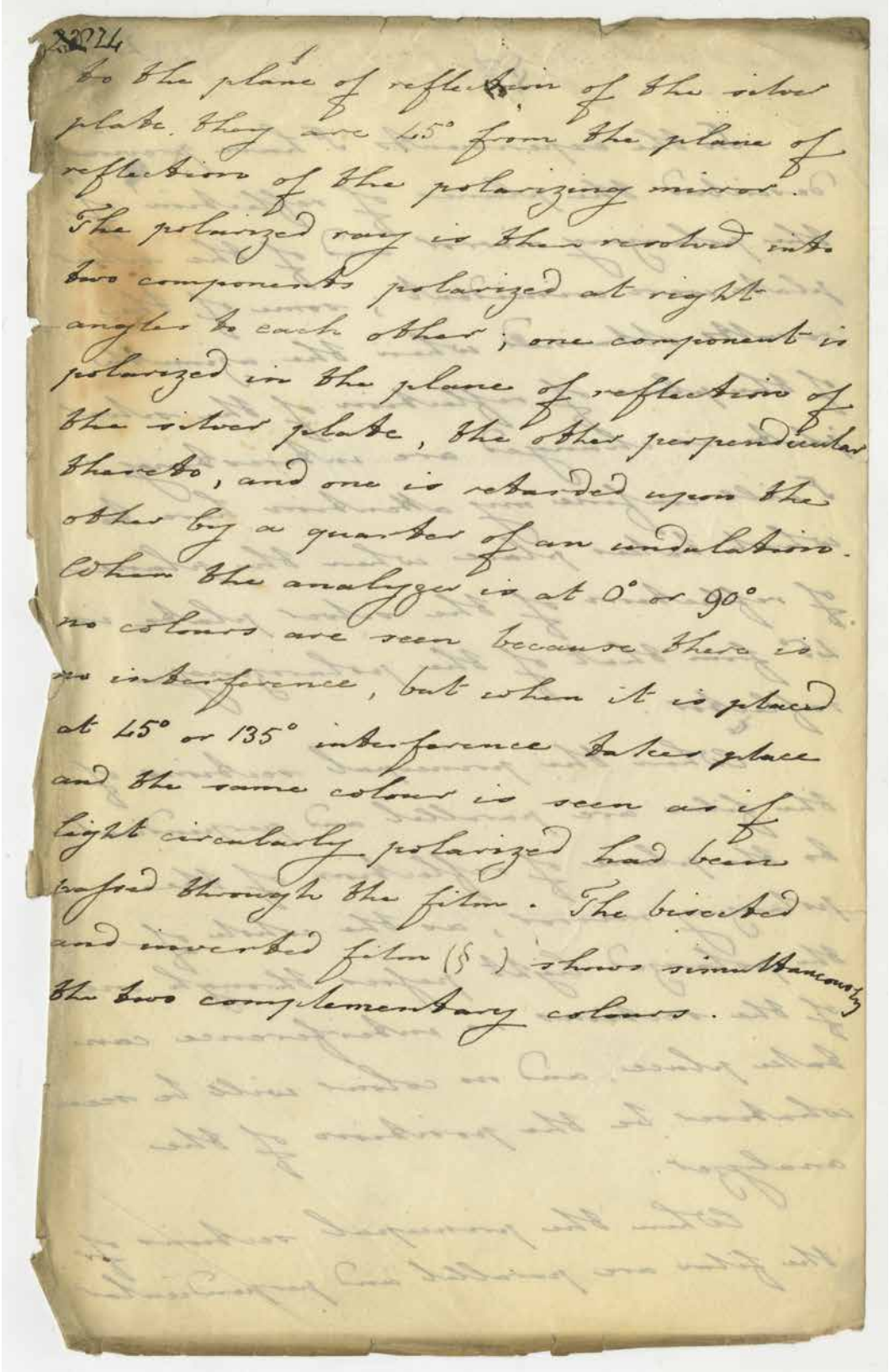

3274

to the plane of reflection of the silver plate. they are 45° from the plane of reflection of the polarizing mirror. The polarized ray is then resolved into two components polarized at right angles to each other; one component is polarized in the plane of reflection of the silver plate, the other perpendicular thereto, and one is retarded upon the other by a quarter of an undulation. When the analyzer 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 polarized had been passed through the film. The bisected and inverted film (§) shows simultaneously the two complementary colours.

K/PP107/4/5/137b

Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 24.

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138 2539

But when the film is placed with one of its principal sections 22½° from the plane of reflection of the polarizing mirror, on turning round the analizer the appearances of successive polarization are reproduced exactly as when the planes of reflection of the silver plate and of the polarizing mirror coincide. For this case the components of the light oppositely polarized in the two sections are unequal being as cos 22½ to sin 22½; these components respectively fall 22½ from the plane of reflection 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.

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Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 25.

(1)

§8

As bearing intimately on the subject of this paper I will here quote a passage from a memoir presented by Fresnel to the French Academy of Sciences in 1817 and published in abstract in the Annales de Chimie T. 28. 1825.

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(2) 140

"If a thin crystallized plate be placed
" between two parallelepipeds of glass
" cut at right angle, in each of which
" the light primarily polarized, undergoes
" two total reflection at the incidence of
56½, at first before its entrance into the
plate (which we suppose perpendicular to
the rays), and subsequently after its
emergence, and if besides the plate is
turned so that its axis makes an angle
of 45° with the two planes of double
reflection, this system will present the
optical properties of plates of rock crystal
perpendicular to the axis and of liquids
which colour polarized light: when the
principal section of the rhomboid with
which the emergent light is analyzed
is turned round, the two images will
gradually change colour; instead of
experiencing only simple variations in
the vividness of their tints, as occurs in
the ordinary case of thin crystallized
plates; besides, the nature of these colours
depend only on the respective inclination
of the primitive plane of polarization and

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the principal section of the rhomboid, that is to say of the two extreme planes of polarization; thus, when this angle remains constant, the system of the crystallized plate and the two parallelepipeds may be turned round the transmitted pencil, without changing the colour of the images. It is this analogy between the optical properties of this little apparatus and those of plates of rock crystal perpendicular to the axis, which enabled M. Fresnel to foresee the peculiar character of double refraction that rock crystal exerts on rays parallel to the axis."

~~Annales de Chimie T. 20. p. 129.~~
~~1822 Annales 1817~~

K/PP107/4/5/140

Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 28.

(3) 139

It does not appear that Fresnel, in any of his published memoirs, has given any further modifications of this experiment, the importance of which has been almost entirely overlooked in elementary treatises on Light. He does not seem 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 colours 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 deduced or experimentally shown

Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 29.

89 141 31 ~~25~~

§ 9

The apparatus fig 1 affords also the means of obtaining large surfaces of uncoloured or coloured light in every state of polarization, 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 reflection.

For the experiments which follow the crystallized plate must be placed on the diaphragm E between the silver plate and the analyzer; and both mirrors must have the same inclinations as before.

K/PP107/4/5/141
Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 31.

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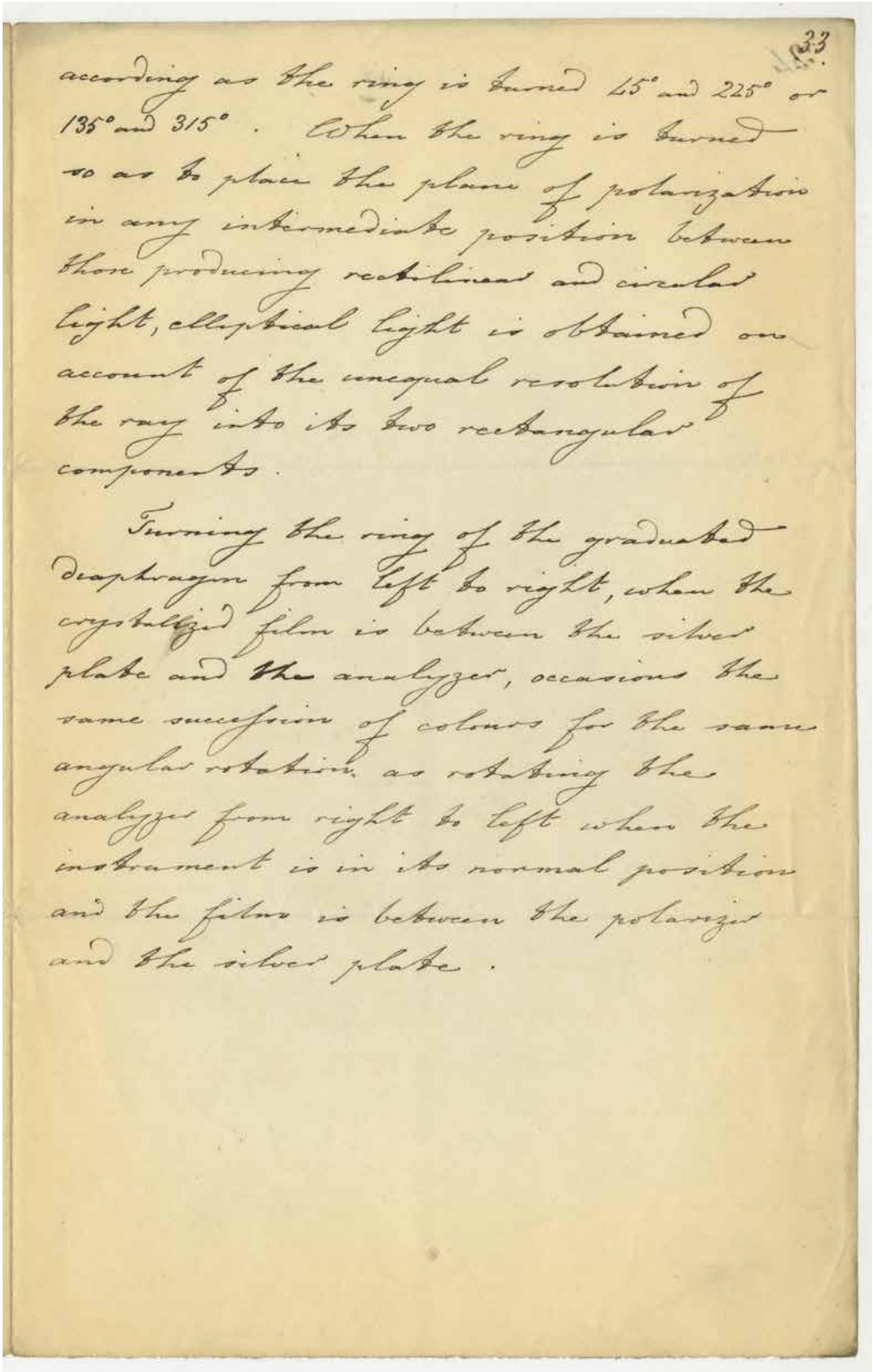
By means of a moveable ring in the graduated circle D the silver plate is caused to turn round the reflected ray, so that, while the plane of polarization of the ray remains always in the plane of reflection of the glass plate, it may assume every azimuthal position with respect to the plane of reflection of the silver plate.

In the normal position of the instrument the ray polarized 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 polarization of the ray falls 45° on one side of the plane of reflection of the silver plate and the ray is resolved into two others polarized respectively in the plane of reflection 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



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according as the ring is turned 45° 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 its two rectangular components.

Turning the ring of the graduated diaphragm from left to right, when the crystallized film is between the silver plate and the analyzer, occasions 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.

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Draft of paper 'Experiments on the Successive Polarization of Light with the Description of a new Polarizing Apparatus', published in the *Proceedings of the Royal Society*, 1871, page 33.

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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 Norrenberg's Polarizer a silvered mirror must be laid horizontal at H, and the instrument straightened as shown at fig 3 so that a line perpendicular to the mirror shall correspond 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

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reflected from the mirror, and the polarized plate will have passed, before it reaches the eye, twice through a crystallized plate placed between the mirror and the polarizer. The result is the same as if, in the ordinary apparatus, the polarized plate had passed through a plate of double thickness.

Fig 2 shows the ~~[illegible]~~ addition to ~~modification of~~ the apparatus when the coloured rings of crystals are to be examined by light circularly or elliptically polarized. a is the optical tube containing the lenses which requires no particular explanation, and b the condenser over which the plate is to be placed.

1846 Feb.

Telegraph by Polarized Light.

In the visual Telegraphs which have hitherto been proposed, form, disposition and colour have alone been employed to produce the signals required. But the various affections of polarized light affords another and, it appears to me, a far superior means of communicating mediately between two distant places. For the light at the place from whence the signals are to be transmitted may be polarized in any plane, or it may be polarized elliptically or circularly, either right handed or left handed, and with which the state which it has been made to assume there whether extent of space it may be made to pass.

~~12 mark~~ 24 distinct signals may thus be obtained

At the place from which the signals are to be transmitted an apparatus must be constructed to polarize the light in the requisite plane or planes, and attached to transmit always in the same straight line to the next station.

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At the station where the signals are to be received, ~~[illegible]~~ a telescope is to be properly fixed and furnished with the compound plate of selenite for reading the signals.

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a blackened glass mirror
b a second do
c a selenitic plate.
p the polarized ray.
x the selenitic axis.

c & b are fixed
a is moveable round the axis x.

This experiment, if it succeeds, will serve to demonstrate that all the affections of polarization are transmitted unimpaired through considerable distances of air.

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Notes proposing a telegraph able to utilise the phenomenon of optical polarisation, 1846 Feb, page 2.

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Partially polarized light.

A beam of polarized light transmitted through a (bi-polarizing) plate, will, according to the position of its plane of polarization with respect to the principal axis of the crystalline plate, either remain entirely polarized or be converted into a beam consisting of ordinary light with a certain excess of polarized light, or in other cases the beam will be partially polarized. When the beam is polarized in a plane parallel with or perpendicular to the principal axis, it remains completely polarized or consists in one of the two rectangular planes; when the plane is 45° from the axis the light consists of two equal rays polarized at right angles to each other and has all the characters of ordinary or unpolarized light, and in all intermediate positions the light is partially polarized. The relative proportions of the two rectangularly polarized beams will be as the squares of the cosines of the angles which the plane of polarization of the incident ray forms with the principal axis. A method has not yet been devised to establish the law of the cosines for all angles, but this applies the refining, for the partially polarized light transmitted may be compounded by reflection from the surface of glass at different angles, and the comparison of the two results will give a proof of the truth of both laws, viz that of the cosines, and that of polarization by reflection.

A plate of tourmaline is a bi-polarizing crystal in which one of the rectangular components is absorbed; the property of a polarizing ray transmitted though it is no doubt as the squares of the cosines. The same observation may be made with regard to a Nicol's prism.

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Notes on partially polarised light, [1846-1875], page 1.

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Let x be the intensity of the incident light which is resolved into two equal portions $\frac{x}{2}$ and $\frac{x}{2}$ polarized in planes at right angles to each other. ~~Each portion undergoes a reflection in general unequal~~ Each of these portions is resolved into a reflected and a refracted beam; the two reflected beams and the two refracted beams may have any proportion to each other according to the angle of incidence. If the reflected portion of the first be $\frac{a}{2}x$ the refracted portion will be $\frac{(1-a)x}{2}$, the reflected portion of the second $\frac{bx}{2}$ and the refracted portion $\frac{(1-b)x}{2}$.

If we consider only the two reflected portions, if the successive reflected beams be again reflected at the same angle from the same substance the resultant will be $a^2x + b^2x$ and after having undergone n similar reflections it will be $a^nx + b^nx$. This consideration will explain very easily the Sir D. Brewster's result with respect to multiple reflections, after repeated reflections a ray becomes sensibly polarized in the plane of reflection, and fewer reflections are required as the ratio between the intensities of the two reflected ray becomes greater. Thus if the 1st reflection is 1/2, the successive reflections give 1/4, 1/8, 1/16 &c if the 1st reflection be 1/5, the successive reflections are 1/25, 1/125, 1/625 &c

If the successive reflections be made at unequal angles or from different substances, the resultant may be equally determined $\frac{acx}{2} + \frac{bdx}{2}$, $\frac{aecx}{2} + \frac{fbdx}{2}$ &c

If a be b or c &c then a perfect compensation is effected and the reflected light is wholly unpolarized. By this means as Sir D. Brewster has shown the quantity of polarized light in a partially polarized beam may be determined.

The experiments adduced by Sir D. Brewster are all in complete ~~numerical~~ accordance with this view.