XXI.—*Observations on the Polarisation of the Atmosphere, made at St Andrews in 1841, 1842, 1843, 1844, and 1845.* By Sir DAVID BREWSTER, K.H., D.C.L., F.R.S., &c. (Plate XII.)

(Read 16th March 1863.)

During the last half century, observations on the polarisation of the atmosphere were made by several eminent observers—by ARAGO, DELEZENNE, BABINET, and ZANTEDESCHI; but no result of special importance was obtained till ARAGO made the great discovery that there existed in the atmosphere a point, or spot, in which there is *no polarisation*. At sunrise or sunset he found that this neutral point was 20° or 30° above the point opposite to the sun, or what we may call the *Antisolar point*. The name of *Arago's neutral point* has been given to this spot without polarisation. It is best seen after sunset. At St Andrews it is above the horizon all the day, between the middle of November and the end of January.

In the year 1840, M. BABINET made the next important discovery respecting the polarisation of the atmosphere. When on a visit to the sea-coast, he discovered that there was a neutral point as far above the sun as ARAGO's neutral point was above the antisolar point.* To this spot the name of *Babinet's neutral point* has been given. It is most distinctly seen immediately after sunset, but is much fainter than the other, on account of the discoloration of the sky by the yellow light of the setting sun.

Upon hearing of this discovery, I saw that we had now the elements for determining the laws of the polarisation of the atmosphere; and, being ambitious of succeeding in such an inquiry, I devoted four years to the study of the subject.

My observations commenced on the 28th April 1841; and I made many hundred on the position of the two neutral points,—on their change of place under different states of the weather, different degrees of transparency in the atmosphere, different degrees of light in the sky, and different altitudes of the sun. I measured also the maximum polarisation of the atmosphere in different azimuths between that which passed through the sun and the zenith, and that which, at sunset, passed through the sun and the horizon. These observations

* Comptes Rendus, &c., 1840. Tom. xi. p. 618.

were not difficult to make when the sky was clear and blue; but in studying the part of the atmosphere between the sun and the horizon, I was perplexed beyond measure with the feeble and uncertain indications of the polariscope. The sky between the sun and the horizon is always the most impure portion of it; and the flood of light streaming from the sun unfits the eye for detecting faint traces of colour. Theoretical considerations had led me to believe that a neutral point should be found between the sun and the horizon, and certain indications of the polariscope, at places around its probable locality, entitled me to infer that it did exist; but, as an inference was not satisfactory, I watched every favourable state of the sky, in the hope of obtaining a more direct result.

An opportunity of doing this at last presented itself to me on the 28th February 1842, when the sun was in the meridian, with an altitude of 22° . The spot beneath the sun was fortunately visible from the end of a long dark passage running north and south, and having concealed the sun himself, and every part around him except the probable position of the spot, I obtained a most distinct view of the new neutral point, situated about 15° or 16° below the sun. After communicating this discovery to M. BABINET early in 1845, he made several ineffectual attempts to confirm it, and it was not till the 23d July 1846 that he succeeded in obtaining a distinct view of this neutral point. Following the usual practice, the French have given to this spot the name of *Brewster's neutral point*.

Fig. 1.

With these three elements of atmospherical polarisation, shown in Fig. 1, I shall now proceed to determine their position in relation to the sun and the antisolar point, and ascertain the changes which they undergo from variations in the optical and meteorological state of the atmosphere.

Observations on ARAGO's Neutral Point.

In observing the different neutral points, I employed chiefly SAVART'S band polariscope, which was kindly presented to me by M. BABINET. It consists of two plates of rock crystal, which give a system of rectilinear polarised bands* attached to an analysing plate of tourmaline. In very feeble lights, I used another instrument, in which the analyser was a NICOL'S prism. When the polariscope is directed to a neutral point, the system of fringes is interrupted, as shown in Fig. 2 at N. P. The bands on one side of the interruption are oppositely polarised to those on the other, the central band in the one being *black*, and in the other *white*.

Fig. 2.

In order to measure the altitude of the neutral point thus observed, I used a common quadrant with a plumb line, which gave, within half a degree, the altitude of the centre of the neutral spot. In order to obtain the height of the neutral point above the sun, or the antisolar point, it was necessary to have the sun's altitude, or his depression beneath the horizon. Having asked Professor HENDERSON for the easiest method of obtaining these with a moderate degree of accuracy, he recommended to me to use MARGETT'S Longitude Tables, from which they were accordingly taken.

The following observations are a selection of some of the most important, out of a very great number recorded in my journal. In order not to crowd the page with figures, I have given only the hour of observation, and the altitude of the neutral point above the antisolar point, and occasionally the maximum polarisation.†

1841, May 12.—Barom. 30·1; Therm. 9^h P.M. 48°. The sky unusually clear.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.	
	In Zenith.	In Horizon.		
7 ^h 10 ^m P.M.	30½°	28½°	20°	33'
7 25 "	...	...	20	29
7 35 "	30½	29½	21	13
7 45 "	28½	28½	21	33
7 55 " The sun set.	...	...	22	8
8 5 "	...	...	21	35
8 15 "	...	...	20	41
8 30 " { The polarized bands faint. }	...	...	22	26

* See Edinburgh Transactions, 1819, vol. ix. p. 148, where the method of producing rectilineal bands, by crossing two plates of rock crystal, was first published.

† See the section on the place of maximum polarisation, and its intensity or R., p. 245.

1841, June 3.

Mean Time.		Height of Neutral Point above the Antisolar Point.
6 ^h 27 ^m P.M.	Neutral Point not risen.	
6 36 "	... very near the horizon.	
6 43 "	... above and close to the horizon.	
7 8 "		18° 20'
7 35 "		20 30
8 4 "		21 43
8 33 "	Sun sets.	

1841, June 10, 2^h.—Barom. 29·7. Singularly fine sky all day; wind east. When the neutral line or point of the polarimeter happened to be above an illuminated wall, the effect was to vary the place of the neutral, as if the polarisation of the sky were diminished. At 3^h 47^m, when the sky was everywhere pure and free of clouds, the *neutral line* of the polarimeter was curved above the land horizon. At 6^h 32^m its curvature was greater above the sea horizon, the deviation increasing towards the horizon.

Mean Time	R=Maximum Polarisation. In Zenith.	In Horizon.	Height of Neutral Point above the Antisolar Point.
6 ^h 35 ^m P.M.	Neutral point in horizon.		
7 13 "	...	...	18° 20'
7 30 "	28½	28½	18 56
7 42 "	...	...	21 0
8 5 "	29½	28½	19 15
8 18 "	...	29½	18 56
8 36 "	Sun set.	...	19 25
8 52 "	29½	30	19 29

1841, July 17.—Barom. 29·60, therm. 55°. Wind south-west. A China-ink sky, with clouds here and there.

Mean Time.	Height of Neutral Point above the Antisolar Point.
7 ^h 35 ^m P.M.	19° 0'
8 0 "	17 48
8 18 " Sun sets.	17 25
8 30 "	17 45
8 47 "	17 19
9 2 "	16 15
9 12 "	17 26
9 22 "	19 7

1841, August 31.—Rain till 1^h P.M., when it cleared up. Barom. 29·7.

Mean Time.	R=Maximum Polarisation. In Zenith.	In Horizon.	Height of Neutral Point above the Antisolar Point.
5 ^h 44 ^m P.M.	27½°	18½°	17° 22'
6 0 "	28½	22½	19 55
6 20 "	...	...	19 59
6 38 "	...	...	20 3

1841, September 6.—Barom. 29·5.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 22 ^m P.M.	29½°	...	19° 7'
6 30 "	...	...	19 45
6 35 "	28½	27½	20 21
6 49 "	28½	26½	21 20
7 0 "	...	...	21 0
7 6 "	...	...	21 2
7 15 "	...	...	23 0

1841, September 12.—Barom. 29·75. Sky clear.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 8 ^m P.M.	27½°	25½°	20° 35'
6 20 "	...	...	20 45
6 24 "	...	...	21 7
6 46 "	...	...	22 2
6 49 "	...	...	22 10
6 58 "	...	...	23 54

1841, September 29.—Barom. 28·73 after rain. Sky clear.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 23' P.M.	37½°	24½°	28° 10'
5 24 "	29½	29½	21 35
5 31 "	30	...	21 0
6 2 "	...	...	23 51
6 12 "	...	...	24 15

At 5^h 24^m the sky was clear, but whitish, and not blue. A little cloud below the neutral point.

1841, October 23.—Rainy day. Cleared up at 3^h P.M.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 18 ^m P.M.	...	...	21° 5'
4 24 "	...	...	21 50
4 29 "	27½	25½	21 27
4 37 "	...	...	21 13
4 44 "	...	...	21 23
4 52 "	26	25½	21 45

1841, November 2.—Barom. 30·7. Fine day; dry haze.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
2 ^h 30 ^m P.M.	The neutral point rises.		
2 30 "	26½°	22½°	13° 20'
2 43 "	...	...	18 20
3 22 "	25	22½	18 45
3 51 "	...	...	21 32
4 15 "	...	...	19 54
4 36 "	...	...	19 20
4 58 "	...	...	22 22

1841, November 4.—Barom. 30·2. A foggy day; sky tolerably clear of clouds.

1^h 50^m The neutral point just risen above the thick haze near the north horizon. The bands of the polariscope are all rugged at the edges, indicating an abnormal state of the air. $R=21\frac{1}{2}^{\circ}$ in zenith, and 15° in horizon.

Mean Time.	Height of Neutral Point above the Antisolar Time.
3 ^h 13 ^m P.M.	24° 52'

This singular height of the neutral point arose doubtless from the haze in the horizon.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
3 ^h 45 ^m P.M.	22 $\frac{1}{2}^{\circ}$	19 $\frac{1}{4}'$	...
4 12 "	...	...	19° 56'
4 17 "	...	...	20 3

1841, November 25.—Barom. 29·63. Singularly fine day.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
10 ^h 31 ^m A.M.	27 $\frac{1}{2}^{\circ}$	25 $\frac{1}{2}'$	14° 30'
12 0 "	27 $\frac{1}{2}$	25 $\frac{1}{2}$	14 6
2 21 "	28 $\frac{1}{2}$	26 $\frac{1}{2}$	17 35
3 3 "	...	...	18 45
4 20 "	...	...	19 50
4 24 "	...	...	18 40
4 38 "	27 $\frac{1}{2}$	27 $\frac{1}{2}$	19 20

1842, January 29.—Barom. 29·93. Fine day; clear sky; snow covers the ground partially.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
3 ^h 34 ^m A.M.	27°	27 $\frac{1}{2}^{\circ}$	21° 46'
3 52 "	...	...	20 38
4 10 "	...	...	20 40

1842, February 15.—Rain in morning; fine day afterwards; Barom. 30·05; wind west.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
3 ^h 13 ^m A.M.	26 $\frac{1}{2}^{\circ}$	{ 18 $\frac{1}{2}^{\circ}$ in S. H. 22 $\frac{1}{2}$ in W. H. }	{ Neutral point not risen.
3 38 "	...	...	In App. H. 7° 30
3 48 "	26 $\frac{1}{2}$	18 $\frac{1}{2}$	8 17
3 58 "	...	...	9 7
4 21 "	...	...	14 35
4 47 "	...	...	16 55
4 51 "	27 $\frac{1}{2}$	22 $\frac{1}{2}$ in S.E.	17 52

The observations at 3^h 38^m, 48^m, and 58^m, are recorded as good, and made in the finest sky.

The state of the atmosphere was peculiar near the horizon, as will be seen in the section on a secondary neutral point.

1842, February 16.—Barom. 30·16.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
12 ^h 0 ^m A.M.	A China-ink muddy sky.		...
2 48 "	19½°	...	Neut. Point not risen.
3 18 "	22½	22½ at 25° Alt..	Do. do.
3 22 "	...	...	10° 30'
3 44 "	A secondary neutral point.		12 0
4 12 "	...	...	17 30
4 37 "	...	...	17 10
4 58 "	...	...	18 20

1842, February 18.—Cold, wind west and rather strong. 12^h 0^m, I observed a curious effect on the polarised bands in the west, the sun's altitude being about 30°. In carrying the bands vertically round, the neutral line, in place of crossing them at a right angle, was the arch of a circle, to which one of the bands was a tangent. The sky was clear, but in a short time a cloud was formed in that place. I had observed the same phenomenon previously. It indicates a state of the air similar to that which produces mirage.

1842, February 21.—Barom. 29·44. Wind west. The sky-line over both the sea and the land unusually distinct and free from haze.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
3 ^h 45 ^m P.M.	10° 29'
3 57 "	12 39
4 31 "	17 40
4 37 "	18 35
5 6 "	19 49

1842, April 5.—Barom. 30·07. Splendid sky.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 25 ^m P.M.	...	...	13° 26'
5 32 "	...	...	15 25
6 21 "	30	26½	19 1
6 55 "	...	...	18 50
7 12 "	30½	...	21 5

N.B.—This and April 8th are the only days on which I was able to observe all the three neutral points, and determine their place. (See pp. 225 and 229.)

1842, April 6.—Barom. 30·05. Considerable haze.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
5 ^h 23 ^m	15° 26'

1842, April 8.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 30 ^m P.M.	...	...	15° 26'
5 38 "	...	...	19 0
5 46 "	...	...	19 0
5 52 "	...	...	19 5
6 5 "	24½	19½	21 25
6 22 "	...	...	20 55
6 47 "	27½	...	20 30
7 5 "	28¾	...	19 55
7 18 "	...	...	20 15

1842, April 13.—Bar om.30·12. Fine day.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 48 ^m P.M.	...	...	16° 20'
6 20 "	29	22½	17 55
6 54 "	29½	...	19 40
7 10 "	...	...	19 45
7 19 "	30½	...	19 4
7 54 "	...	...	22 10

At 7^h 32^m the maximum polarisation was 32½, the greatest ever observed.
(See p. 250.)

1842, April 20.—Barom. 30·02. Wind west; very fine day.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
5 ^h 50 ^m P.M.	22° 50'
6 29 "	19 21
6 59 "	20 55
7 45 "	20 10
7 59 "	24 8

1842, April 26.—Barom. 30·00. Not a cloud in the sky from morning till
night.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
5 ^h 21 ^m P.M.	13° 43'
6 6 "	13 51
6 38 "	19 28
7 9 "	20 10
7 32 "	19 15

1842, April 29.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
5 ^h 54 ^m P.M.	18° 4'
6 1 "	18 35
6 45 "	22 25

1842, May 15.—A haze.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 29 ^m P.M.	15°	15°	28° 35'
6 46 "	...	...	28 12
7 26 "	20½	...	24 6
8 26 "	23½	...	19 59

1842, November 14.—Barom. 29·6. Fine frosty and clear morning.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
8 ^h 55 ^m A.M.	25½°	19½°	19° 50'
9 3 "	...	...	18 40
9 16 "	...	...	15 22
9 31 "	...	...	15 0
9 43 "	...	...	14 30
9 48 "	...	...	13 45

1842, November 20.—Barom. 29·74. Cold and clear.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
10 ^h 8 ^m A.M.	21½°	...	18° 5'
10 15 "	...	...	17 30
10 27 "	...	...	16 25
10 39 "	...	...	45 15
10 55 "	...	...	15 5
11 0 "	Neutral point lingering in the horizon.		

1842, November 21.—Barom. 29·77; therm. 31°. Frosty morning.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
9 ^h 1 ^m A.M.	...	...	21° 10'
9 13 "	26½°	19½°	20 25
11 4 "	...	...	15 45
12 22 P.M.	Neutral point below land horizon; bands scarcely visible in horizon.		
12 43 "	Neutral point in horizon.		
1 40 "			16 30

The decrease in these numbers as the sun's altitude increased is very interesting. The light of the sky was increasing till noon, whereas, when the numbers increase, the light of the sky diminishes.

The observations on the 14th, 20th, and 21st Nov. were the only *morning* ones I made.

1842, December 28.—Barom. 29·56. Sky very fine at 11^h 38^m.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
11 ^h 38 ^m P.M.	29°	...	17° 20'
11 58 "	27	18½	17 21
1 0 A.M.	...	...	18 25
1 28 "	...	...	22 16
2 33 "	14½	...	22 15

See in p. 237 the state of BABINET'S neutral point at this date, when a halo of 45° encircled the sun.

1843, February 2.—Barom. 29·05. Snow storm with wind.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
9 ^h 55 ^m A.M.	24½°	17½°	...
Polarisation of the sun's light by the snow hardly perceptible, whether we look towards or from the sun.			
2 5 P.M.	Neutral point in sea horizon.		12° 5'
2 47 "	26½	19½	14 35

1843, February 14.—Barom. 29·45. Bitter cold day; frost in the morning.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
2 ^h 48 ^m A.M.	Neutral point below horizon.		12° 5'
2 53 "	{ Neut. pt. } { in horizon } 28½		11 45
		23½	

1843, March 25.—Barom. 29·97.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 35 ^m A.M.	25°	Neutral point in horizon.	10° 0'
5 15 "	...	...	11 30
5 44 "	28	...	18 31
6 9 "	29½	...	17 30

1843, June 21.—Barom. 29·75. Fine day; wind west.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
7 ^h 12 ^m A.M.	27½°	22½° { N.pt.in horizon }	9° 40½'
7 44 "	...	...	16° 31
8 30 "	29	...	19 22
9 16 "	30	...	18 29

1844, February 3.—Barom. 29·90. Snow covering the ground.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 7 ^m A.M.	26°	23°	18° 20'

1844, February 21.—Barom. 29·28. Snow partially covering the ground.

Apparent Time.	R=Maximum Polarisation.		Height in Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
3 ^h 30 ^m A.M.	27°	...	13° 3'
4 40 "	28½	...	12 35
4 13 "	28¾	...	17 34
4 40 "	...	...	19 24

1844, June 10.—Barom. 29·70.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
7 ^h 36 ^m A.M.	...	...	21° 20'
7 44 "	...	...	21 20
8 11 "	24¾	22½	21 35
8 52 "	27½	23½	21 50

1844, June 13.—Barom. 29·4. Windy; wind south-west.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
7 ^h 0 ^m A.M.	Neutral point in horizon.	...	11° 10'
7 12 "	24½	20½	13 2

In the following observations, the altitude of the sun was not estimated. The numbers in the fourth column are the altitudes of the neutral point above the horizon.

1845, April 15.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Horizon.
	In Zenith.	In Horizon.	
5 ^h 48 ^m A.M.	26½°	22½°	7° 25'
6 48 "	27½	24½	18 55

In the normal state of the atmosphere, as represented in the Map, Plate XII., namely, when the sun is in the horizon, ARAGO's neutral point is about $18\frac{1}{2}^{\circ}$ above the horizon, or above the antisolar point; but when the sun is 11° or 12° above the horizon, and the antisolar point as much below it, the neutral point is in the horizon, and consequently only 11° or 12° above the antisolar point.*

As the sun descends to the horizon, and the antisolar point rises, the distance of the neutral point from the latter gradually increases; and when the sun reaches the horizon, the neutral point is $18\frac{1}{2}^{\circ}$ above it, and therefore $18\frac{1}{2}^{\circ}$ distant from the antisolar point.

After the sun has set, the distance of the neutral point from the antisolar point increases; that is, it rises faster than the sun descends, and its maximum distance, when the twilight is very faint, is about 25° .

When the sun is advancing to the meridian, and the light of the sky is increasing, the distance of the neutral point from the antisolar point diminishes, as shown in the *morning* observations on the 14th, 20th, and 21st November 1842.

On a Secondary Neutral Point accompanying ARAGO's Neutral Point.

When the sea horizon was terminated by a dark purple belt about $1\frac{1}{2}^{\circ}$ above it, I observed that the vertical bands of the polariscope became brighter over that belt.

The same phenomenon was seen, but less distinctly, over the land horizon. It was difficult to measure the amount of this new polarising influence, but it was obvious that we should observe it separately when the neutral point came above the belt. In this case, it would eclipse, as it were, the neutral point, which would recover itself when it emerged from the belt. It was obvious also, that when the negative or oppositely polarised bands came over the belt, the new polarising influence would extinguish them where they had the same polarising force, and form a *secondary neutral* point, the primary one being then out of the belt.

On the 8th of June 1841, at 5^h 50^m P.M., when the polarised bands were strongest, both on the land and sea horizon, I watched the rise of the neutral point, which, as I had foreseen, *did not appear first in the horizon, but about $1\frac{1}{2}^{\circ}$ above it*, the compensation taking place where the vertical or positive polarisation was weaker than in the horizon. We had now the singular phenomenon of a neutral point with positive polarisation on each side of it. When this phenomenon was more fully developed under a favourable state of the horizon, the positive

* In abnormal circumstances, sometimes only 7° , 8° , 9° , or 10° , as in 1842, February 15 and 16.

polarisation was overcome by the advancing negative polarisation. The negative polarisation was then immediately below the ascending neutral point; but at a

Fig. 3.

certain distance (a few degrees below the neutral point), the negative polarisation was compensated by the excess of positive polarisation close to the horizon, and the beautiful phenomenon was seen of two neutral points, a primary and a secondary, separated by bands of negative polarisation, as shown in the annexed figure.

1841, June 10, 6^h 40^m.—The neutral point a little above the horizon, with vertical or + polarisation *on both sides of it*. The new vertical polarisation had more than compensated the horizontal, or negative polarisation, and left a balance of positive polarisation, which soon disappeared when the rising horizontal polarisation overpowered it.

1842, Feb. 22.—Both on this day and on the 13th, the neutral point was above the horizon, though not visible, being eclipsed or masked by the cause which produces the secondary neutral point. Over a space of $3\frac{1}{2}^{\circ}$ above the sea, the positive bands almost wholly disappear before the negative bands are perceptible, and the neutral point is 5° high when the secondary neutral point is distinct in the sea horizon.

Although I have observed the secondary neutral point more than twenty-two times, it has generally appeared under slightly different forms, varying with the intensity of the new polarising cause which produces it, and with the point of the horizon where the neutral point rises.

It is unnecessary to describe these different forms,—I shall mention only an observation made on the 21st April 1849, under very favourable circumstances. At 6^h 22^m, when the primary neutral point was about 15° high, the secondary neutral point was $2^{\circ} 50'$ high, the negative bands covering a space of 8° or 9° between them, the positive bands being above the sea-line. A fog prevailed to some extent, and above the sea-line there was the dark purplish belt previously mentioned, over which the positive bands were stronger than on the part of the sky above it.

Observations on BABINET'S Neutral Point.

In the year 1840, when M. BABINET had occasion to visit the sea coast, he proposed to observe if the neutral point of ARAGO varied in its height as the sun rose or set, and to observe it also when the sun was beneath the horizon; but he was allured from these observations by a circumstance which he had never even suspected, namely, the existence of a *second neutral point* above the setting sun,

and nearly as high in the atmosphere as the neutral point of ARAGO. "I afterwards,"* he says, "determined, a great number of times, the position of this new neutral point which appeared in the west, even when the sun was just on the horizon before setting, and in the east when he had risen only a few degrees. A very imperfect estimate made me sometimes believe, that this new neutral point was a little less high than that of ARAGO."

The following observations on this neutral point were made generally on the same day, and even in the same hour, as those on ARAGO's neutral point, and therefore under the same atmospherical influences.

1841, May 12.—Wind west in the evening.

Mean Time.

8^h 10^m P.M.

Height of Neutral Point above
the Antisolar Point.

16° 4'

1841, May 16.—Barom. 29·24. Windy.

Mean Time.

7^h 0^m P.M.

Height of Neutral Point above
the Antisolar Point.

8½°

1841, June 10.—Barom. 29·27. Very fine sky.

Mean Time.

10^h 10^m A.M. Sun's altitude about 50°.

7 17 P.M.

7 35 "

7 52 "

8 8 "

8 21 " Sun sets.

8 39 "

8 52 "

9 3 "

9 15 "

Height of Neutral Point above
the Antisolar Point.

2° or 3°

13° 15'

14 55

14 5

16 37

15 27

17 15

16 25

16 42

16 20

1841, September 6.—Barom. 29·55.

Mean Time.

6^h 30^m

6 45

6 58

7 6

Height of Neutral Point above
the Antisolar Point.

16° 15'

14 45

12 55

13 8

1841, September 12.—Barom. 29·75. Sky clear.

Mean Time.

6^h 54^m

7 0

Height of Neutral Point above
the Antisolar Point.

18° 53'

18 20

1841, September 29.—Barom. 28·73. After rain sky clear.

Mean Time.

5^h 46^m

5 57

6 7

Height of Neutral Point above
the Antisolar Point.

12° 53'

14 55

16 15

* Comptes Rendus, &c., 1840, tom. xi. p. 619.

1841, October 23.—Rainy day; cleared up at 3^h P.M.

Mean Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 21 ^m	...	...	17° 33'
27	27½°	25½°	15 35
30	...	...	14 30
39	...	...	15 13
45	26	25½	14 22
53	...	...	15 53

1841, November 2.

Mean Time.	Height of Neutral Point above the Antisolar Point.
4 ^h 50 ^m	14° 51'

1841, November 4.—Barom. 30·2. Foggy day; sky tolerably free from clouds.

Mean Time	Height of Neutral Point above the Antisolar Point.
3 ^h 13 ^m	14° 4'
4 9	19 0
4 14	17 48

1841, November 25.—Barom. 29·63. Splendid day.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
10 ^h 31 ^m P.M.	...	...	3° 20'
12 9 "	27½°	25½°	6 24
12 26 "	...	...	12 5
2 24 "	28½	26½	13 47
3 10 "	...	...	16 35

1842, January 29.—Barom. 29·93. Fine day; clear sky; snow covers the ground partially.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
3 ^h 32 ^m	27°	21½°	16° 35'
3 53	...	...	17 38
4 8	...	...	17 51

1842, February 15.—Rain in morning, then a fine day.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 25 ^m	...	...	21° 58'
4 44	...	...	20 24
4 55	27½°	22½° in S.E. Hor.	20 30

At this hour clouds rose in the S., N., and N.E. horizon; a dark band of distant haze 6° or 8° high rose above the sea horizon.

1842, February 21.—Fine day; wind west.

Apparent Time.	Height of Neutral Point above the Antisolar Point.
4 ^h 35 ^m	18° 57'
5 8	18 32

1842, March 2.—A wet day; the place of the sun was seen only as a white spot. The polarisation everywhere feeble.

2^h 20^m.—The neutral point was 75° above the horizon, or about 54° above the sun. The polarisation was negative from the neutral point to the horizon beneath the sun, and positive to the horizon opposite to the sun.

1842, March 16.—Barom. 29·96. The sun occasionally shining through a thickish haze in a China-ink sky without any blue; the wind in the south-west, and slight.

10^h 45^m.—Sun's altitude about 30½°; the polarisation below the sun was negative down to the horizon; the neutral point was 30° above the sun, or more than 60° high!

1842, April 5.—Barom. 30·07. Splendid sky.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 23 ^m	30°	26½°	19° 17'
6 58	...	...	18 46
7 7	30½	...	15 45

The polarisation was unusually great, equivalent to a rotation of the plane of polarisation of about 29°; it became stronger as it grew darker.

N.B.—This day and April 8th were the only days on which I was able to observe the three neutral points, and determine their place. (See pp. 217 and 229.)

1842, April 8.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 0 ^m	24½°	18½°	17° 15'
6 25	...	...	18 20
6 45	27½	...	19 11
7 7	28¾	...	21 5
7 20	...	...	19 31

1842, April 13.—Barom. 30·12. Fine day.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 51 ^m	...	...	18° 50'
6 23	29°	22½°	18 0
6 58	29½	...	18 40
7 12	...	...	17 35
7 21	30½	...	17 57

At 7^h 32^m, the maximum polarisation or rotation was 32½°, the greatest ever observed. (See p. 235.)

1842, May 15.—A haze.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 34 ^m	15°	15°	18° 10'
6 48	...	...	19 55
7 28	20½	...	17 44
8 29	23½	...	18 1

1842, November 14.—Barom 29·6. Fine frosty and clear morning.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
8 ^h 58 ^m A.M.	25½°	19½°	14° 7'

1842, November 21.—Barom. 29·77. Frosty morning. Thermometer 31°.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
9 ^h 4 ^m A.M.			18 36'

1842, December 28.—Barom. 29·56.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
11 ^h 40 ^m A.M.	29°	...	13° 41'
12 3 "	27	18½°	13 37
1 4 "	...	...	25 25!
1 23 P.M.	...	...	27 30!
2 31 " .	14½	...	27 48!

These remarkable results were doubtless owing to the causes which produced the following phenomenon :—At 1^h 4^m, when the neutral point started away from the sun, a white halo of 45° appeared round the sun, and continued till 2^h 31^m. It was slightly brown on its inner rim. At 1^h 23^m the altitude of the halo was 32° 10', and the sun's altitude 8° 30', so that the radius of its outer rim was 23° 40'.

When the vertical bands of the polariscope passed over the apex of the halo, *their intensity* was increased, and when they passed over the halo in a direction parallel to its horizontal diameter their intensity was diminished. As the crystals of ice, by which the halo was produced, are doubly refracting, one of the pencils must have been weaker than the other, an effect which would be produced if the surfaces of the crystals were not perfectly smooth.*

The polarisation of the sky was greatly reduced by the crystals of ice floating in the air, which produced the halo.

1843, March 25.—Barom. 29·97.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 46 ^m	28°	...	18° 25'
6 11	29½	...	17 41

1843, April 17.—Barom. 29·84. Fine day; wind east.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
6 ^h 33 ^m			17° 32'
7 7			18 4
7 33			18 44

1843, April 29.—Barom. 29·63. Wind east. The heat of the rising sun very great, and the vapour rising copiously from the ground. Everything more than

* See Phil. Trans., 1819, p. 146.

a quarter of a mile distant invisible. The sun shone occasionally, showing his pale white disc.

Apparent Time.

10^h 20^m A.M. The bands were negative from the zenith through the sun to the horizon, and positive to the opposite horizon. The maximum polarisation was 90° from the sun, but was so weak that it was compensated by the refraction of a plate of ground glass, at an angle of incidence of about 30°, the negative bands being then scarcely visible.

2^h 55^m. The vapour still rising copiously, and the place of the sun not visible. The bands were hardly visible, the polarisation, when a maximum, being compensated by the refraction of a plate of glass, at an angle of 5°.

1843, May 3.—Barom. 29·65. Easterly haur.

Apparent Time.

4^h 25^m. Mist flying before the sun, and the neutral point oscillating from near the sun to the zenith as the mist thickens.

1843, June 21.—Barom. 29·75. Fine day; wind west.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
7 ^h 46 ^m	...	...	15° 55'
8 33	29°	...	17 57
9 14	30	...	16 28

1844, Feb. 3.—Snow covering the ground.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
4 ^h 11 ^m	26°	23°	17° 55'

1844, April 15.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
5 ^h 54 ^m			25° 6'
6 50			18 10

1844, June 10.—Barom. 29·70.

Apparent Time.	R=Maximum Polarisation.		Height of Neutral Point above the Antisolar Point.
	In Zenith.	In Horizon.	
8 ^h 20 ^m	24 $\frac{3}{4}$	...	18° 14'

In a normal state of the sky, when the sun is rising or setting in a fine day without clouds, the neutral point of BABINET is situated about 18° 30' above the sun. Owing to the great quantity of light in the neighbourhood of the sun, this neutral point is not so easily seen as that of ARAGO, and escaped the scrutiny of that distinguished observer. In high latitudes it is above the horizon the greater part of the year, and, being above the sun, it is of course always visible in a clear sky, when he is above the horizon. When the sun is in the zenith, this neutral point coincides with the sun's centre, its distance from the sun gradually increasing till it becomes 18° 30' at sunrise or sunset, when the sun's altitude is nothing.

Like that of ARAGO, the neutral point of BABINET *must* be accompanied, in certain states of the horizontal sky, with a secondary neutral point, but I have never had an opportunity of observing it.

Observations on the Neutral Point below the Sun.

This neutral point, which I discovered in 1842, is much more difficult to be seen than that of BABINET. In November, December, and January, it cannot be seen in our latitude, unless when, early in November and late in January, a high degree of polarisation in the sky brings it above the horizon at noon.

The following interesting remarks of M. BABINET on his successful attempt to confirm the existence of this neutral point, explain in the clearest manner the causes of the difficulties which were experienced, and which every future observer will experience in observing this remarkable spot, with its surrounding polarisations:—

“On the 23d July,” says M. BABINET, “after having observed from half-hour to half-hour the polarisation of the sky below the sun, the regularity of this polarisation appeared to change after 4^h; and from 4³/₄^h to 5¹/₄^h I observed in placing the bands horizontally—

“1st, A space without polarisation below the sun.

“2d, Below this space a second space, when the bands were certainly seen; and,

“3d, Lower still a neutral space, where no bands were seen; and,

“4th, In approaching to the horizon, a fourth space, where the bands were very visible. The phenomenon is therefore no longer doubtful; but the immense brightness of the sun in a clear day, the intense illumination of the atmosphere in the region immediately below him, and the reflexion from the strongly illuminated earth, all concurred in rendering this observation difficult to make, and very painful to the eyes, even if we take the precaution of shielding the head and the polariscope from the direct rays of the sun, and the reflexion from the earth.

. M. BREWSTER was doubtless guided in his research by theoretical views, otherwise it appears to me very improbable that, by merely observing the atmospherical polarisation, he could have made the remarkable discovery of this neutral point, so difficult to see, and which, after him, I have several times tried in vain to rediscover. The small quantity of polarised light which is observed between the neutral point of BREWSTER and the Sun, seems to me to reach the limit which it is possible to observe, and perhaps to exceed the limit which it is possible to measure.”*

1841, Nov. 17.—Barom. 29.43.

Apparent Time.

12^h 0^m. The polarisation between the sun and the horizon decidedly *negative*, but no neutral point there.

* Comptes Rendus, &c., 1846, tom. xxiii. p. 234.

1842, Feb. 16.—Barom. 30·16.

Apparent Time.

12^h 0^m. Sun's altitude about 21° 13'; a China-ink muddy sky. There is clearly a neutral space below the sun, and a little above the horizon. The bands on the sun and below him are negative; but as the negative polarisation becomes very weak, it must pass into a neutral point.

1842, Feb. 18.—Cold, wind west, and rather stormy.

Apparent Time.

12^h 0^m. The neutral point below the sun was distinctly seen, the polarised bands being negative over and below the sun, and below the neutral point positive down to the horizon. The sun's altitude was about 22°, and the distance of the neutral point from the sun about 15°.

1842, Feb. 21.—Barom. 20·44. Fine dry day; wind west.

Apparent Time.

Distance of Neutral Point from Sun.

12^h 39^m. Neutral point 6½° above the horizon, 15° 0'
The positive polarisation between the neutral point and the horizon was compensated by the refraction of one plate of glass, at 20° of incidence. The neutral line was convex towards the sun in the west horizon.

1842, March 10.—Sky clear in zenith; wind west.

Apparent Time.

11^h 15^m. The neutral point distinctly seen below the sun.

1842, April 3.—Barom. 29·8. Fine clear sky; cold; hail in the afternoon.

Apparent Time.

11^h 45^m. Neutral point below the sun very distinctly seen, the sun's altitude being about 39½°, and the height of the neutral point 26½°. The distance of the neutral point from the sun was 13°. The bands over the sun down to the neutral point were negative, and those below it down to the horizon positive.

1842, April 5.—Barom. 30·07. Splendid sky.

Apparent Time.

Distance of Neutral Point from Sun.

12 ^h 27 ^m .	Neutral point seen distinctly below the sun.	
12 27		15° 25'
12 53		14 40
12 56		15 45
4 13		15 35
4 33		15 22

N.B.—All the three neutral points were observed, and their places ascertained this day, and also on April 8. (See pages 217 and 225.)

1842, April 6.—Barom. 30·05. Considerable haze.

Apparent Time.

Distance of Neutral Point from Sun.

8 ^h 51 ^m .	Neutral point distinctly seen below the sun.	
11 6		12° 0'

1842, April 8.

Apparent Time.

2^h 7^m. The neutral point below the sun beautifully seen. Estimated distance from the sun, 16° 0'

1842, April 15 and 17.

Apparent Time.

3^h 0^m. Neutral point below the sun distinctly seen.
3 30

1842, April 20.—Barom. 30.02. Very fine day; wind west.

Apparent Time.

Distance of Neutral Point from Sun.

12 ^h 10 ^m	11° 20'
12 37	10 40
2 21	12 0
3 45	12 35

The maximum polarisation was very great.

1842, April 25.—Thin hazy clouds before the sun.

Apparent Time.

1^h 11^m. Sun's alt. $45\frac{1}{2}^\circ$. Alt. neutral point below sun 34° . Distance below sun $11\frac{1}{2}^\circ$.

1842, April 26.—Barom. 30.08. Not a cloud in the sky from morning till night.

Apparent Time.

Distance of Neutral Point from Sun.

11 ^h 1 ^m	12° 15'
11 46	12 30
3 30	14 35
3 35	15 5
4 10	17 45

1842, April 27.—Barom. 30.04. Singularly fine sky.

Apparent Time.

Distance of Neutral Point from Sun.

10 ^h 45 ^m	12° 5'
12 12	A fog from the sea has just come on, and has driven the neutral point beneath the horizon, the bands being negative all the way to the horizon.
1 20	The fog has diminished. The neutral point is now seen near the horizon, playing up and down from 4° to 6° above the horizon, as the fog becomes denser or rarer!

1842, April 28.—Barom. 30. Fine sky; wind east.

Apparent Time.

Distance of Neutral Point from Sun.

11 ^h 24 ^m	10° 55'
---------------------------------	---------

1842, April 29.

Apparent Time.

Distance of Neutral Point from Sun.

11 ^h 4 ^m	11° 20'
--------------------------------	---------

1842, May 3.—China-ink sky; wind east.

Apparent Time.

Distance of Neutral Point from Sun.

11 ^h 29 ^m	10° 15'
12 15	9 25

1842, May 16.—Barom. 30.3. Thick haze; sun faintly seen.

Apparent Time.

8^h 49^m A.M. Neutral point below the horizon. The sun now quite hid, and no bands seen below him. A great glare of light, and a sort of *quaque-versus* polarisation.

N.B.—When the neutral point is out of the plane passing through the sun, the zenith, and the observer, it arises in certain cases from there being a greater haze on one side of the plane than on the other.

1842, May 17.—Barom. 30·22. Haze all the day.

Apparent Time.

11^h 0^m. The neutral point beneath the horizon.

12 30 *Several neutral points, three at least below the sun, as the haze flies past in different thicknesses.*

1842, Aug. 17.—Barom. 28·8. Fine day; sky clear at 2^h.

Apparent Time.

2^h 9^m. Neutral point seen both below and above the sun.

1842, Aug. 28.—A diffused haze came over a bright blue sky.

Apparent Time.

3^h 49^m. The neutral point below the sun was almost in the horizon, and BABINET'S neutral point near the zenith.

5 30 Sun invisible; mist thick; and the polarisation everywhere positive, and very feeble.

1843, Feb. 13.—Barom. 29·7. Fine sky.

Apparent Time.

1^h 10^m

Distance of Neutral Point from Sun.

15° 0'

1843, Feb. 16.—Barom. 29·15. Fine sky.

Apparent Time.

12^h 57^m

Distance of Neutral Point from Sun.

11° 25'

1843, April 30.—Barom. 30·07. Not a cloud. Neutral points distinctly seen, both above and below the sun.

Apparent Time.

4^h 15^m. Neutral point under the sun still above the horizon.

1843, June 15.—Barom. 30·03. Splendid day; wind east.

Apparent Time.

12^h 13^m

7 0

Distance of Neutral Point from Sun.

8° 10'

9 49

1844, May 3.—Barom. 30·15.

Apparent Time.

11^h 3^m. The neutral point below the sun distinctly seen. In order to see it well, I look at it perpendicularly through a plate of glass. The bands on each side of it are increased in intensity, the bands above being reversed.

When the sky is clear the neutral point under the sun approaches to the sun as his altitude increases, and coincides with the sun's centre when he is in the zenith.

As the neutral points of ARAGO and BABINET may be seen before the sun has risen, and after he has set, they are comparatively distinct and limited in their area; but as the neutral point below the sun never can be seen unless when the sun is shining, it has a less defined boundary and a wider area, owing to the flood of light in which it is generally enveloped. Hence arises the great difficulty of seeing it, and of detecting the form of the lines of equal polarisation which surround it. For the same reason, we can hardly expect to see the secondary neutral point, which must accompany it, when it rises or sets on a sea horizon in a condition to produce that phenomena.

On the Place of Maximum Polarisation, and its Intensity.

Next in importance to the determination of the place and movements of the three neutral points is the determination of the place and intensity of the maximum polarisation of the atmosphere.

In order to obtain these elements, a *polarimeter*, or instrument for measuring degrees of polarisation, is required. M. ARAGO constructed a very ingenious polarimeter, and I have described two forms of a polarimeter in the "Transactions of the Royal Irish Academy for 1841;"* but these instruments are too complex to be used from hour to hour during transient conditions of the atmosphere, when observations must be made with great facility and quickness. I was therefore obliged to use the following instruments.

1. Into one end of a tube 5 or 6 inches long and $1\frac{1}{4}$ of an inch wide I inserted a band polariscope, and in the axis of the tube I placed in a trough several (six to twelve) well annealed thin glass plates with their surfaces inclined to the axis of the tube at such an angle as to equal or compensate the average maximum polarisation to be measured. This compensation was effected more simply by adding or removing one or more plates when those in the trough had been previously placed at a fixed angle to the axis of the tube. It is obvious that, by giving the pile of plates a motion in one plane so as to vary the angle of refraction of the incident light, we should have an instrument for measuring all degrees of polarisation. I preferred, however, to use a polarimeter, all the parts of which were absolutely fixed.

In looking through this instrument we have a circular field SA, and when we direct it to the region of maximum polarisation, with the polarised bands parallel to SA, S being towards the sun, we shall see an interruption in the bands somewhere between S and A. If this interruption, or point of compensation, is at the point 2 in SA, I call S_2 the measure of the maximum degree of polarisation at the time of observation. After some practice, I had no difficulty in estimating by the eye when the neutral line was at 1 or $1\frac{1}{2}$, or 2 or $2\frac{1}{2}$, without placing marks at 1, 2, 3, &c., on a plate of glass at the end of the tube.

Fig. 4.

Having found that S_0 S_1 S_2 , &c., corresponded with degrees of polarisation, measured by the rotation of the plane of polarisation, I thus had a measure of the maximum polarisation of the atmosphere at the time of observation.†

When it was necessary to measure very small degrees of polarisation, I preferred using a polarimeter with a single plate, to one with a pile of plates

* Vol. xix. part ii.

† See Phil. Trans. 1830, pp. 69, 133, 145, 287, and Trans. Irish Acad., vol. xix. part ii.

receiving the light at very small angles of incidence. This instrument, shown in the annexed figure, consists of two tubes of the same length, one of which, EFHG,

Fig. 5.

moves within the other ABDC. One plate of glass, EL, longer than AB, moves round a joint at E the end of the tube EFHG, resting upon C the end of the tube ABDC, so that when this tube EFGH is pushed in, the plate EL forms a greater angle with the axis of the tube, and when it is pulled out a smaller angle.

Now, if $AB = EF$, BF will be $= AE$, the tangent of the angle ACE , AC being radius, or of the angle of incidence of rays that fall upon EL parallel to the axis of the tube. The degrees of rotation, R , therefore, of the planes of polarisation produced by the refraction of the plate EL at different inclinations to the axis of the tube may be calculated from the formulæ—

$$R = \phi - 45^\circ, \text{ and} \\ \text{Cot. } \phi = \cos^2 (i - i');$$

i being the angle of incidence, and i' the angle of refraction. The values of R , the measures of the degrees of polarisation, being laid down on the tube EF , we have a polarimeter which gives us direct measures of the polarisation of atmospheric, or any other kind of polarisation, when it does not exceed the maximum polarisation produced by the refraction of one plate. In this instrument the *zero* of the scale is at F , and B is the index.

In place of one plate, EL , we may use two, three, or more plates, and thus obtain a measure of all degrees of polarisation. If n is the number of plates, the value of R will be as follows:—

$$R = \phi - 45^\circ, \\ \text{Cot. } \phi = \cos^n (i - i').$$

In the instrument which I constructed the radius AC was 1.13 inch, or $\frac{33.9}{30}$ inch, and the scale on FB was laid down from the following table, the index of refraction of the plate EL being 1.51.

Angles of Incidence i .		Angles of Refraction i' .		Rotation R .	Length of Tangent.
0°	0	0°	0'	0'	
30	0	19	20	1	0.655 inches.
40	34	25	31	2	0.968
47	46	29	22	3	1.244
53	17	32	4	4	1.515
57	39	34	1	5	1.784
61	25	35	3	6	2.074

Angles of Incidence i .	Angles of Refraction i' .	Rotation R.	Length of Tangent.
64° 40'	36° 46'	7	2.386 inches.
67 29	37 43	8	2.726
70 0	38 29	9	3.104
72 19	39 7	10	3.544

By setting off the tangent 0.655 inch from the zero at F, we obtain the place of 1° of rotation, and so on with the rest. The polariscope P is then placed at the end FH of the tube.

Having observed the maximum polarisation of the atmosphere by the polarimeter, and its place, we take its altitude A, and by means of the sun's altitude A', observed or computed, we obtain the distance D of the place of maximum polarisation from the sun:—

$$D = 180^\circ - A + A'.$$

The following are all the values of D which I obtained. I have added the values of R or the degrees of polarisation in the zenith and in the horizon, when they happen to have been measured:—

Observations in 1841.

Apparent Time.		Values of D.	Rotation in Zenith.	Rotation in Horizon.
April 28.	3 ^h 0 ^m	88° 16'	...	...
" 30.	2 5	79 15	...	...
May 17.	1 20	99	181½°	151½°
June 6.	4 45	+ 90	161½	221½
" 9.	4 30	+ 90	251½	241½
" 10.	10 39	92 35	...	...
" 10.	12 0	88 26	30 15'	29
Sept. 15.	10 18	88 4	27 0	261½
Oct. 26.	4 30	93	281¼	271½
Dec. 17.	9 7 A.M.	Appt. + 90	27	241½
" 18.	9 0 "	time. + 90	28	27

Observations in 1842.

Apparent Time.		Values of D.	Rotation in Zenith.	Rotation in Horizon.
Jan. 7.	9 ^h 0 ^m A.M.	120°	Haze	241½°
April 5.	6 58	+ 90	301½°	261½
" 20.	12 49	84	25	17
" "	2 25	86	25	19
" "	3 35	88 20'	25	...
" "	4 32	90	27	17
" 21.	11 0	90	23	...
" "	12 0	90	23	...
" "	1 10	90	...	25
" 25.	1 17	90	261½	...
" 26.	10 53 A.M.	90	29	...
" "	11 46	88	29	...
" "	3 42	88	29	...
" 27.	10 41 A.M.	87	29	...
" 28.	11 34 A.M.	87	29	...
" 28.	1 50 "	88	29	...
" 29.	1 34 "	87½	29	...
May 3.	11 29 "	89	20	...

Omitting the three extreme values of D ,—viz., $79^\circ 15'$, 99° , and 120° ,—the mean of all the other values is 89° ; but, considering that five of the values of D are marked as more than 90° , we may conclude that 90° is, in the normal state of the atmosphere, the distance from the sun of the place of maximum polarisation, and 45° the corresponding angle of incidence.

This determination of the place and angle of maximum polarisation affords a highly probable explanation of the *azure* colour of the sky. Sir ISAAC NEWTON considers this colour as a “*Blue* of the first order, though very faint and little, for all vapours, when they begin to condense and coalesce into small parcels, become first of that bigness whereby such an azure must be reflected.”*

Professor CLAUSIUS considers the vapours to be vesicles or bladders, and ascribes the *blue* colour of the first order to reflection from the thin pellicle of water. In reference to these opinions the following facts are important:—

1. The azure colour of the sky, though resembling the *blue* of the first order, when the sky is viewed from the earth's surface, becomes, as observed by Mr GLAISHER in his balloon ascents, an “exceedingly deep *Prussian blue*” as we ascend to the height of five or six miles, which is a *blue* of the second or third order.
2. The maximum polarising angle of the atmosphere being 45° , is that of air, and not that of water, which is 53° .
3. At the greatest height to which Mr GLAISHER ascended, namely, at the height of five, six, and seven miles, where the blue is the brightest, “the air is almost deprived of moisture.”

Hence it follows that the “exceedingly deep Prussian blue” cannot be produced by vesicles of water, but must be caused by reflection from the molecules of air, whose polarising angle is 45° . The faint blue which the sky exhibits at the earth's surface, is therefore not the blue of the first order, and is merely the blue of the second or third order rendered paler by the light reflected from the aqueous vapour in the lower regions of the atmosphere.

Immediately after the values of D , I have placed the values of R , or the degree of maximum polarisation, in order to show the relation between these two quantities; but as the values of D were taken only when it was convenient, the numbers R do not show the maximum intensity of the polarisation of the atmosphere. I have therefore selected the following from several hundreds of observations recorded in my journal.

	Mean Time.	Rotation in Zenith.	Rotation in Horizon.
1841, April 13.	7 ^h 32 ^m	$32\frac{1}{2}^\circ$	...
“ “ 16.	7 37	32	29°
1841, May 14.	4 30	$30\frac{1}{2}$	25
“ “ “ 7	10	$30\frac{1}{2}$	$28\frac{1}{2}$

* Newton's Optics. 3d Edit. Book ii. part 3. Prop. vii. p. 232. See also Prop. v. p. 228, from which it would appear that by “small parcels” Newton meant solid globules of water.

	Mean Time.	Rotation in Zenith.	Rotation in Horizon.
1842, May 14.	7 ^h 35 ^m	30½°	29°
1842, Sept., 29.	4 37	30½	...
Very frequently the value of R was		29	...

The following observations show the changes which take place in the maximum polarisation in a few hours :—

	Mean Time.	Rotation in Zenith.	Rotation in Horizon.		Apparent Time.	Rotation in Zenith.	Rotation in Horizon.
1841, May 12.	4 ^h 12 ^m	30½°	25°	1842, Dec. 24.	12 3	26½	...
" " "	6 0	27	24½	" " "	12 44	28	...
" " "	7 10	30½	28½	" " "	1 32	27	...
" " "	7 35	30½	29	" " "	2 24	29	...
" " "	7 45	28½	28½	" " "	3 8	27½	...
Apparent Time.				" " "	3 39	29½	...
1842, April 16.	6 0	23	Much less	" " "	27. 11 48	26½	...
" " "	6 33	24	21½	" " "	12 0	23½	16½
" " "	6 59	27½	20½	" " "	1 45	24	...
" " "	7 23	29½	24½	" " "	2 35	27½	...
" " "	7 37	32	29½	" " "	3 15	29	...
" " "	20. 4 44	27½	17½	" " "	28. 11 38	29	...
" " "	5 54	28½	...	" " "	11 48	27½	18½
" " "	6 53	28	...	" " "	11 58	27	18½
" " "	7 1	29½	...	" " "	2 31	16½!	Hazy
" " "	7 24	30	...	1843, Feb. 16.	3 28	29½	24½
" Sept. 13.	5 58	29½	...	" " "	4 3	29½	26½
" " "	5 31	29	...	" " "	5 4	30	...
" " "	6 38	29½	...				

The great rotation, amounting to 32½° on the 13th April 1842 at 7^h 32^m, the greatest ever observed, was occasioned by an unusually favourable state of the sky. (See pp. 230 and 235.) I consider 30° as the maximum rotation in a normal state of the sky.

Having, in a normal state of the atmosphere, fixed the locality of the three neutral points, and determined the place and degree of maximum polarisation, we have the means of ascertaining approximately the form of the lines of equal polarisation, and of constructing a map of them when the sun is in the horizon.

In a paper published in Johnston's *Physical Atlas*, I have shown how this may be done, and have given two projections of these lines—one on a plane passing through the zenith of the observer, and perpendicular to the line joining the observer and the sun, and the other on the plane of the horizon. These two projections on a reduced scale, and without any of the numbers upon the larger ones, are given in Plate XII. and in the *Physical Atlas*. It will be seen from these projections that the lines of equal polarisation approximate to lemniscates, like the isochromatic lines in biaxial crystals.

On the Polarisation of Clouds and Exhalations.

The polarisation of clouds and other vapours presents some interesting phenomena, and should be studied in climates more genial than ours.

On the 29th June 1850, at about 8^h 30^m P.M., several reddish-white clouds appeared in the south-west sky at different heights, and in the zone of maximum polarisation. They were illuminated by the setting sun, and the sky around, and of course behind them, was of a deep blue. Upon looking at one of these clouds through Nicol's prism, I found that its reddish-white light was polarised in a plane at right angles to that in which the light of the sky was polarised. When the sky was dark by the disappearance of the blue polarised light in one position of the prism, the cloud was bright; but when the sky was brightest in a rectangular position of the prism, the cloud was of a dark blue colour.

July 15, 1850, 9^h 12^m P.M.—All the clouds to the east of the plane passing through the sun and moon, between the south-west and south, are black seen against the sky; but when we view them with a Nicol's prism, so as to extinguish as much as possible the polarised light of the sky, the clouds are white seen against the dark sky. When the Nicol's prism is turned round 90°, they again become black.

July 1, 1850, 8^h 30^m P.M.—A fine rainbow, with the secondary and supernumerary bows, appeared in the south-east. When the bands of the polariscope crossed either of the two bows at right angles, the bands at the intersection were very brilliant. When the rainbows were invisible from the great faintness of their light, they became visible, that is, the invisible portion became visible, when crossed with the bands of the polariscope. This effect did not seem to be produced when the bands crossed the supernumerary bows.

When the sun shines upon a light transparent vapour interposed between the observer and terrestrial objects, these objects are indistinctly seen through the light reflected by the vapour. As this light is partially polarised, it may be extinguished by a Nicol's prism, or a pile of thin plates of glass, or by reflection at the polarising angle from a glass plate. The terrestrial objects are then seen with great distinctness. This mode of obtaining improved vision of objects imperfectly visible, or of seeing objects not otherwise visible, may occasionally be of great use at sea.

On the Theory of Atmospheric Polarisation.

When the atmosphere is illuminated by the sun, his rays fall upon the aerial particles which compose it at all angles of incidence. In the immediate vicinity of the sun, where the angle of incidence is 180°, there is no polarisation. The polarisation increases with the angle of incidence, and becomes a maximum, as we have seen, at about 90° from the sun. It now diminishes with the angle of incidence, and becomes nothing at 180°, the point opposite to the sun.

At all these points the polarisation is said to be *vertical*, being in the vertical plane passing through the sun and the observer.

In addition to the vertical polarisation produced by the direct illumination of the aerial particles, there must be an opposite polarisation by which the neutral points are produced. M. ARAGO, M. BABINET, and, we believe, every other writer on the subject, have sought for this counter-polarisation "in the secondary illumination which the same aerial particles receive from the reflexion of the rest of the atmosphere, which sends to them light polarised horizontally,"* or oppositely to the light polarised vertically. That is, all the phenomena of atmospherical polarisation are produced by the opposite action of two lights polarised by reflexion, the one vertical, arising from the direct illumination of the aerial particles, and the other horizontal, produced by a secondary illumination of the same particles by the rest of the atmosphere.

This theory of atmospherical polarisation, omitting all consideration of the light polarised by refraction, never appeared to me satisfactory. There is no evidence whatever that such a secondary reflexion exists, even in a perfectly cloudless sky, and still less evidence that, if it did exist, it would be capable of neutralising the light polarised by reflexion at considerable distances from the antisolar point. It must be very feeble when the neutral point is about to disappear at the close of twilight; and as the polarisation by direct reflexion must be visible when the secondary reflection ceases to be visible, this cessation ought to be marked by a return of the neutral point to the antisolar point, the place which it would occupy were there no secondary reflexion.

Were the neutral points produced by a secondary reflexion, their distances from the antisolar point and from the sun ought to be affected when the sky is more or less covered with clouds; but though I have observed the neutral point of ARAGO in a clear part of the sky, I never observed that its distance from the antisolar point was changed when the rest of the atmosphere was obscured by clouds.

On these grounds I was led to the opinion that the neutral points must be produced by the opposite action of two polarised lights which had nearly the same relative intensity, and this opinion was strengthened by observations which I had made on the polarisation of light by refraction and transmission through piles of glass plates. In these experiments, published in the "Philosophical Transactions" for 1814, I observed phenomena analogous to neutral points, that is, the co-existence in the transmitted light of rays polarised by reflexion, and rays polarised by refraction, but I did not observe the effect where the intensities of these rays were such as to neutralise each other.

Guided by these views, I never doubted that the three neutral points in the atmosphere, and the partial polarisation of the light which it reflects, are produced by the opposite action of lights polarised by reflexion and refraction; and con-

* BABINET, *Comptes Rendus*, &c. 1846. Tom. xxiii. p. 233.

sidering the congeries of separate molecules which constitutes the atmosphere as a rough or dispersing surface, I made a series of experiments on such surfaces as were likely to act upon light in the same manner as the aerial molecules. In these experiments, which have been already communicated to the Society,* I found that such surfaces not only polarised partially the incident light, but produced neutral points, like those of the atmosphere, by the opposite action of the rays which they polarised by reflexion and refraction.

* See page 205.

LINES OF EQUAL
POLARIZATION

OF THE
ATMOSPHERE.

Sir David Brewster, K.H. D.C.L. F.R.S. Edin.