

not acquainted with the formation of two spectra when the rays of light were made to fall perpendicularly on one of its plane sides; but I should suppose that he considered this as a self-evident corollary of the general principle of refraction. Indeed, if Newton had mentioned this as a particular discovery, he might as well have told us that when two opaque bodies were interposed between the sun and a wall, there were also formed two shadows. Dr. R. says that "mathematicians are here obliged to relinquish one of their favourite laws, that rays striking at right angles to plane surfaces suffer no refraction;" but he will here be pleased to recollect, that when rays fall at right angles to one of the faces, they must strike either of the other faces obliquely, and consequently be refracted at their emergence.

I should consider it an idle task to proceed any further in the refutation of doctrines which do not carry along with them any thing like demonstrative evidence, but hinge entirely on the author's own *ipse dixit*; my principal object being only to show the inconsistencies which result from the rejection of the law of refraction.

The Doctor has requested me to read his paper on Vision, published in a former Number of your Magazine; but I suppose he must mean that which he published some time ago in "The Annals of Philosophy," which I have also read; but consider it quite foreign to the matter in question, whether the ideas of visible objects be conveyed to the mind by retinal or corneal images. I am, sir,

Your most obedient servant,

His Majesty's Ship Queen Charlotte,
Portsmouth Harbour, May 26, 1822.

CHARLES STARK.

II. *An Account of the Repeating Circle, and of the Altitude and Azimuth Instrument; describing their different Constructions, the Manner of performing their principal Adjustments, and how to make Observations with them; together with a Comparison of their respective Advantages.* By EDWARD TROUGHTON, Esq. F.R.S., and Member of the American Philosophical Society*.

OF all astronomical instruments, those fixed in national observatories must be considered of the first importance to science; and in a commercial country, like our own, perhaps those subservient to nautical astronomy ought to be regarded as the next point in of utility. Those which I would call the third class are

* From the Memoirs of the Astronomical Society of London.

numerous ;

numerous; they are such as are used in the small observatories of the amateur, to which they are in general equally adapted, as to the service of the gentleman who may travel to foreign parts. Of those, the two I have named in the title, are the most approved of for these purposes; and to draw up a comparison of their respective constructions and merits, is what I have chosen for the subject of this communication. Were I able to treat it as it deserves, I should entertain no doubt of its coming within the views of this Society, nor of its usefulness; particularly in assisting those, who may not already have become acquainted with the different kinds of instruments, in the selection of such as may be best suited to their purposes.

The repeating circle, till within these few years, has been very little used in this country, and in truth its merit but ill-appreciated; facts however are not wanting, although dispersed and insulated, sufficient to remove all prejudice; particularly experiments recently made, with a small instrument of this kind, at the principal stations of our grand national survey. On the continent of Europe, where the art of graduation is not so successfully cultivated as it is with us, an instrument which of all others depends the least upon accuracy of division, could hardly escape being too much commended: be this as it may, observations lately made on the other side of the British channel, simultaneously with those used in the survey mentioned above, have I believe given the best informed of all parties a more correct idea of what may be expected from this instrument.

The altitude and azimuth instrument has I think been almost exclusively made in this country: many of them have been sent abroad, but from their not having been used in great national operations, the advantage of them has seldom been made known to the world. Nearly the same may be said of those which remain at home; for although some of them have been much and skilfully used, yet owing to their having been only in the hands of private individuals, who had no common medium of communication, the labours of those who possessed them have hitherto been almost lost to astronomy. From this general remark I must however except the observations of the 36 brightest fixed stars, which Mr. Pond made at Westbury with a 30-inch circle of this kind, and which appeared in the *Phil. Trans.* for 1806. This indeed was the first thing (notwithstanding some doubts and surmises from abroad) that unequivocally demonstrated a change of figure in the Greenwich quadrant, and subsequently led to the procuration of new instruments for our national establishment.

The repeating circle has by no means failed for want of
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publicity; on the continent, astronomers and others have written a great deal about it, and the results of thousands of observations have been published; the greater part of which were made on *Polaris*, a star, to which, on account of its slow motion, this instrument is peculiarly adapted. Although the altitude and azimuth instrument, as a portable one, was produced about the year 1792, we find no description of it in print, until the article *CIRCLE* appeared in Rees's and Brewster's *Encyclopedias**; the latter of which is referred to for the use of those who may wish to see a more detailed account of both the instruments under consideration, than can be given in the following brief descriptions.

Description of the Repeating Circle.

The lowest part of this instrument is a strong tripod, having at its extremities three steady foot-screws; one of which, at least, should stand upon a well known apparatus, for the purpose of supplying a slower and finer motion to the upper part, than can be given by the screw itself. This apparatus should support that particular foot which during observation is directed to the meridian, or is opposite to the object observed. In the centre of the tripod is fixed a strong vertical axis, of a height sufficient for allowing head-room for observing conveniently when the telescope is pointed towards the zenith. A pillar of the same height with the axis, is nicely fitted at both ends upon the latter, and both together, when the axis is vertical, produce a steady azimuthal motion. To the lower end of the pillar is fixed an azimuth circle: and to the higher end, a cross piece; on the two extremities of which stand, about five inches apart, two upright bars for supporting a cross axis, to which the principal circle by its centre-work is attached, and round which axis the circle may be turned into any position from one side of the pillar to the other. A semicircle is fastened to one end of the cross axis, which, together with a clamp attached to one of the upright bars, affords the means of securing the circle in any position. The principal circle, or that of repetition, has (affixed to the middle of its plane, and opposite to the one divided) centre-work, the length of which

* It is true that the late Rev. Francis Wollaston, in the *Phil. Trans.* for 1793, gave a description of a two-feet circle which had an azimuth. That instrument, however, was solely designed for a meridian one, and was in fact quite unfit for any other purpose. The same gentleman, in the Appendix to his *Fasciculus*, points out the best means of using an altitude and azimuth circle (properly so called), but without giving any description. The Westbury circle described in the *Phil. Trans.* for 1806, although well constructed for observing azimuths, was not designed for taking transits, and besides was not a portable instrument.

is equal to about two-thirds of the diameter of the circle; the outer part of which, being perforated from end to end, becomes the socket for an axis of the same length, to which the index of the circle and telescope is attached in front. The index has four branches placed at half right angles to the telescope, each of which subdivides the divisions of the circle into spaces of $10''$. To the middle of the cross axis is fixed a socket, which receives about two-thirds of the length of the centre-work: and the exterior surface of the remaining third of that work becomes the axis for another telescope and a level to revolve contiguous to the back of the circle. This is a complicated matter, difficult to be described or understood without a figure: it will however be sufficient, if it is conceived that there are three concentric motions in planes parallel to that of the circle: namely, a general one within the socket of the cross axis, which carries round together, the circle, level and two telescopes; another, by which, upon the exterior part of the centre-work the level and back telescope revolve; and a third, that gives motion to the fore telescope and the verniers, so as to make them advance upon the circle, which is produced from the interior axis. These motions are independent of each other, and are all furnished with clamping and tangent screws. A counterpoise is placed upon the exterior end of the centre-work, which, by balancing the circle, telescopes, and level, keeps them stationary in any position. The greatest part of these instruments, which have been constructed in London, have the back telescope on one side of the axis, and the level parallel to it on the other side, which latter, being made heavier than would be otherwise required, becomes a counterpoise for the former, a thing not attended to in the earlier constructions of the repeating circle. The azimuth circle of this instrument, only just named above, was in the first construction small, and of no other use than to point out roughly when the upper circle had been turned half round; but, in most of those made in London, to that circle has been given the same radius, and the same attention paid to its execution as to the upper one. In the best construction of this part the circle is attached to the tripod, and three indices fastened to the vertical pillar revolve round it; thus may a horizontal angle be taken on three equidistant parts of the circle, and, what is of equal importance, by simply reversing the position of the telescope and turning half round in azimuth, a similar observation may be made, in which the readings will fall at 60° distance from the former ones. By this double operation simple errors of division may be considered as very much diminished, each sight

having been read off on six places; and in both parts of the operation the error arising from eccentricity is, as to any sensible quantity, totally done away.

Description of the Altitude and Azimuth Instrument.

The lower part of this instrument, like the other, consists of a tripod and feet-screws; which latter, being a recent contrivance, and hitherto undescribed, may in this place deserve particular notice. Each of the three screws is double; that is, a screw within a screw: the exterior one, as usual, has its female in the end of the tripod, and the female of the interior screw is within the exterior. The interior one is longer than the other, its flat end rests on a small cup on the top of the support, and its milled head is a little above the other. Now by this arrangement we gain three distinct motions; for, by turning both screws together, an effect is produced equal to the natural range of the exterior screw: by turning the interior one alone, the effect produced is what is due to this screw: and by turning the exterior one alone (which may be done, because the friction of the interior screw in the cup is greater than that which exists between the two screws) an effect is produced, equal to the difference of the ranges of the two screws. Thus, were the exterior one to have 30 turns in an inch, and the interior 40, the effect last described will be exactly equal to what would be produced by a simple screw of 120 threads in an inch. This is an improvement applicable to all instruments that are supported on screws, and of course to the repeating circle. A few of the last made in London possess this advantage. The vertical axis of the altitude and azimuth instrument is fixed in the centre of the tripod, of a length equal to about the radius of the circle. At the lower end is centred upon it the azimuth circle, in close contact with the tripod; to the three branches of which it is fastened, but in such a manner as to admit of a circular motion of about 3° , which motion is governed altogether by a slow moving screw. The intention of this motion is, in geodetic operations, to bring the zero of the circle to the point of commencement; and, in astronomy, to place that point exactly in the meridian. In an instrument for my own use, however, I could dispense with this adjustment, because I know that it is easier and more accurate to *read off* than it is to *set*: and from what point I begin to reckon, is a thing quite indifferent to me. Just above the circle the axis is embraced by a cone, which is also well centred upon the upper end. To the lower end of the cone is fixed an entire circular plate, formed in the strongest manner; which not only bears the two or three
microscopes

microscopes that read and subdivide the divisions of the circle, but also supports the whole of the upper works. On opposite sides of the cone, and distant from it about half the radius of the plate, are erected two columns, of a height to support a transit axis, so as to allow the telescope to pass the upper end of the vertical axis, when it is pointed towards the zenith. The transit axis is one-third longer than the distance between the columns, upon which *out-riggers* are placed, having Y's or angles on their extremities, that support the axis: and each of the angles is acted upon by an adjusting screw, not only for making the transit axis horizontal, but also for placing the centre of the circle of the same height with the horizontal microscopes. The horizontal axis is crossed, as in an ordinary transit, by a telescope; the length of which exceeds the diameter of the circle by about one-third. The circle framed upon the axis is double; the two parts being placed at a distance from each other to allow the telescope a lodging between them: and they are connected with each other by pillars inserted perpendicularly between them. The front portion of the circle (or that which bears the division) is of a less radius than the other by about one-eighth part of an inch: the longer radius of the portion behind is what is required for the clamp and screw for slow motion to act upon, while the shorter radius of the one in front keeps it clear of that apparatus when the axis is reversed for collimation. Many of these instruments have been constructed with vernier readings; but as I consider those by the microscopic micrometer preferable, I shall confine this description to the latter. My preference to one of those excellent contrivances for minute subdivision is mainly grounded on the circumstance that, in the employment of the more ancient method, the indices rub against the divisions which they subdivide; whereas in the modern, which is detached, the motion is free and unembarrassed.

In the description of the repeating circle, the advantage of three readings was stated; but that contrivance originated with the instrument I am now describing: and if it be a real improvement (which I believe no one will doubt), the repeating circle owes the advantage solely to the latter. Three readings are not only better than two, but also better than four: for, with four, when the objects are in the horizon, or near it, on reversion the opposite indices only change places; a circumstance clearly in favour of the odd number. But, in astronomy, where the upper circle is chiefly concerned, the same advantage does not occur: for, at the zenith, on reversion, the telescope changes place in azimuth only: therefore, as the indices have no change of place, more readings than two could be

be of no use. It is true that in proceeding downwards we gradually come to the horizon, where the same effect, that was stated respecting the azimuthal angle, takes place: but here the uncertainty of refraction destroys all confidence. I may also state that three readings to a vertical circle cannot be all equally well illuminated in the night time; nor at any time are they to be read with equal convenience, as is the case where two readings are placed horizontally. However, as microscopic readings are expensive, and as astronomy is generally the chief object of those who procure this instrument, two microscopes to each circle may be sufficient. But were I to have for my own use an instrument of this kind with verniers, the lower circle should have three, and the upper one four.

When the vertical circle has two readings, and these microscopic, they are affixed to the ends of two horizontal tubes fastened to one of the columns; which also support a good hanging spirit level. Another level of the best quality is occasionally applied to the pivots of the transit axis, in order, independently of every thing else, to verify its horizontality.

Adjustment of the Repeating Circle.

The vertical axis is made perpendicular by means of the feet-screws of the tripod, and the spirit level, in the same manner as is required for other instruments; an operation so easy and well known, that to mention it is all that seems necessary. To adjust the collimation of the telescope parallel to the plane of the circle, an object should be chosen as nearly in the horizon as can be estimated: the middle wire of the telescope under adjustment, being correctly pointed to the object, what is shown on the indices of the azimuth circle must be carefully noted. Reverse the telescope both vertically and horizontally, bisecting again the same object with the same wire, and again read off what the indices give. Take of these readings the mean, or middle point, and set with great care the indices so as to show that mean. Now, by the screws, which act upon the wire-plate, move the wire so as to make it bisect the object: this being well done, the other telescope, to be adjusted, wants only its vertical wire moved in the same manner till it bisects the object. The above, however, is true only when the object is very distant; for, as both telescopes are eccentric, as respects the vertical axis, and unequally so, it becomes necessary, when no remote object can be seen, to put up marks, say two circles, the radii of which are equal to the eccentricities of the respective telescopes. The next essential adjustment, is to place the plane of the upper circle vertical; or its axis horizontal. The best practical method of doing this, and which is quite

quite equal to the purpose, is to look with the front telescope at any elevated object, whether remote or near, and having made the middle vertical wire bisect it, look at the same object when reflected from the surface of a fluid. If the wire does not cut the reflected image, the circle must be turned round the cross axis, to bring the wire as nearly as can be estimated half way towards that image; now by turning the instrument in azimuth, make the bisection, then elevate the telescope to the object, and if the bisection is not perfect, the operation of estimating and turning in azimuth must be repeated. A level, which is placed parallel to the axis of the circle, must now be adjusted so that the bubble may stand in the middle of its tube; which afterwards becomes the index for the vertical position of the circle. Another adjustment, which is not however of so much importance as either of the former, is to make the cross axis at right angles to the vertical one; which is indeed the business of the maker. If, when the vertical axis is adjusted, he brings the upper circle horizontal by means of a pocket-level, which is to be placed upon the face of the circle at right angles to this axis, then, by placing the level parallel to the axis, he will see which of the supports wants to be shortened by the file.

Adjustments of the Altitude and Azimuth Instrument.

The axis of azimuth is rendered vertical by means of the level and feet-screws; exactly in the manner that was required in the other instrument; and it may be stated that either or both of the levels belonging to it may be used for this purpose. That adjustment, which answers to the second for the repeating circle, or setting the line of collimation perpendicular to the axis, is no other than the usual way practised for doing the same thing in a plain transit; namely, by moving in azimuth bring the middle vertical wire to any object, then reverse the horizontal axis end for end upon its supports, and if in this position the wire does not cut the same object, alter one half the error by turning in azimuth, and the other by means of the screws which act upon the wire-plate. The transit axis is brought to the horizontal position simply by placing the level upon the pivots of the axis, and observing if the air-bulb changes its place on turning the level end for end. If it does, nothing more is wanted to effect the adjustment, than with the screw below either of the pivots, to bring the bubble, according to the indication of the divided ivory scales, just half way towards the place which it occupied in the first position.

Both the circles under consideration require many more adjustments: but as those belong to the minor parts, and are
common

common to many instruments, even to enumerate them in a paper like this, could hardly answer any useful purpose.

Manner of using the Repeating Circle.

In geodetical observations this instrument gives the angular distance between two observed objects, whatever be their elevation above, or their depression below the horizon. The horizontal angle is always the thing wanted; to obtain which, it is necessary to find by observation how the objects are situated respecting the horizon; these give the requisite data for trigonometrical computation. Previous however to this, the observed angle itself has to be corrected for the eccentricity of the telescopes; which correction varies according to the quantity of eccentricity, and the measured, or estimated, distance of the observed objects. To place the plane of the repeating circle parallel to the line that joins two objects, the angular distance of which was to be observed, had been no easy task, until about thirty years ago from my little gazebo I attempted to take the angular distance of two spires. Their distance was by no means my object; it was simply to acquire the habit of observing by repetition, and putting to trial an instrument that I thought well of. After having made three attempts, without effect, to obtain the thing wanted, and a fourth placing me still further from the point, I quitted my instrument, disgusted at my own unskillfulness, and retired to consider whether the instrument had not within itself some principle from which a precise rule might be made out. This inquiry proved successful, for I saw that by pointing one foot of the tripod, the cross axis and the back telescope towards one of the objects, the fore telescope by turning round the cross axis and by its own proper motion might be brought to the other object without altering the angular direction of the back telescope. The rule is this. Set one foot of the tripod as nearly as you can guess in a line with that object of the two, which you judge to have the least elevation or depression; and with the plane of the circle vertical, and the back telescope horizontal (both to the exactness of two or three minutes), bring the back telescope to the object, partly by turning in azimuth, and partly by turning or propping the foot-screw. Next turn the circle round on the cross axis, until it seems to the eye to occupy the proper position; then a second time bring the back telescope to the object by the foot-screw, and turning in azimuth; lastly, complete the operation by bringing the upper telescope to the other object by its own proper motion in conjunction with that of turning round the cross axis. The above operation being performed, (which it is necessary to repeat at every angle that is taken, even

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at the same station,) the business of observing by repetition may be commenced as follows. Set the fore telescope to zero, as is usual; or what is better, as was said before, read off what the indices (being clamped) happen to show; and, by turning round by the general motion, place the intersection of the middle wires exactly on the object to the left. Then, by its own motion in the same manner set the back telescope to the object on the right; and examine if the angle between the objects be accurately comprehended between the two telescopes. Now by the general motion, without touching any thing else, move the back telescope until its wires coincide with the object on the left. To complete the first operation unclamp the fore telescope, and carry it round to the object to the right; when its indices will have advanced upon the graduated limb through an arc equal to double the angular distance of the objects. To read off this double result would be rather detrimental than useful; instead of which, with the fore telescope fixed at this position, the three steps of another operation, as described above, should be taken in order to obtain a second double result. A third, fourth, &c. course of operations must succeed, until it is judged that sufficient has been done to produce the accuracy required. At last the indices must be read, and the total number of degrees, minutes and seconds, that have been passed over by the indices, taken and divided by double the number of operations; when the simple angle between the objects will appear. If all the results had been read, the intermediate errors of division would have come into the account, and produced an effect that has been avoided by the process described: for, except at the beginning and end, the observations were carried on as if there had been no divisions. It is in this solely, that this instrument claims an advantage over others, and justly; for they have a beginning and end to every double result; but this, as far as graduation is concerned, has only a beginning and an end to a whole course of observations. In geodesy, the levels are of no use, except in the operation of bringing the plane of the circle into that of the two objects: and it may be observed here, that in astronomy the back telescope is altogether unnecessary.

To observe zenith distances of the heavenly bodies by repetition, is a process so similar to what has been described, that a shorter course may be taken to explain it. The instrument being adjusted, and the indices set or read, by the general motion (the level being horizontal) bisect the star, and examine that both are correct at the same time: now turn the instrument half round in azimuth, correcting with the foot-screw the position of the level if required, and move the telescope by its

own proper motion to the star again, which will cause the indices to pass over an arc equal to twice the zenith distance. Again turn the instrument half round in azimuth, and with the telescope fixed in the last position, by the general motion again bisect the star, and again by its proper motion make the level horizontal: now turn half round in azimuth, correct the position of the level as before, and in order to come at another double zenith distance, carry round the telescope to the star again. This process having been continued until enough has been done, the total arc passed over by the indices, divided by double the number of complete operations, gives the zenith distance of the star. There is indeed another way of observing by repetition with this instrument. For the same effect will be produced, if, instead of turning half round in azimuth, the circle be turned to the other side of the pillar, on the motion of the cross axis. But, in this case, there must either be a stop to prop the circle on the other side when its plane is vertical, or else the level must be a hanging one, which will give the circle its vertical position whether it is above or below the axis. It would be altogether unnecessary to describe the process of repetition in this case; for, except in what has just been stated, it differs not from the former one. A nominal difference indeed takes place; for the former method proceeded by stops of double zenith distance, and this proceeds by stops of double altitude.

[To be continued.]

III. On the Hypothesis of Gaseous Repulsion. By JOHN HERAPATH, Esq.

Cranford, London, July 4, 1822.

“**B**UT whether,” says Sir Isaac Newton, after having investigated the laws of a supposed repulsion between the particles of aëriform bodies, “elastic fluids do really consist of particles mutually flying one another, is a *physical question*. I have mathematically demonstrated the property of fluids having such particles, that hence *philosophers may take occasion to discuss that question*.”—*Principia*, Book ii. Prop. 23. Scholium.

Notwithstanding this unqualified declaration of Newton himself to the contrary, some philosophers strangely assert, that he has demonstrated the existence of a repulsive property in the particles of gaseous bodies. Convinced of the justness of most of his observations, from the failure of my attempts in a different course in the early part of my pursuits; and satisfied that it is to a steady prosecution of his ideas unmixed with those of others, that I owe whatever success I may have met with, few individuals would be less disposed than I should