the winds, temperatures, and barometrical indications might have been added for the like reason.

13. Table XI. also requires a note of the season of the year and the number of days of observations. It may here be asked, how is the discrepancy to be reconciled between the lessening of ozone as you sail *to the Polar Regions*, and the increase of ozone as you ascend in the air, when the temperature as regularly falls in the one case as in the other.

14. The records showing the connection between *phosphorescence* and manifestation of ozone are very satisfactorily drawn out, and may probably become of much value in a new investigation.

15. The less prevalence of ozone in the higher *extratropical latitudes* may be due, as suggested in another case, to the dryness of the atmosphere impairing the *sensitiveness of the test papers*, so that for the present such deductions are under suspicion.

16. The idea that the prevalence of ozone is coincident generally with a *low barometer* seems well supported by the observations recorded, but some explanation will be required to account for its maximum occurrence with *south-east winds* in Tables IX. and XI., if one should accept the theory of its connection only with equatorial winds.

17. That its presence may be connected with *warm temperatures* of the air seems better established at sea than on land, as also its coincidence with *humidity of the air*, though this is somewhat vitiated by the conscientious suggestion that its manifestation may be due to the increased susceptibility of the test-papers when moist.

18. In the statement that ozone increases as you ascend *mountainous elevations*, it is not stated what winds were blowing at the time, which would appear to be necessary, if the idea of its prevalence with any particular wind were considered essential.

19. The key to the origin and prevalence of ozone in the atmosphere seems still undiscovered, and we do not yet appear to have determined if it belongs to aqueous vapour or a special wind, or whether it be an additional constituent of the air, like carbonic acid, or a floating entity, like a cloud.

NUBIBUS

The Limits of the Gulf Stream

As one of those engaged in the compilation of the Atlantic pilot-charts published by the Admiralty, on which are given the limits, velocity, and general features of the Gulf Stream, as well as the boundaries of the regions in which ice and icebergs may be fallen in with in the North Atlantic, I cannot allow the letter in NATURE (vol. ix. p. 343), by W. W. Kiddle, of the White Star Mail steamship *Oceanic*, to remain unchallenged.

The Gulf Stream and ice boundaries, delineated on the North Atlantic chart, referred to in that letter, are in their details transcripts from the Atlantic pilot-charts.

These details were the result of much patient investigation, and obtained from many sources probably unknown to Captain Kiddle; among the most valuable were the painstaking and sound observations made by members of the United States Coast Survey, and to be found embodied in the annual reports between 1843 and 1859; and especially from the exhaustive and learned work on currents, so well known to cultivators of nautical science, by the late Major Rennell.

If the average boundaries of the Gulf Stream cannot be laid down within reasonable limits from the authorities I have quoted, aided, too, by the many observations of ships of war, extending over the present century, I fear that Captain Kiddle's results will not assist us in a more accurate delineation.

It is, however, to be hoped that Captain Kiddle's information on the currents may be more reliable than that he has ventured upon giving with regard to the limits of iceberg-drift; here recorded facts are irresistibly against him. He has only to consult any North Atlantic memoir on the subject, and he will find that icebergs have been fallen in with so far south as 36° 10′ N., or 7° south of the high authority he quotes. I would refer him on this interesting subject, as well as how icebergs are found on the southern edge of the Gulf Stream, and why it is possible "that bergs could drift square across the heated waters of the Gulf Stream to lat. 39° N.," to a paper by the well-known W. C. Redfield, of the United States (reprinted in the *Nautical Magazine* for 1845), who gathered the facts that have simply been utilised in the Admiralty charts.

London, March 11 THOMAS A. HULL

The Great Ice-Age

MR. GREEN, reviewing Mr. J. Geikie's work on the "Great Ice-Age" (NATURE, vol. ix. p. 318), expresses the opinion that a glacial period must have been one of intense cold. This is the general opinion, and yet I think it can be shown to rest on a misconception. If the climate at any given elevation is cold enough to form glaciers, no decrease of the winter temperature will increase their magnitude; while on the other hand a low summer temperature is shown by the facts of physical geography to be eminently favourable to glaciation. This last may almost be called an identical proposition, for permanent snow means snow which lasts through the summer.

As Mr. Croll has pointed out, there have been periods where the sun's greatest and least distances were respectively greater and less than now. He thinks that a glacial period occurred when, in the course of the precession of the equinoxes, the sun's greatest distance occurred in the winter, so as to cause a *cold winter*. I think the true theory of the glacial climate is exactly the reverse of this: that is to say, it was caused by the *cold summer* which occurred when the sun's greatest distance was in the summer.

I have stated these views at greater length in the *Journal of the Geological Society of London*, 1869, p. 350.

Old Forge, Dunmurry, Co. Antrim, March 8 J. J. MURPHY

Mars

IN a most interesting article on the planet Mars, in your issue of NATURE for Feb. 19, which has just been shown to me, the Rev. T. W. Webb directs attention to the question of the colours of Mars being due to effects of contrast or not, and says—"Nor does it seem to have been noticed that no effect of contrast has been traced in the Polar snows."

Kindly permit me to inform Mr. Webb that, in a paper on Mars in the last volume of the "Monthly Notices of the Royal Astronomical Society," I expressly state that, "on May 14, 1873, the south Polar ice appeared (in an 8½-inch silvered glass reflector, by Browning) of quite a pale sky-blue colour, evidently by contrast," and I may add that this effect I noticed also on two or three subsequent occasions.

Burton-on-Trent, March 12 EDWARD B. KNOBEL

POLARISATION OF LIGHT *
VI.

MENTION was made in the previous article of the bands produced in the spectra of polarised light. Beside the fact of the existence of these bands it has been found upon examination that the state of polarisation at different parts of the interval between two successive bands varies; and such an examination may be made by means of a quarter-undulation plate or a Fresnel's rhomb.

If we carefully examine the spectrum of light which has passed through a selenite, or other ordinary crystal, we shall find on turning the analyser that, commencing with two consecutive bands in position, the parts occupied by the bands and those midway between them are plane-polarised, for they become alternately dark and bright; while the intermediate parts, *i.e.* the parts at one-fourth of the distance from one band to the next, remain permanently bright. These are, in fact, circularly polarised. But it would be incorrect to conclude from this experiment alone that such is really the case, because the same appearance would be seen if those parts were unpolarised, *i.e.* in the condition of ordinary light. And on such a supposition we should conclude, with equal justice, that the parts on either side of the parts last mentioned (*i.e.* the parts separated by one-eighth of the interval between two bands) were partially polarised. But if we introduce a quarter-undulation plate between the selenite and analyser, with its axis inclined at 45° to that of the selenite, circular polarisation will be converted into plane and plane into circular. This being so, the parts which

* Continued from p. 326.

were originally banded ought to become bright and to remain bright, while those that were originally bright ought to become banded during the rotation of the analyser. The effect to the eye will consequently be a general shifting of the bands through one-fourth of the space which separates each pair. Further, as on the one hand plane polarisation is converted into circular right-handed or left-handed by two positions of the plate at right angles to one another; so on the other right-handed circular polarisation will be converted by the plate in a given position into plane polarisation having the vibrations in one direction, and left-handed into plane polarisation having the vibrations in a direction at right angles to the former. Hence, if the plate be turned through a right angle from the position first described, the band will be shifted in a direction opposite to that in which they were moved at first. In this we have evidence not only that the polarisation on either band is circular, but also that on the one side it is right-handed, while on the other it is left-handed.

All the phenomena hitherto described manifestly depend upon the internal structure of the crystal plate, in virtue of which it affects the vibratory movement of the ether within it differently in different directions. And seeing that most crystals, when broken, divide themselves naturally into smaller crystals having the same form, *i.e.* having their planes and edges similarly inclined, we are naturally led to conclude that the structure of these bodies may differ not so much in different parts, as along different lines or planes connected with the forms into which they break, or (as it is also described) with their planes of natural cleavage. And this suggests the question whether an uncrystalline body might not, by pressure, or strain, or other mechanical distortion, be caused to affect the motions of the ether within it in a manner dependent upon their direction, and in that way to exhibit chromatic effects with polarised light analogous to those described above. Experiment answers this question in the affirmative.

The simplest experiment in this branch of inquiry consists in taking a rectangular bar of ordinary glass; and having crossed the polariser and analyser so as to give a dark field, to strain the bar with both hands as if we were trying to bend it or to break it across. The side towards which it may be supposed to be bent is of course compressed, while the opposite is stretched out. Between these two there must be an intermediate band, more or less midway between the two, which is neither compressed nor stretched. The moment the strain is put upon the bar light will be seen to pass through the parts of the bar nearest to both sides, while a band remains dark midway between the two.

This shows that the mechanical strain has imparted to portions of the glass a structural character analogous, at all events optically, to that of a crystal. The effects may be increased and rendered more striking by placing the glass in a frame furnished with a screw, by which the rod may be firmly held and considerable pressure applied at particular points. When this is done the structural character becomes more completely developed, and the dark band is fringed with colours which appear to flow inwards or outwards according as the pressure is increased or diminished. A slightly different, but more effective, exhibition of chromatic polarisation is produced by squeezing a thick square plate of glass in a vice. In this case the pressure may be carried further without fear of fracture, and the chromatic effects heightened.

It is, however, well known that molecular forces, such as those due to heat and cooling, in many cases far transcend in intensity those which we can exert by mechanical arrangements. And, in fact, if a block of glass be unequally heated to a very moderate degree, the internal structural effects immediately reveal themselves by dark bands, which indicate the border land between strain and pressure. As the block cools, these landmarks gradually disappear, and the field becomes again uniformly dark. But by far the most splendid effects (and these are permanent) are produced by unannealed glass; that is, by glass which has been rapidly and therefore unequally cooled. When a mass of glass has been cast in a mould in the form of a thick plate, then whatever be the contour line, the outside will cool first and become a rigid framework to which the interior of the mass must accommodate itself. The nature and direction of the pressure at each point of the interior will be primarily dependent upon the form of the contour; and by adopting various forms of contour the most beautiful and varied figures with coloured compartments may be produced. The forms and colours of the figures produced by transparent bodies when submitted to polarised light have been conversely used as a means of measuring, with almost unparalleled accuracy, the mechanical pressures which such a body is undergoing.

Besides glass many other substances may be used as reflectors so as to produce polarisation; for example, leaves of trees, particularly ivy, mahogany furniture, windows, shutters, and often roofs of houses, oil paintings, &c., and last but not least the surface of water. In each of these cases when the reflected beam is examined with a Nicol the alternations of light and darkness are most strongly marked, and the colours (if a crystal plate be used) are most vivid, or in technical language the polarisation is most complete, when the light is reflected at a particular angle. In proportion as the inclination of the incident light deviates from this angle the colours become fainter, until when it deviates very greatly all trace of polarisation disappears.

It will be found very interesting to examine the polarisation of sunshine reflected from ripples on the surface of a lake, or better still from the waves of the sea, and its different degrees of completeness produced at the variously inclined portions of the waves. But without having recourse to nature on so large a scale, an artificial piece of water may be placed in our room. A tea tray will serve as well as anything else to form our little sea; and a periodic tap at one corner will cause ripple enough for the present purpose. The waves appear bright, and although brighter in some parts than others they are nowhere entirely dark. But on turning the Nicol round the contrast of light and darkness becomes much stronger than before. In parts the light is absolutely extinguished, or the polarisation is complete; in others it is incomplete in various degrees. And if a selenite or other crystal plate be introduced we have the beautiful phenomena of iris-coloured rings playing over the surface of our miniature sea.

Suppose that we now turn our attention to the sky, and on a clear bright day we sweep the heavens with a polariscope, or even with a mere Nicol's prism, we shall find traces of polarisation in many directions. But if we observe more closely we shall find that the most marked effects are produced in directions at right angles to a line drawn from our eye to the sun, when in fact we are looking across the direction of the solar beams. Thus, if the sun were just rising in the east or setting in the west, the line of most vivid effect would lie on a circle traced over the heavens from north to south. If the sun were in the zenith, or immediately overhead, the most vivid effects would be found on the horizon; while at intermediate hours the circle of strongest polarisation would shift round at the same rate as the shadow on a sun-dial, so as always to retain its direction at right angles to that of a line joining ourselves and the sun.

Now, what is it that can produce this effect, or indeed, what produces the effect of light from all parts of a clear sky? The sky is pure space with no contents, save a few miles of atmosphere of the earth, and beyond that the impalpable ether, supposed to pervade all space, and to transmit light from the furthest limits of the stellar universe. The ether is however certainly inoperative in the diffusion of light now under consideration. But a very simple experiment will suffice to show that such a diffusion or, as it has been better called, a scattering of light, is due to the presence of small particles in the air. If a beam from an electric lamp or from the sun be allowed to pass through a room its track becomes visible by its reflection from the motes of floating bodies, in fact by the dust in the air. But if the air be cleared of dust by burning it with a spirit lamp placed underneath, the beam disappears from the parts so cleared, and the space becomes dark. If, therefore, the air were absolutely pure and devoid of matter foreign to it, the azure of the sky would no longer be seen and the heavens would appear black; the illumination of objects would be strong and glaring on one side, and on the other their shadows would be deep and unrelieved by the diffused light to which we are accustomed. Now, setting aside the dust, there are always minute particles of water floating in the atmosphere. These vary in size from the great raindrops which fall to earth on a sultry day, through intermediate forms of mist and of fine fleecy cloud, to the absolutely invisible minuteness of pure aqueous vapour which is present in the brightest of skies. It is these particles which scatter the solar rays and suffuse the heavens with light. And it is a remarkable fact, established by Prof. Tyndall, while operating with minute traces of gaseous vapours, that while coarser particles scatter rays of every colour, in other words scatter white light, finer particles scatter fewer rays from the red end of the spectrum, while the finest scatter only those from the blue end. And in accordance with this law clouds are white, clear sky is blue.

But the point which most concerns us here is the fact, also discovered by Prof. Tyndall, that light scattered laterally from fine particles is polarised. The experiment by which this is most readily shown is as follows: Allow a beam of solar or other strong light to pass through a tube about thirty inches long filled with water, with which a few drops of mastic dissolved in alcohol have been mixed. The fluid so formed holds fine particles of mastic in a state of suspension, which scatter the light laterally; and if the scattered light be examined with a Nicol traces of polarisation will be detected. But better still, instead of using the scattering particles as a polariser and the Nicol as an analyser, we may polarise the light before it enters the tube and use the particles as an analyser, and thus produce the same effect as before, not only upon the particular point of the beam to which the eye is directed, but upon the whole body of scattered light. As the Nicol is turned the light seen laterally begins to fade; and when the instrument has been turned so as to cut off all vertical vibrations, the only parts remaining visible in a horizontal direction will be those reflected from the larger impurities floating in the water independently of the mastic. The direction of vibration of the light polarised by lateral scattering is easily remembered by the fact that the vibrations must be perpendicular both to the original and to the scattered beam; if, therefore, the latter be viewed horizontally, they must be perpendicular to two horizontal straight lines at right angles to one another, *i.e.* they must be vertical.

An effect still more beautiful, and at the same time perhaps more instructive, may be produced by interposing a plate of quartz between the Nicol and the tube. The whole beam then becomes suffused with colour, the tint of which changes for a given position of the spectator with the angle through which the Nicol is turned.

And not only so, but while the Nicol remains at rest the tints are to be seen scattered in a regular and definite order in different directions about the size of the beam. But this radial distribution of colours may also be shown in a more striking manner, by using a bi-quartz, which as explained before distributes the colours in opposite directions. The beam should in every case be viewed at right angles; the more obliquely it is viewed the less decided is the polarisation.

The colours here seen are those which would be observed upon examining a clear sky in a position 90° from that of the sun; and the exact tint visible will depend upon the position in which the Nicol is held, as well as upon that of the sun. Suppose, therefore, that a Nicol and quartz plate be directed to that part of the sky which is all day long at right angles to the sun, that is, to the region about the north pole of the heavens (accurately to the north pole at the vernal and autumnal equinox), then if on the one hand the Nicol be turned round, say, in a direction opposite to that of the sun's motion, the colours will change in a definite order; if, on the other, the Nicol remain stationary while the sun moves round, the colours will change in a similar manner. And thus, in the latter case we might conclude the position of the sun, or in other words the time of the day, by the colours so shown. This is the principle of Sir Charles Wheatstone's Polar clock, which is one of the few practical applications which this branch of polarisation has yet found.

Figs. 18 and 19 represent general forms of this instrument described in the following passage by the inventor.

"At the extremity of a vertical pillar is fixed, within a brass ring, a glass disc, so inclined that its plane is perpendicular to the polar axis of the earth. On the lower half of this disc is a graduated semicircle divided into twelve parts (each of which is again sub-divided into five or ten parts), and against the divisions the hours of the day are marked, commencing and terminating with VI. Within the fixed brass ring, containing the glass dial plate, the broad end of a conical tube is so fitted that it freely moves round its own axis; this broad end is closed by another glass disc, in the centre of which is a small star or other figure, formed of thin films of selenite, exhibiting when examined with polarised light strongly contrasted colours; and a hand is painted in such a position as to be a prolongation of one of the principal sections of the crystalline films. At the smaller end of the conical tube a Nicol's prism is fixed so that either of its diagonals shall be 45° from the principal section of the selenite films. The instrument being so fixed that the axis of the conical tube shall coincide with the polar axis of the earth, and the eye of the observer being placed to the Nicol's prism, it will be remarked that the selenite star will in general be richly coloured, but as the tube is turned on its axis the colours will vary in intensity, and in two positions will entirely disappear. In one of these positions a smaller circular disc in the centre of the star will be a certain colour (red, for instance), while in the other position it will exhibit the complementary colour. This effect is obtained by placing the principal section of the small central disc $22\frac{1}{2}$° from that of the other films of selenite which form the star. The rule to ascertain the time by this instrument is as follows:—the tube must be turned round by the hand of the observer until the colour star entirely disappears while the disc in the centre remains red; the hand will then point accurately to the hour. The accuracy with which the solar time may be indicated by this means will depend on the exactness with which the plane of polarisation can be determined; one degree of change in the plane corresponds with four minutes of solar time.

"The instrument may be furnished with a graduated quadrant for the purpose of adapting it to any latitude; but if it be intended to be fixed in any locality, it may be permanently adjusted to the proper polar elevation and the expense of the graduated quadrant be saved; a spirit-level will be useful to adjust it accurately. The instrument might be set to its proper azimuth by the sun's shadow at noon, or by means of a declination needle; but an observation with the instrument itself may be more readily employed for this purpose. Ascertain the true solar time by means of a good watch and a time equation table, set the hand of the polar clock to correspond thereto, and turn the vertical pillar on its axis until the colours of the selenite star entirely disappear. The instrument then will be properly adjusted.

"The advantages a polar clock possesses over a sun-dial are :—1st. The polar clock being constantly directed to the same point of the sky, there is no locality in which

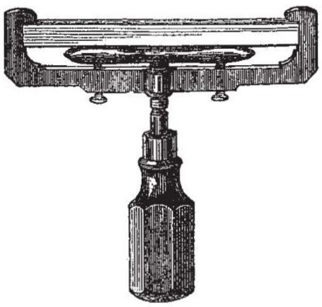

FIG. 16.

it cannot be employed, whereas, in order that the indications of a sun-dial should be observed during the whole day, no obstacle must exist at any time between the dial and the places of the sun, and it therefore cannot be applied in any confined situation. The polar clock is consequently applicable in places where a sun-dial would be of no avail ; on the north side of a mountain or of a

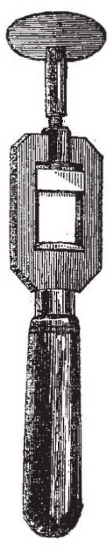

FIG. 17.

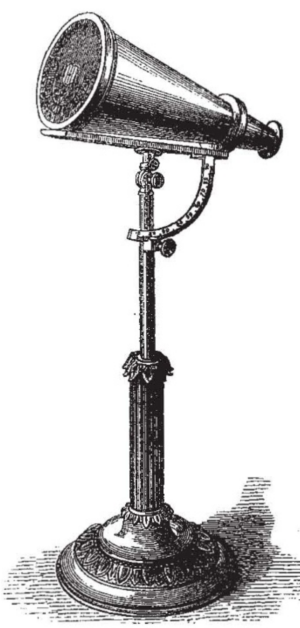

FIG. 18.—Wheatstone's Polar Clock.

lofty building for instance. 2ndly. It will continue to indicate the time after sunset and before sunrise ; in fact, so long as any portion of the rays of the sun are reflected from the atmosphere. 3rdly. It will also indicate the time, but with less accuracy, when the sky is overcast, if the clouds do not exceed a certain density.

"The plane of polarisation of the north pole of the sky moves in the opposite direction to that of the hand of a watch ; it is more convenient therefore to have the hours graduated on the lower semicircle, for the figures will then be read in their direct order, whereas they would be read backwards on an upper semicircle. In the southern hemisphere the upper semicircle should be employed, for the plane of polarisation of the south pole of the sky changes in the *same* direction as the hand of a watch. If both the upper and lower semicircles be gra-

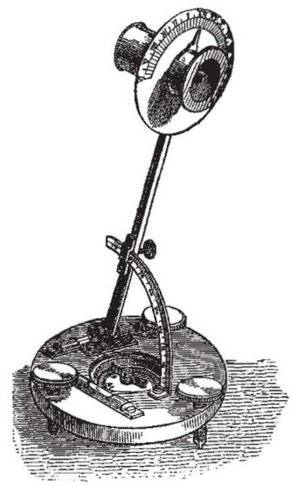

FIG. 19.—Wheatstone's Polar Clock.

duated, the same instrument will serve equally for both hemispheres."

The following is a description of one among several other forms of the polar clock which have been devised. This (Fig. 20) though much less accurate in its indications than the preceding, beautifully illustrates the principle.

"On a plate of glass twenty-five films of selenite of equal thickness are arranged at equal distances radially in a semicircle ; they are so placed that the line bisecting the principal sections of the films shall correspond with the radii respectively, and figures corresponding to the hours are painted above each film in regular order. This plate of glass is fixed in a frame so that its plane is inclined to the horizon 38° 32′, the complement of the polar elevation ; the light passing perpendicularly through this plate falls at the polarising angle 56° 45′ on a reflector of black glass, which is inclined 18° 13′ to the horizon. This ap-

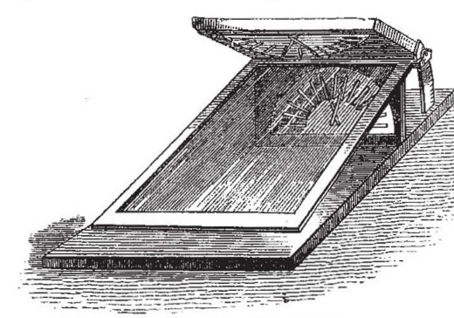

FIG. 20.—Polar Clock.

paratus being properly adjusted, that is so that the glass dial-plate shall be perpendicular to the polar axis of the earth, the following will be the effects when presented towards an unclouded sky. At all times of the day the radii will appear of various shades of two complementary colours, which we will assume to be red and green, and the hour is indicated by the figure placed opposite the radius which contains the most red ; the half-hour is indicated by the equality of two adjacent tints."

W. SPOTTISWOODE

(*To be continued.*)