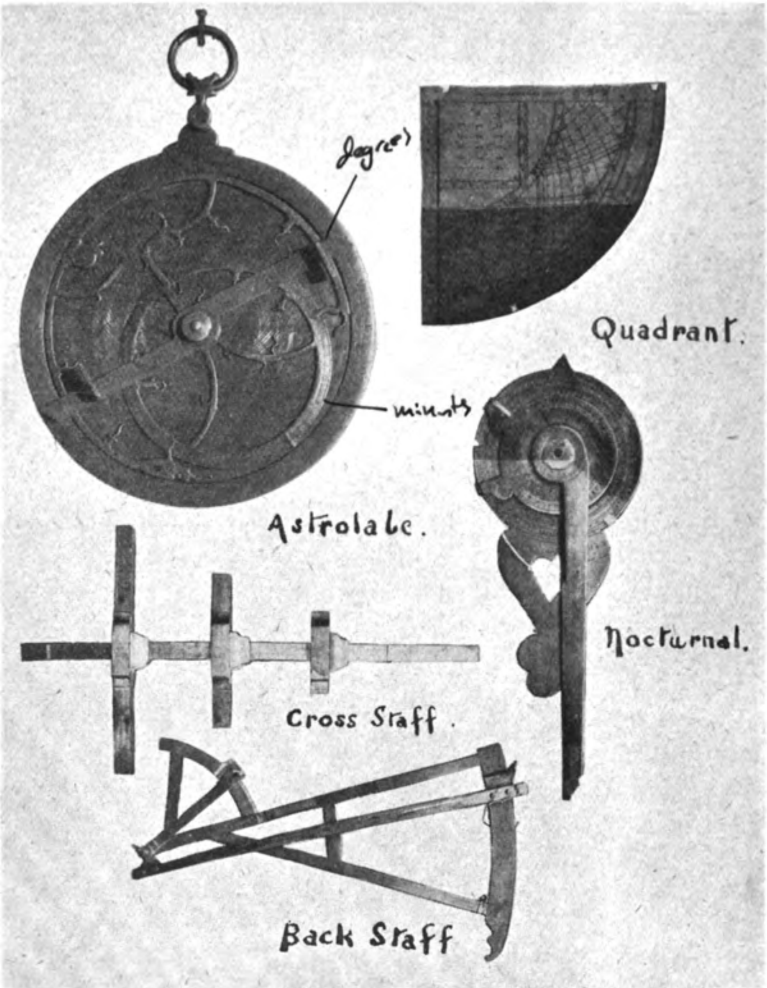

OLD INSTRUMENTS.

The Book of the Sextant

WITH

Ancient and Modern Instruments of Navigation

BY

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The Astrolabe.

THE astrolabe is probably the earliest form of instrument designed for taking altitudes at sea, such as the altitude of the pole, the sun, or the stars. It was invented by Hipparchus, 160 B.C., and simplified by Stoleing, 187 A.D.

The common astrolabe consists of a large brass ring about 15 inches in diameter, whose limb, or a convenient part of it, is divided into degrees and minutes. It is fitted with a moveable label or index which turns upon the centre and carries two sights.

To make use of the astrolabe it is suspended on the thumb by the small ring at the top and turned towards the sun or heavenly body so that the rays may pass freely through both the sights: then the label will cut the altitude on the divided ring.

Gunter's Quadrant.

Gunter's quadrant, so called from the inventor, Edmund Gunter, consists of a quarter of a circle divided into 90° fitted with plane sights and a plummet suspended from the centre. It also has a stereographic projection of the sphere on the plane of the equinoctial, also a calendar of months next to the division of the limb.

To find the sun's meridian altitude for any given day, lay the thread to the day of the month in the scale next the divisions, then the degree it cuts is the sun's meridian altitude.

To find the hour of the day, having set the bead which slides on the thread to the sun's place in the ecliptic, observe the sun's altitude by the quadrant, then if the bead be laid over the same on the limb it will fall on the hour required.

To find the sun's declination, bring the bead to the sun's place in the ecliptic, and move the thread to line of declination, when the bead will cut the degree of declination.

To find the sun's right ascension, lay the thread on the sun's place in the ecliptic, and the degree it cuts on the limb is the right ascension.

To find the sun's azimuth, set the bead for time as above, observe the sun's altitude, bring the bead to the complement of the altitude, and the position of the bead will give the azimuth sought among the azimuth lines.

The Nocturnal.

The nocturnal was an instrument chiefly used at sea to take the altitudes of the Pole Star and other stars about the pole in order to find the latitudes and hour of night. There are several kinds of this instrument, some of which are projections of the sphere, such as the hemisphere or planisphere on the plane of the equinoctial. The seamen commonly used two kinds, the one adapted to the Pole Star and the first of the guards of the Little Bear, and the other to the Pole Star and the pointers of the Great Bear.

The nocturnal consists of two circular plates applied over each other. The greater, which has a handle, is about 2½ inch diameter, and divided into twelve parts answering to the twelve months, also each month is divided into every fifth day and in such manner that the middle of the hand corresponds to that day of the year in which the star inspected has the same right ascension with the sun. When the instrument is fitted for two stars the handle is made moveable. The upper circle is divided into twenty-four equal parts for the twenty-four hours of the day, and each hour subdivided into quarters. These twenty-four hours are denoted by teeth to be told in the night. In the centre of the two circular plates is adjusted a long index moveable on the upper plate, and the three pieces, two circles and index, are joined by a rivet, which is pierced through the centre with a hole 2 inches in diameter for the star to be observed through.

To use the nocturnal, turn the upper plate till the longest tooth marked 12 is against the day of the month on the upper plate, and, bringing the instrument near the eye, suspend it by the handle with the plane nearly parallel to the equinoctial, then, viewing the Pole Star through the hole in the centre, turn the index about till by the edge coming from the centre you see the bright star or guard of the Little Bear, if the nocturnal is fitted for that star. Then that tooth of the upper circle under the edge of the index is at the hour of the night on the edge of the hour circle, which may be known without a light by counting the teeth from the longest, which is for the hour of twelve.

Cross Staff or Fore Staff.

Cross staff or fore staff, an instrument formerly used at sea for taking the altitudes of the heavenly bodies. It is so called because the observer in using it turns his face towards the object. The fore staff is formed of a straight square staff of about 3 feet long, having each of its four sides graduated like a scale of tangents, and four sides sliding upon it of unequal length, the halves of which represent the radii to the scales of tangents on the different sides of the staff. The first or shortest of these vanes is called the 10 cross or vane, and belongs to the 10 scale or that side of the instrument on which the divisions begin at 3° and end at 10°. The next longer cross is called the 30 cross, belonging to that side of the staff where the divisions begin at 10° and end at 30°. The third vane is called the 60 cross, and belongs to that side where the divisions begin at 20° and end at 60°. The last or longest vane is called the 90 cross, and belongs to that side where the divisions begin at 30° and end at 90°.

The chief use of the instrument is to take the height of the sun and stars or the distance between two stars, and the 10, 30, 60, or 90 cross is used according as the altitude is less or more; that is, if the altitude be less than 10° the 10 cross is used, if above 10° the 30 cross, and so on.

The Back Staff.

Back staff, an instrument formerly used for taking the sun's altitude at sea, so called because the back of the observer was turned towards the sun when he made the observation. It was sometimes called Davis' quadrant, from its inventor, Captain John Davis, the celebrated navigator, who produced it about 1590.

The instrument consists of two concentric arches of boxwood and three vanes. The arch of the longer radius is of 30° and the other of 60°, making between them 90° or a quadrant. The vane at the centre of the head of the instrument is called the horizon vane, that on the 60° arch the shade vane, and that on the 30° arch the sight vane.

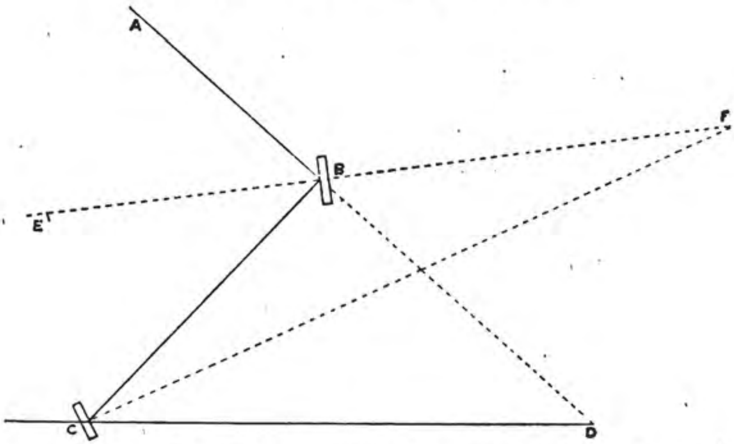
To use the back staff, the shade vane is to be set on the 60° arch at an even degree with some latitude less by 10°, 15° than the complement of the sun's altitude is judged to be. The observer then turns his back on the sun, lifts up the instrument and looks through the sight vane, raising or falling the quadrant till the shadow of the upper edge of the shadow vane falls on the upper edge of the slit in the horizon vane, and then if he can see the horizon through the said slit the observation is exact and the vanes are rightly adjusted. But if the sea appears instead of the horizon the sight vane must be moved downward, or if the sky appear it must be moved upwards. The observer then examines how many minutes and degrees are cut by the edge of the sight vane, and to them he adds the degrees cut by the upper edge of the shade vane. The sum is the sun's distance from the zenith or the complement of its altitude.

For many years the instruments depended on the plumb line or required the observer to look in two directions, but in 1729 Pierrot Bowgier introduced a new form, in which the sun's rays passed through a sight and illuminated a peg which is kept in line with the horizon by the observer. The position of the sight vane on the arc determined the altitude.

The first true reflecting instrument was invented by John Hadley in 1730. The instrument consists of the following parts:—An octant or eighth part of a circle, the index, the speculum, two horizon glasses, and a set of coloured shade glasses and two sight vanes. The arc is graduated to 90°.

The original pattern of this instrument was generally made about 18 inches radius of mahogany or ebony with ivory arc. As time went on it was gradually reduced in size, and with the exception of the back sight by which a back observation was taken, and which is not now fitted, it is practically the same instrument as is generally in use at the present time.

Principles of the Sextant.



1st. The angle of incidence equals the angle of reflection in a plane which contains the normal to the reflecting surface at the point of reflection.

Let ***B*** and ***C*** represent the index and horizon glasses.

E B F is the normal or perpendicular to ***B***.

C F is the normal or perpendicular to ***C***.

A B is the ray of light falling from the star on the index mirror ***B***.

B C is the path of reflection from the index mirror to horizon mirror.

C D is the final course of the ray reflected from the horizon mirror to the eye.

Then by the first principle $ABE = EBC$
and $BCF = FCD$

2nd. If a ray of light suffers two successive reflections in the same plane, by two plane mirrors, the angle between the first and last direction of the ray is twice the angle of the mirror.

Then ***A D C***, which is the angle between the first and last direction of the ray ***A B C D***, is by geometry—

$$ABC - BCD$$
$$ABC = 2\,EBC$$
$$BCD = 2\,BCF$$
$$\therefore ADC = 2\,EBC - 2\,BCF$$
$$= 2\,(EBC - BCF)$$
$$= 2\,BFC$$
$$= \text{twice the angle of the mirrors.}$$

Construction of the Sextant.

The Limb *A*.—The frame of the sextant is called the limb and is constructed of a very superior bell metal alloy containing 7 per cent. of tin. In order to give rigidity to the framework, it is essential that the limb should be incapable of bending, as even a small flexure will produce large errors. The design of the framework is, therefore, very important, and only those patterns should be selected which ensure a proper rigidity.

The three circle, the diamond, the triangle, are all well-known patterns of framework which have stood the test of time. Several instruments of these patterns have been re-tested at the National Physical Laboratory and have given the same errors all along the arc after 50 years' of hard wear.

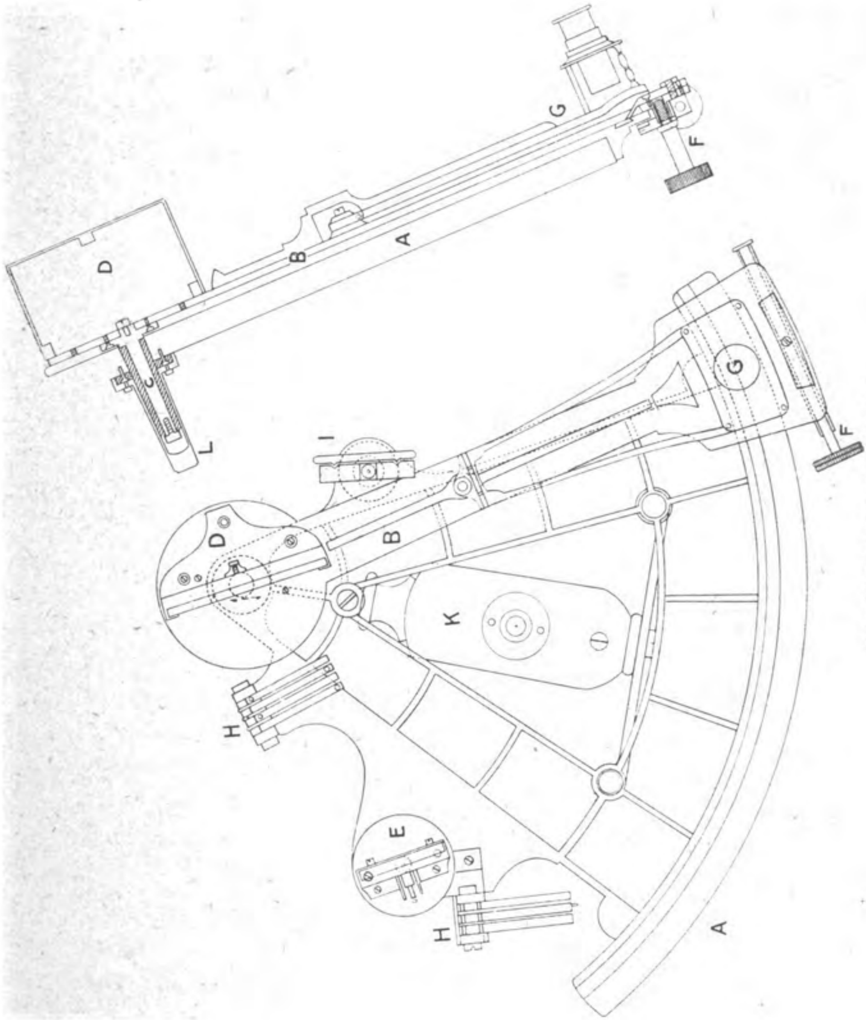


DIAGRAM OF SEXTANT.

Sextants are sometimes made of an alloy of aluminium for lightness, but that is not a great advantage, as a certain amount of weight gives steadiness. Four lbs. weight has been found the maximum for comfort in taking observations.

The arc of the sextant on which the divisions are made is inserted in the sextant limb and the face turned flush. The arc is either of silver or platinum, both of which have a very low co-efficient of expansion. With a platinum arc, great care should be taken not to leave it in the sun, as the great difference in the degree of expansion between the metal limb and the platinum arc will sometimes cause the latter to spring out of its groove.

The Index Bar ***B*** is a flat casting of brass well hammered, into one end of which the centre is fitted in a central hole and secured by three screws and above which is fixed the index clip. The other end of the index bar carries the vernier scale, a strip of silver or gold which is soldered to the index bar in such a way that when the back of the index bar is finished or smoothed off very carefully, the feather edge of the vernier lies perfectly flush with the face of the arc. This is very important as, when the sextant is divided, a slight lift to the right or left will give a false cut and reading. The index bar also carries the clamp and tangent screw at the same extremity as the above, and in the middle is usually attached the reading arm or magnifier.

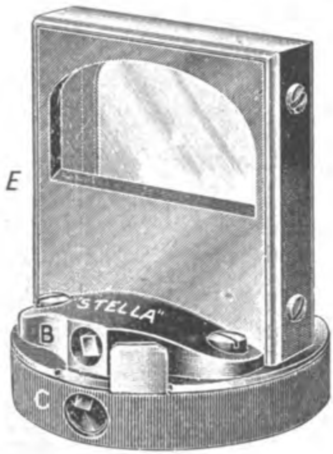
Centre and Socket ***C.***—The centre work of a sextant requires special attention. The centre socket of brass, after boring and broaching, is ground on a hard steel arbor, so ensuring a straight and clear round hole.

The centre, which is of specially hard metal, is turned in a precision lathe nearly to a fit. It is then ground to a fit by means of fine stone powder and finished with pencil dust. The fitting hole in the limb for the centre socket also requires special attention. The limb, after being turned, is tested on a true surface plate before the hole to receive the socket is turned out, thus ensuring the axis of the hole being at a perfect right angle with the plane of the limb and that the index arm will move parallel to the limb.

The Index Glass and Clip *D*.—The index glass is a plane mirror with its two faces ground parallel and the one silvered. It is set in a brass frame fitted over the centre of motion of

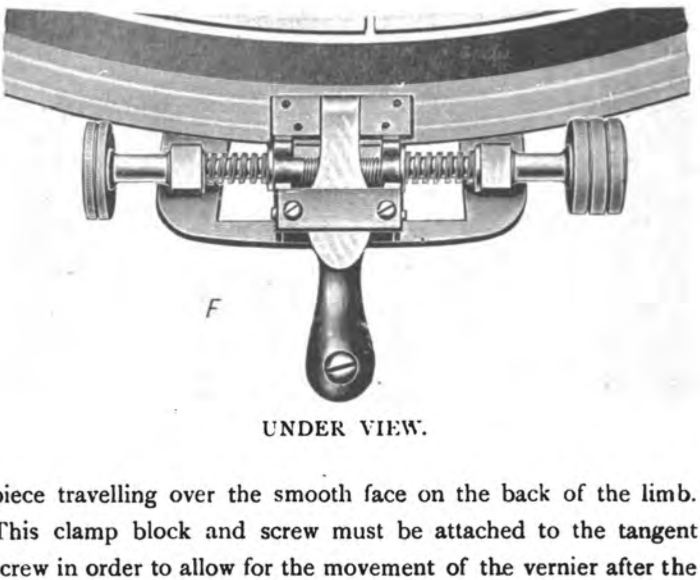
the index bar. Its face is perpendicular to the plane of the instrument and an adjusting screw in the base of the clip protected by a cover provides the means for setting the glass perpendicular.

The Horizon Glass and Clip *E*.—The horizon glass is a plane mirror with only one half of the glass silvered, the other



half being left clear for the direct vision of the horizon. The clip consists of a brass frame securely fitted to the frame of the sextant with two adjusting screws at the base of the clip, one for adjusting the horizon glass perpendicular to the plane of the instrument, and the other for adjusting the horizon mirror parallel to the index mirror. They are fitted in such a way that no pressure is brought to bear on the glass. A light screen covers the adjusting screws. Some sextants are made with the adjusting screws placed on the back of the clip with brass covers, but this way is more awkward to adjust and is liable to put a torsion on the glass.

Clamp and Tangent Screw *F*.—The clamping of the index bar to the limb is usually effected by a brass screw and block-



UNDER VIEW.

piece travelling over the smooth face on the back of the limb. This clamp block and screw must be attached to the tangent screw in order to allow for the movement of the vernier after the index has been clamped. The tangent screw is fixed at right angles to the index bar and provides a fine motion for the vernier. Sufficient length of screw is provided to give $1\frac{1}{2}°$ each way and great care must be taken in the fitting to prevent lost or dead motion. The screw is usually of steel with a spiral spring against which the tangent screw works and this lost motion is avoided.

An improved form of tangent screw is made with a spring on each side of the clamp block, so that immediately the clamp is released the vernier takes up a central position and all danger of the fine screw being used up at the critical moment is removed.

Sextants can be fitted with a tangent screw which works in a thread or rack cut on the back of the limb, but this is open to objection as the fine motion is sacrificed and the vernier in course of time is liable to be fitted at one corner or the other.

The Magnifier *G*.—The reading microscope or magnifier for reading the vernier scale is fitted in a small cell which screws into an arm attached to the middle of the index. The best forms of reader arm carry a large refractor or piece of ground glass to diffuse the illumination of the vernier evenly and should be fitted so as to work just on the surface of the index arm. In the old pattern of reader arms with the stem standing off the index any pressure on the reader arm is liable to bend the index arm.

The magnifier has a very important duty to perform. In traversing the vernier it is necessary for delicate reading that it should rotate on the same centre as the index bar. This is not possible in the ordinary sextant, but in the improved form of quintant described on page 50, by moving the legs in front and the index and horizon glass at the back it is easily arranged.

The Shades *H*.—The shade screens are of large size to ensure no naked rays from the sun passing through the horizon glass to the eye, which is important in making a clear observation. They are mounted in brass frames attached to the frame of the sextant in front of the index glass and behind the horizon glass and consist of well selected shades of neutral glass.

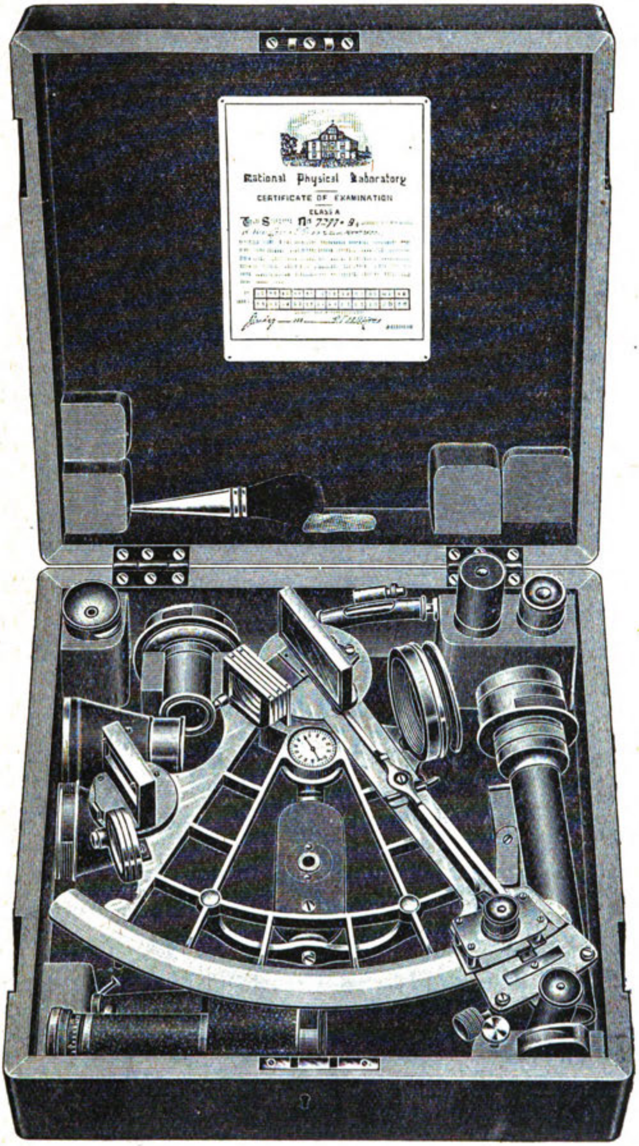
The Telescope Holder *I*.—The telescope holder or rising piece consists of a brass ring fitted in another collar with a square or triangular stem which slides up and down in a socket fitted in the limb just opposite the horizon glass. The telescope is screwed into the first collar, which is provided with two adjusting screws for setting the axis of the telescope parallel to the plane of the sextant. The collar and telescope can be raised or lowered by means of a large milled head at the end of the socket, thus bringing the optical centre of the telescope opposite any part of the horizon glass in a line parallel to the sextant plane. This is the arrangement by which relative brightness of the reflected and direct image is regulated. The first collar is sometimes made with three segments of the thread cut out so that the telescopes can be quickly inserted with arc turn only. A stay or strut should be fixed from the telescope holder socket to the hollow leg *L* in order to prevent errors arising from any pressure being put on the telescope or its socket.

The handle *K* is usually of hard wood, ebony or cocus, fitted at the back of the sextant. The best form is the bridge handle, which has a bridge with two screws for attaching it to the limb at each end of the handle.

Sextant Case.—A sextant case should be of well seasoned wood polished inside and out. It should be sufficiently large to take the star telescope focussed as well as the sextant with its index clamped to any division on the arc between 0° and 100°. The packings in the case should be secured with screws and a camel's hair brush and screw driver. A brass folding counter sunk handle with hooks and studs and good lock also provided.

Dividing.—The most important operation in the making of a sextant is the cutting of the arc. This is done on a dividing machine, which consists of a large surface plate, revolved by an extremely accurate micrometer screw attached to a rachet wheel and pulley. The dividing point is fixed in a swinging arm mechanically controlled and so brought to the right cutting point both vertically and horizontally.

The sextant limb is laid flat on the surface plate and centred.



SEXTANT IN CASE.

Great care is taken to ensure the back of the limb being perfectly in contact all over the surface plate and is finally clamped down at three or four points. The vernier is treated in the same way and the length is very carefully laid off from the arc of the sextant.

The method of dividing recommended by the Commissioners of Longitude in 1767 contains the principle upon which the dividing engines are constructed. It can be briefly described as setting off a radius which is a measure of a chord of 60°, on the circle to be divided and by bisection and subdivision filling up the space between the principal points. Another method is employed, which is known as stepping, consists in taking from the measured radius a chord of a number of degrees, say 16°, and laying it off a number of times in succession, then proceed by bisection to fill in.

The arc of a sextant is usually graduated to divisions of 10 minutes each, as the number of parts into which the section of the dividing circle requires to be subdivided is very great. To obtain this both methods are employed to ensure practically perfect results.

Errors of graduation in a sextant may be described as of two kinds, regular or accidental. The regular errors arise from a want of coincidence between the centre of the vernier and the centre of the graduated arc. These errors, which recur at regular intervals according to a periodic law, are not caused by defective dividing, but by defects in the fitting of centre or socket however slight, or by want of perfect flatness in the limb.

Accidental errors, which follow no regular law, may occur at any given division, due to a peculiar strain in the limb or contraction of the sextant at that point.

The errors of graduation or eccentricity of a sextant can only be found by comparing the various angles measured with the sextant with their known values found by some other means. This is carried out by the National Physical Laboratory at

Teddington, where they have lately erected a new system of collimators fixed at various positions round a centred pillar, with illuminated wires to take the place of stars.

The equality of the distances throughout the arc may be tested by successively placing the index of the vernier in exact coincidence with each division of the limb till the last division of the vernier reaches the last division of the limb. The arc usually extends from 0° to 130° or 140°, and figured at every 10°; each degree is marked by an outstanding line. In all the best instruments the arc is extended 5° to the right of zero in order to provide excess divisions for obtaining the index error.

The Vernier, so called after its inventor, Pierre Vernier, a Frenchman who lived about 1630. By some it is called a Nonius, after the Portuguese, but the invention of the latter was different.

It consists of a small arc concentric with the circle, and graduated into a number of divisions which occupy the space of $N - 1$ divisions of the circle.

Then if d = value of a division of arc

d^1 = value of a division of vernier

$$(N - 1)\, d = n\, d^1$$

$$d^1 = \frac{n-1}{n} d$$

$$d - d^1 = \frac{1}{n} d$$

$d - d^1$ is called the least count of a vernier, which is therefore $\frac{1}{n} d$ of the circle division.

The least count of the vernier in sextants for astronomical observations is usually 10″, but for surveying work it can be made 20″ or 30″.

If $d - d^1 = 10''$, and the sextant arc is divided to 10 minutes, then $n - \frac{d}{d - d''} = \frac{10'}{10''} = 60$ divisions $= 10°$, and the length of the vernier $= 59$ divisions $= 9°\ 50'$.

In actual practice for clearer reading the vernier is extended by using every other division on the arc, and we get—

$$2n = 20^\circ$$

$$2n - 1 = 19^\circ\ 50'$$

To read off observations on the vernier, note where the zero of the vernier is and read off the value of the nearest division of the arc to the highest of it. Then run the eye along the vernier to the left until you find the vernier line which coincides with an arc graduation. This value can be read from the vernier and added to the first reading off the arc.

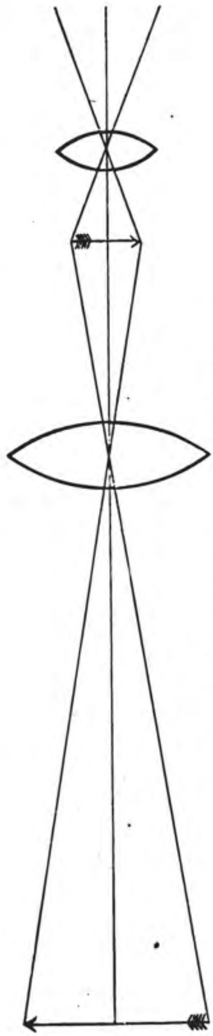
To read an angle on the arc of excess, read left to right the number of degrees and minutes on the arc between its zero and the zero mark of vernier. Read off the vernier as before and subtract from 10′, add the difference to the arc reading. If the vernier is figured both ways this reading can be had without subtraction.

Astronomical Telescopes.

For astronomical purposes we may assume that all the rays from the sun or star falling on the object glass at different points are parallel to each other.

The three most important points in astronomical telescopes are:—(1) Magnifying Power; (2) Field of View; (3) Brightness of Image. The magnifying power of the telescope depends on the apparent angular magnitude of the image produced at the focus of the object glass and upon the focus of the eye-piece. The image of the sun at the focus of the object glass is very small, but has a very great apparent angular magnitude at the short distance of the focus of the eye-piece, which short distance finally determines the magnifying power of the telescope. The shorter the focus of the eye-piece, the greater will be the magnifying power.

The field of view depends upon the effective aperture of the eye-piece and its distance from the objective. Most telescopes



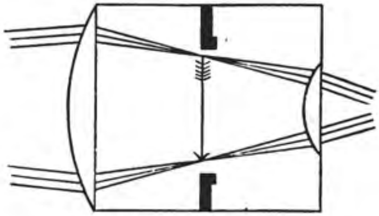
SIMPLE ASTRONOMICAL TELESCOPE.

have diaphragms placed within the tube to cut off rays from the extreme edges of the objective as well as stray light falling down the tube, and this slightly reduces the field of view.

The brightness of image is proportional to the square of the diameter of the object glass and inversely proportional to the square of the magnifying power. Since in the best achromatic telescopes the ratio in which the light is diminished by its passage through all the glasses of the telescopes is about 20 per cent. we see that the brightness of the object is always greatest with the naked eye. The relative intensity of the brightness of a star in the sky must not be confused with brightness of the image in the telescope. Intensity of light is independent of the magnifying power and can become very great when the object glass is large. This is the reason why exceedingly faint stars can be seen through a telescope with a large objective, but conversely with high magnifying powers very faint stars may often be seen which are wholly invisible in the same telescope with lower powers owing to the brightness of the sky.

Object Glass.—All the parallel rays from an object which fall upon a simple spherical lens cannot be brought to a single point focus in any case, but appear ill-defined and disfigured by coloured light. These defects are called spherical and chromatic aberrations. To render the telescope both aplanatic and achromatic, compound lenses are used in which the component lenses are made of glass of different degrees of refractive and dispersive power. One is a bi-convex lens of crown glass and is that which is turned towards the object, the other is a meniscus or concave convex lens of flint glass. By giving the four spherical surfaces of the component lenses suitable curvatures, both the spherical and the chromatic aberration produced by the crown glass lens are very nearly corrected by the flint glass lens.

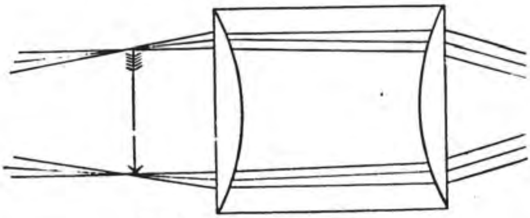
Eye-pieces.—The eye-pieces most commonly used are of two kinds, the Huygenian and Ramsden. The Huygenian eye-piece consists of two plano-convex lenses of crown glass, the convex surfaces of both being turned towards the object. The first lens receives the converging rays, coming from the object glass before



HUYGENIAN EYE-PIECE.

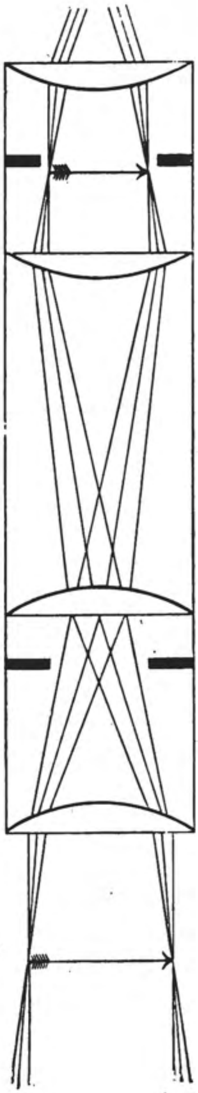
they reach the principal focus, and brings them to a focus half-way between the two lenses. The image formed at the focus of the second lens is distinctly visible to the eye behind it.

The Ramsden eye-piece consists of two plane convex lenses,

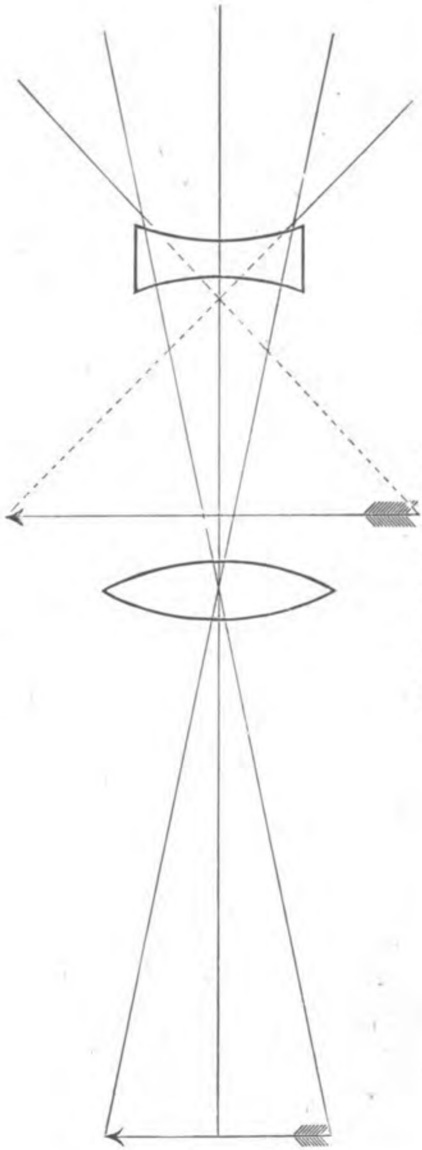


RAMSDEN EYE-PIECE.

but the plane surface of the lens nearest the object is turned towards the object. The diverging rays from the image formed at the principal focus by the object glass are rendered less divergent by the first lens and finally parallel by the second lens. This eye-piece is used where spider threads are placed at the focus of the object glass for the purpose of measurement. Threads are, however, often placed in the focus of a Huygenian eye-piece merely to mark the centre of the field, as in the eye-piece of the telescopes of a sextant. Neither of these eye-pieces change the apparent position of the image which remains inverted. Achromatic eye-pieces designed to show objects in their erect



RE-INVERTING EYE-PIECE.



GALILEAN TELESCOPE.

positions usually consist of four lenses. They are chiefly used for land objects, as the great loss of light from the additional lenses is an objection to them for astronomical purposes.

The lenses composing the eye-piece are fixed at the proper distance from each other in a separate tube, which has a sliding motion in another tube, so that it can be pushed in or drawn out and thus adapted for different eyes.

The Galilean form of telescope is used in erect telescopes for star observations. It consists of a double convex or plano-convex object glass with a double concave eye-piece placed beyond the focus of the object glass at the distance of virtual focus of the eye lens, and this combination forms an erect virtual image, the disadvantage of this telescope is its small field but it has the advantage of being shorter than the inverting telescope of the same power, as the distance between the lenses is approximately the difference of these focal lengths in the astronomical it is the same.

In the latest forms of inverting telescopes for sextants, the focus is got by racking out the object glass; this allows of the eye-piece being pushed right home and the wheel head used on it without danger of shifting the focus at a critical moment.

The eye-pieces or powers of the inverting telescope used in a sextant are usually 7 and 14 diameters and in the erect or star telescope 2, 3, and 1½ diameters. These provide a range of powers suitable and sufficient for all changes of weather and object.

A high power re-inverting telescope is sometimes supplied, but as stated above, this involves serious loss of light due to extra lenses required to re-invert the image. The same objection applies to prismatic monocles of high power which are sometimes fitted to sextants. The later models of Zeiss and Busch Prismatic Monocles have partly overcome this objection by using large apertures with a power of 6.

In all star telescopes the object glass should be as large as

STAR TELESCOPES AND BINOCULARS.

possible and the larger it is the greater need of a suitable combination of lenses to render the telescope both aplanatic and achromatic.

Binocular glasses are sometimes fitted to sextants and are very convenient for observing stars, but great care must be taken in fitting them in the collar as they are very liable to give errors of collimation.

Adjustment of the Sextant.

To set the index glass perpendicular to the plane of the sextant :—

Place the index at about 60°, turn the arc away from you and hold the instrument nearly horizontal, look obliquely into the index glass and observe if the arc seen directly and its reflection appear in the same plane ; if not, slightly turn the screw till the arc and its reflection seem to form one continuous arc. This adjustment is but seldom required.

To set the horizon glass perpendicular to the plane of the sextant :—

Clamp the index at zero, and observe with the inverting telescope, a star—one of the second or third magnitude in preference to a brighter one. Turn the tangent screw and observe whether the direct and reflected images coincide when passing each other; if they do not, use the adjusting screw till coincidence be obtained. The sun, moon, or indeed any well defined terrestrial object can be used for making this adjustment, but a star is to be preferred.

To set the horizon glass parallel to the index glass when the index is at zero :—

This adjustment is not absolutely necessary, as the error arising from the inclination of the two glasses is easily determined and can be allowed for. Perfect adjustment is by no means easily made, but it is well to have the error called "index error" conveniently small, so an approximate adjustment should be made in the following manner :—

Fix the index exactly at zero and observe a second or third magnitude star through the inverting telescope. If the reflected and direct images be not coincident, turn the adjusting screw at the base of the horizon glass till the two images appear as one. Here, as in the case of the second adjustment, the sun, moon, or a well defined distant terrestrial object may be employed when there happens to be no star suitable for observation.

To place two of the cross wires of the telescope parallel to the plane of the instrument :—

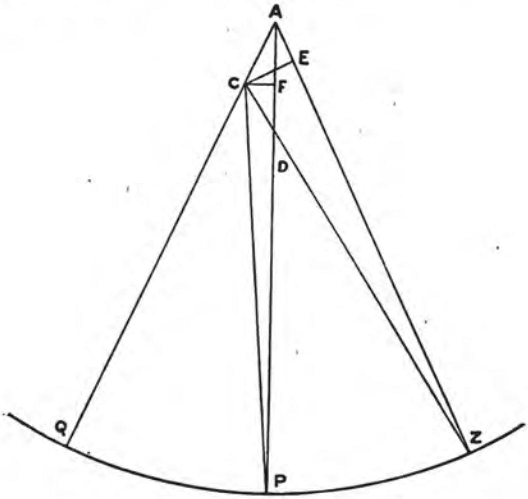
Observe a star or any point through the telescope, and by placing the index 3 or 4 degrees on either side of zero, separate the reflected and direct images so that one of them shall be near the top and the other near the bottom of the telescopic field, bring the edge of the vertical wires into contact with the image near the top of the field and revolve the telescope tube in its cell, till the same edge of the same wire is in contact with the lower image. The wire will then be parallel to the plane of the instrument, and tube and cell may be marked so that the former on future occasions can be at once placed in its proper position.

To set the axis of the telescope parallel to the plane of the sextant :—

Turn the sliding tube of the inverting telescope till two of the wires are parallel to the plane of the sextant, select two celestial objects, as the moon's limb and star, the moon's limb and the sun's limb, or two stars—whose angular distance is between 100° and 120°—bring the reflected image of one and the direct image of the other into contact at that part of the field of the telescope which is close to the wire nearest the sextant plane, clamp the index and, by slightly changing the position of the instrument, bring the image close to the wire farthest from the plane of the sextant. If the contact still remains perfect, no adjustment is required, but if on the other hand the two objects appear to separate, slack the screw in the telescope ring farthest from the sextant frame, and tighten the one on the opposite side. If the images overlap, reverse the operation. If this adjustment be not perfect the observed angles are always too large.

Unadjustable Errors of the Sextant in the Examination of "Sextant Errors."

Mr. T. P. Baker gives the following excellent explanation of centreing error :—



"Suppose A is the centre of arc and C the centre round which the arm rotates. P is the position of the vernier zero.

Then if Z is the zero the reading is $2\,PAZ$, but the angle rotated through by the arc is PCZ and the true reading, being twice the rotation from zero of the moveable mirrors should, be $2\,PCZ$. The reading is therefore too great by $2\,PCZ - 2\,PAZ$.

$$= 2\{(PDZ - CPD) - (PDZ - CZA)\}$$
$$= 2\,(CZA - CPA)$$

Now since $\sin.\ CZA = \frac{CA}{CZ}\sin.\ CAZ$

and $\sin.\ CPA = \frac{CA}{CP}\sin.\ CAP$

so that $2\,(CZA - CPA) = 2\,\frac{CA}{CP}\,(\sin.\ CAZ - \sin.\ CPA)$

since CP and CZ are very nearly equal and CZA and CPA are both small angles.

If the centre, C always remains the same point in all positions of the arm, then we can look upon the first part of this error, viz. :—

$2\,\frac{CA}{(CP)}$ sin. CAZ as a permanent error which can be conveniently included in the index error, and we can then say that the centreing error is proportional to the sine of the arc PQ.

This variable portion will therefore vary as a curve of sines along the arc, having zero value at the point Q and A maximum $2\,\frac{CA}{CP}$ at a point 90° away from Q or 180° if we speak of the difference of sextant readings, since these are cut on a scale of one-half. In a sextant of 7″ radius the maximum error would be as much as 10″ if $\frac{2}{7}\,CA = \sin.\ 10''$; that is to say if CA were about ·0002 of an inch. At the same time it should be noticed that if the line QCA fell about the middle of the arc, the maximum error possible could only amount to $\frac{2}{7}\,CA\,\sin.\ 35°$, so that in such circumstances CA could be as much as ·003 inch in order that the centreing error should never be greater than 10″."

Centreing Error.—The eccentricity of the centre can be found for the various angles of the sextant by measuring the distances of well-known stars and comparing them with the apparent distances computed from their right ascensions and deductions.

Professor Chauvenent gives the following equations :—

Let z = sextant reading.

x = the index correction supposed to be unknown.

z^1 = the true value of measured angle.

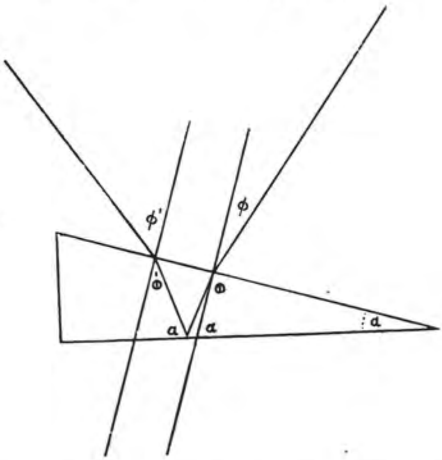
e = eccentricity and E = constant for sextant and putting putting $N = z^1 - z$.

$$n = x + 2e \cos. E \sin. \tfrac{1}{2} z^1 + 2e \sin. E \cos. \tfrac{1}{2} z.$$

To find the three unknown quantities x.

$2e \cos. E$ and $2e \sin. E$, it is necessary to have three equations derived from three angles falling in different parts of the arc, for example, near 0°, 60° and 120°. The error being found for certain places on the arc, the correction for any angle may be obtained.

Professor Chauvenent also gives the following method of finding the error of a prismatic index glass.



Let m = index of refraction for glass, then in fig. .

$$\sin. \phi = m \sin. \theta$$
$$\sin. \phi^1 = m \sin. \theta^1$$

If we put M = the angle of prism, then— 1.

$$90° - \theta = a + M$$
$$90° - \theta^1 = a - M$$
$$\text{or} \quad \theta^1 - \theta = 2M. \qquad 2.$$

From the above, having ϕ, m, M, given we can determine ϕ^1 or $\phi^1 - \phi$. From equation 1—

$$\cos. \tfrac{1}{2} (\phi + \phi^1) \sin. \tfrac{1}{2} (\phi^1 - \phi) = m$$
$$\cos. \tfrac{1}{2} (\theta + \theta^1) \sin. \tfrac{1}{4} (\theta^1 - \theta),$$

or by equation 2—

$$\sin.\ \tfrac{1}{2}\ (\phi^1 - \phi) = m \sin.\ M = \frac{\cos.\ \frac{1}{2}\ (\theta + \theta^1)}{\cos.\ \frac{1}{2}\ (\phi + \phi^1)}$$

M being small it will be sufficient to take—

$$\sin.\ \tfrac{1}{2}\ (\phi^1 - \phi) = m \sin.\ M = \frac{\cos.\ \theta}{\cos.\ \phi} \quad \text{or,}$$

$$\phi^1 - \phi = 2mM \sec.\ \phi \sqrt{1 - \frac{\sin.^2 \phi}{m^2}},$$

which may be reduced to—

$$\phi^1 - \phi = 2M \sqrt{1 + (m^2 - 1) \sec.^2 \phi}$$

$$\text{put} \quad q^2 = m^2 - 1,$$

$$\phi^1 - \phi = 2M \sqrt{1 + q^2 \sec.^2 \phi} \qquad 3.$$

The error varies with ϕ, and consequently with the angle measured. Let r equal angle given by sextant. The whole error in the measured angle will be the difference of the errors produced at the reading r and at the zero point of the sextant; at the zero point $\phi = B$. Hence the error will be the difference of the values of equation 15, for $\phi = \phi\ \frac{1}{2}r + B$ and $= B$. If $r^1 =$ true value of angle, then—

$$r - r^1 = 2M \left[\sqrt{1 + q^2 \sec.^2 (\tfrac{1}{2}r + B)} - \sqrt{1 + q^2 \sec.^2 B.} \right] \qquad 4.$$

m is 1.55 usually, ∴ $q^2 = 1.\ 1.40025$. If $M = 10''$, $B = 10^\circ$ and $r = 120^\circ$, then $r - r^1 = 41''$.

The effect of the error is evidently less for small values of B than for large ones. Moreover, the smaller the angle B is, the larger the angle which can be measured by the sextant, for all reflection from the index glass ceases when $\phi = 90^\circ$, and this value gives $r = 180^\circ - 2B$ as the limit of measures with sextant.

The preceding investigation is confined to the case where both faces of the index glass are perpendicular to the plane of the instrument, but this is the case in which the effect is greatest. The glass reflects from its outer surface as well as from the silvered face. If the faces are parallel, the images reflected from the two surfaces will converge to the same focus in the telescope and produce but a single image of the object. If the glass is prismatic there will be two images, if the object is a star it will appear large or elongated. The best position of the glass, to examine this defect, is when the index is at the 120° end of the arc. If the instrument is found defective in this respect, determine the error as follows:—Adjust the instrument, determine the index correction and observe a large angle between two well-defined terrestrial objects. Now take out the index glass, turn it end for end, replace it, re-adjust the instrument, determine a new index correction; observe the same angle as before. Half the difference of the two observations, each having been corrected for its index error, is the error caused by the prismatic form of the index glass. Repeating the operation for various sized angles we can form a table from which, by interpolation, we can determine the error for any given angle. A prismatic form of horizon glass affects all angles the same, the index correction included, and therefore produces no error in the results.

The Shade Error.—In examining the shades of the horizon glass and index glass, if the reflected and the direct images of the sun do not remain in contact, the angle through which the index arm must be moved to restore contact is the error of the shade, or of the combination of shades which should be recorded and reckoned positive when on the arc proper and negative when on the arc of excess. The shade correction is applied with the contrary sign.

Index Error.—This may be determined by viewing the sea horizon by the sun or by a star.

(1) *By the Sea Horizon.*—Hold the sextant perpendicularly and using the telescope, bring the direct and reflected image of the horizon into exact continuation of each other. The reading on the arc is the index error, positive on the arc proper, negative on the arc of excess. The index error is applied with the contrary sign.

By the Sun.—Clamp the index at 30′ on the arc proper, fix the inverting telescope, hold the sextant horizontally, bring the right limb of the reflected sun into contact with the left limb of the real sun, observe the reading on the arc. Clamp the index on the arc of excess and repeat the operation, observe the reading on the arc of excess. The reading on the arc proper is marked + and the reading on the arc of excess −. Take the algebraic sum of the two readings and the result is the index error with its proper sign.

By a Star.—Bring into coincidence the direct and reflected image of the star. The reading on the arc proper or the excess will be the index correction to be applied with the contrary sign.

Method of Using the Sextant.

To measure the angular distance between the sun and the moon, screw in the telescope, placing the threads parallel to the plane of the instrument, direct the telescope towards the moon and hold the instrument so as to reflect the image of the sun. If the sun is to the right of the moon, hold the sextant face up, if to the left, face down. A general rule in taking an observation is to direct the instrument to the fainter object, for the brighter object will then lose some of its brightness by the two reflections from the index and horizon glasses. Adjust the objects to an equal degree of brightness by interposing the coloured glasses. Move the index forward until the sun's image is nearly in contact with the moon's nearest limb, this is the rough adjustment. Now clamp the index and make the contact perfect by using the tangent screw; this is the fine adjustment. At the same time rotate the instrument slowly about the axis of the telescope; the objects will then appear to pass each other, and the contact of the limbs may be very accurately made. The point of contact of the limbs must always be midway between the parallel wires. The reading of the sextant will be the instrumental distance between the nearest limbs of the sun and moon. By applying the I.C. to the instrumental distance we obtain the *observed* distance.

To measure the distance between the moon and a star, direct the telescope to the fainter object, the star, and move the index till the reflected image of the moon is nearly in contact with the star, clamp the index and rotate as before, making the fine adjustment with the tangent screw, when the objects are midway between the parallel wires. The reading of the index will be the instrumental distance, and correcting for I.C. will give the observed distance.

It often happens that the nearest limb of the moon is not the enlightened limb, in which case the angular distance to the farther limb is measured. In this case you must subtract the moon's semi-diameter from the observed distance to get the distance to the moon's centre, instead of adding it, as we do when the nearest limb is observed. It is well to set the instrument to the approximate distance, if it can be ascertained before making the observation. It may save the taking of the wrong star.

To measure the altitude of a celestial body above the sea horizon, direct the telescope towards that part of the horizon which is beneath the object, move the index till the reflected image of the object is brought down to touch the horizon at the point immediately under it. Clamp the index and rotate or vibrate the intrument about the sight line as before, at the same time turning the instrument to the right and left, taking care to keep the reflected image of the object in the middle of the field of view. The object will appear to sweep in axis, the lowest point of which must be made to touch the horizon by using the fine adjustment or tangent screw. The angle given by the index will be the instrumental distance; correct it for I.C. and we have the observed distance.

To measure the angular distance between two terrestrial objects, hold the instrument face up and direct the telescope to the left-hand object. Move the index till the right-hand object is brought nearly into coincidence with the left. Clamp the index and make the final adjustment with the tangent screw. The reading of the index corrected for I.C. will be the observed distance. If the horizontal angular distance is required, then the objects and the eye must be in the same horizontal plane, or a correction must be applied to the observed distance. This correction can be computed after observing the altitude of each object above the horizontal plane passing through the eye.

In taking observations there are three important things to do. First make the images well defined by focussing the telescope; second, by interposing neutral glasses, lessen the brightness of the objects so as not to fatigue the eye and yet have them distinct; third, adjust the neutral glasses so that the intensities of the light from the two objects will be as nearly equal as possible. The shade heads or neutral glasses for the eye-piece of the telescope should be fitted on, not screwed. The best attachment for this purpose is the wheel head, in which several pieces of neutral glass are mounted in a rotating disc fixed to one head. To change the tint the disc need only be rotated by the finger.

To Resilver the Index and Horizon Mirrors.

The mirrors of sextants will after some time in use at sea get dimmed by damp or spotted, and it is sometimes very useful for the navigator to be able to resilver them for himself, but it must be remembered that every time the mirrors are resilvered the surfaces suffer a slight diminution of polish and the reflection will be less distinct. It is advisable to leave the mirrors with the original silvering as long as possible.

To resilver a piece of tinfoil of good quality some clean mercury and some best sealing wax dissolved in spirits of wine are required. Take a piece of tinfoil larger than the glass and smooth it out on a perfectly flat surface, such as a piece of glass or a thick smooth book cover; make sure it is free from pin holes. It is well to cut a few suitable pieces a day or two before they will be required, and to shut them up in between the pages of a clean and heavy book. When ready to use, place the tinfoil on a piece of flat stone and pour a small drop of mercury on it, and gently rub it with a clean pad of chamois leather till the whole surface is bright and smooth, then pour mercury on till the piece of foil is quite fluid, and brush any large spots of dross lightly off. Draw a piece of clean blotting paper gently but firmly over the fluid surface and thus draw away all impurities on the surface of the mercury. Take the glass well cleaned on its under surface and lay it on the clean fluid surface with a clean piece of paper underneath it, then pressing on the glass with one hand, withdraw the paper with the other, slowly and steadily, and a perfectly clean surface will appear under the glass. Tip the piece of stone on which the glass is and let the superfluous mercury run off, and then leave it slightly on the incline for some hours; place little strips of tinfoil from the glass edge to the edge of stone to assist in running away. After twelve hours the amalgam will be dry and firmly adhering to the glass. Cut the edges carefully round with a sharp knife or old razor, taking care not to drag away any of the foil on the glass. Then varnish lightly off with the red wax, using a soft camel's hair brush, and applying two or three coats as they dry.

In the case of the horizon glass, resilver the whole of the glass, then, when the foil is dry and just before the wax is applied, place a flat edge of a razor across the glass at the point where it requires cutting, gently press and draw away the portion of foil not required, then apply the wax as before.

To replace the wires in the eye-pieces of the inverting telescope, take out the diaphragm from the telescope, lay it on the table and scrape off the broken wires, make a cut with the knife for the position of the wire on the diaphragm, then place the wire tightly across the hole and secure it by closing the raised edge of the cut over the wire with a blunt point. If no wire is obtainable the web of a spider will do, but it must be secured with a drop of Canada balsam.

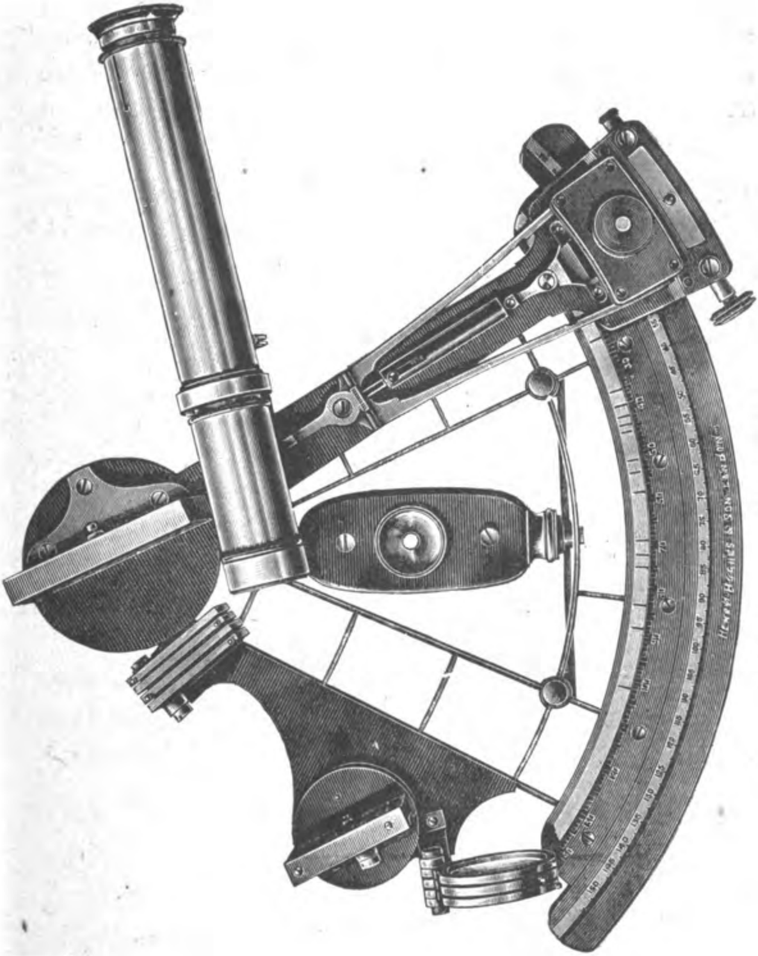
When the arc and vernier become tarnished a handy method of cleaning is to rub them with a soft pencil rubber, but a method less injurious to the surface is to clean them with chamois skin dipped in ammonia. A little sweet oil and powdered charcoal occasionally rubbed over the arc and wiped off with the chamois leather will render the divisions more distinct. Never allow the arc to be polished.

Sextant Accessories.

The Supplementary Arc.—A sextant is sometimes fitted with an extra arc attached to the limb of the sextant inside the curve of the proper arc. It is made of aluminium, and a spring pencil is fitted to the index bar in such a way that the observation can be marked by the pencil on the supplementary arc. This arc is solely for the purpose of taking two or three land bearings quickly, and is only divided to 10″, which can be read quite easily with the eye.

A transparent vernier line or mark is fitted to the index bar, but the arc is primarily intended for the recording, by pencil marks which can be quite easily rubbed out, of a number of angles which the observer wishes to take quickly and read off afterwards.

Greatest angle clamps are little sliding blocks with a spring placed on the arc so that the edge of the index catches them and carries them forward quite easily. When two angles are to be taken quickly one after the other the greatest angle clamp can be used with the first observation, which must be the greatest angle of the two required, and left in position while the second is taken, the index being moved back from the angle

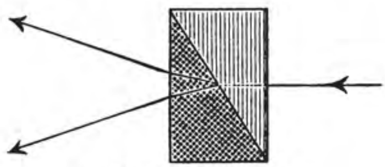


SEXTANT WITH RECORDING ARC.

clamp, then after reading the second observation the index is gently set back in position with its left edge against the greatest angle clamp.

The Lenticular.—This is a cylinder lens fitted in between the index and horizon mirror to intercept the star and draw the image out into a line or band or light parallel to the horizon. The index error if any of the lenticular can be obtained from an observation of the star in the usual way.

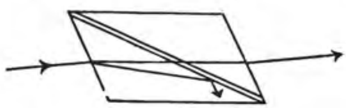
The Woolaston Prism.—This is a cylindrical pair of prisms in the form of two wedges, with sufficient difference in thickness or refractive index to form two distinct images of the star, the



WOOLASTON PRISM.

result gives a very clear cut in observation taken from the horizon. The prism is fitted in between the index and horizon mirror.

The Nicol Prism.—To do away with the annoying and error-producing glare so often witnessed on the sea horizon till the sun gets above 50° or so, a Nicol prism or polarizer can be inserted in

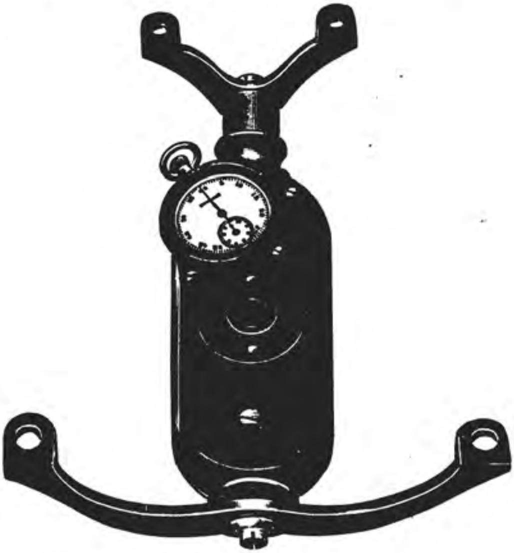


NICOL PRISM.

the inverting telescope on the object glass side of the diaphragm. This is so placed that when the telescope is screwed home, the polarising plane of the prism would be parallel to the plane of the sextant and consequently perpendicular to the plane of the horizon when taking observations. By this means, the horizon is rendered comparatively dark and clearly defined.

Electric Lamp.—The accurate readings of the sextant readings depend very largely on the illumination of the vernier scale, and in order to facilitate readings at night a small electric bubble is fitted behind the refractor. It is supplied complete with the battery in a leather case and sufficient wire to allow of the battery being in the pocket whilst taking readings.

Chronographs.—A small chronograph can be fitted in the frame or handle of the sextant in such a position that the observer can stop it at the moment of observation. A set of

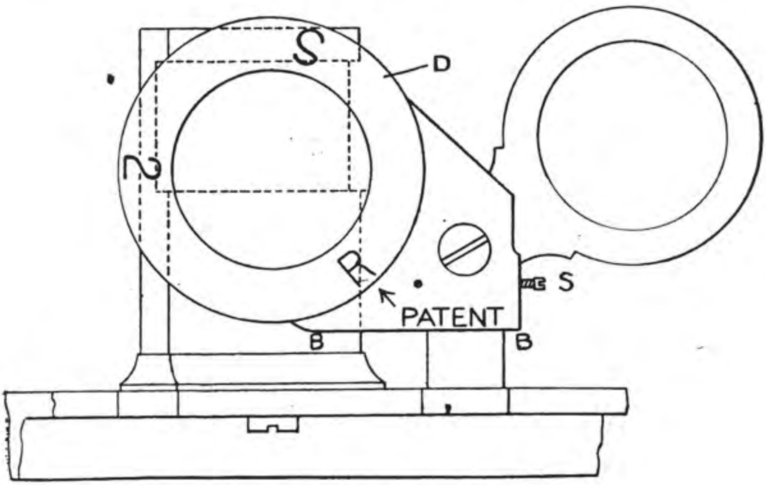


CHRONOGRAPH.

three chronographs fitted in this way makes a very valuable and useful method of taking three observations. Especially if combined with :—

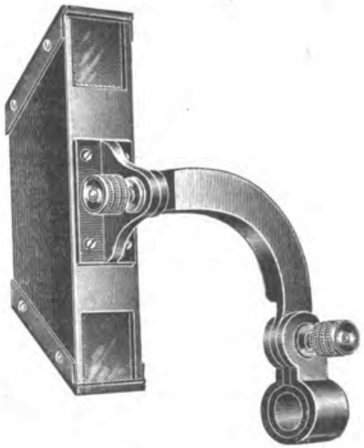
The "Baker" Sight Repeater.—The object of this instrument is to enable an officer "taking sights" to obtain three observations without reading the sextant for each one. The tangent screw of the sextant has not to be moved after the first observation is made, and it is unnecessary to move the eye from the telescope until all the sights are taken. Consequently better results can be obtained, since the observer's eye is occupied solely in noting the instant of contact between the sun's limb and the horizon, instead of being engaged alternately in taking the sight and reading the sextant, a process which tends to produce bad observations and bad readings. A further advantage is that as the sextant has not to be taken from the eye the difficulty of finding the sun or star for the second and third observations—a difficulty which is always encountered when using the artificial horizon—is thereby eliminated.

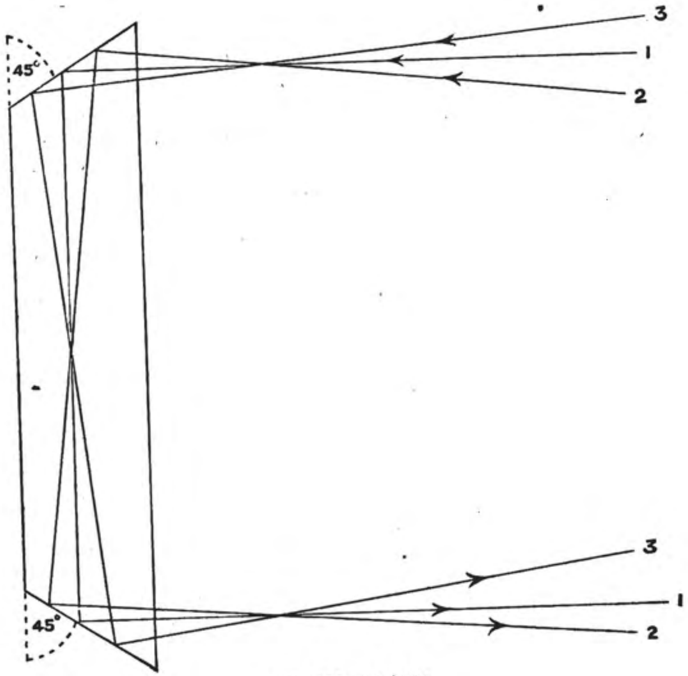
Description of the Instrument:—In a framework fixed to the horizon shade bracket, a circular cell is fitted which carries a suitably mounted prismatic glass and which is capable of rotation



BAKER SIGHT REPEATER.

in either direction. As this cell is rotated, it engages in three positions with a spring catch in the framework, and these are the





BLISH PRISM.

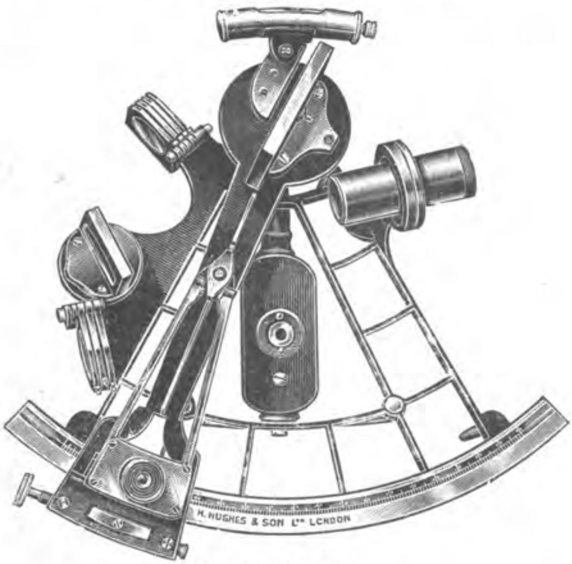
three positions (taken in the proper sequence) for the three separate observations.

The Blish Prism.—Captain Lecky says in his *Wrinkles of Navigation*, "Owing to the uncertainty of the effects of refraction, the apparent position of the sea horizon can never be depended upon. It is found to be sometimes above its normal place and at others below it. This displacement of the horizon sometimes occurs to a great extent."

In order to eliminate this error as far as possible, Commander Blish, of the U.S. Navy, designed an attachment to the sextant for observing back and front horizon simultaneously and thus eliminate the error. It consists of a long rectangular prism with the end two faces bevelled off at 45° with the long axis at right angles with each other. A portion at each end of the flat side is polished. This prism is attached by means of a casing to the hollow leg or false centre of the sextant in such a manner that one polished flat face is directly opposite the top of the index mirror and the other polished flat face is looking over the observer's head, the prism being made long enough to do so comfortably. With the index set at 0° the observer looks directly at the sea horizon in front of him and at the same time sees the back horizon inverted, reflected by the prism. The two horizons are separated by twice the dip. When the horizons are brought into line, the corrected reading of the sextant is twice the angle of the dip.

The prism is very accurately ground and polished, as its value depends entirely on the angles being exactly right angles. The prism can be tested at the National Physical Laboratory and its error given.

The Zenometer.—This is an attachment to the sextant for taking distances of objects below the water-line where no angle of a known height can be observed. It consists of a small curved bubble tube with an adjusting screw fitted in sliding groove on the index bar just above the index glass. When the index bar is set at 90°, the bubble in the tube corresponds to the position of the zenith and the bubble is visible on a line drawn across the

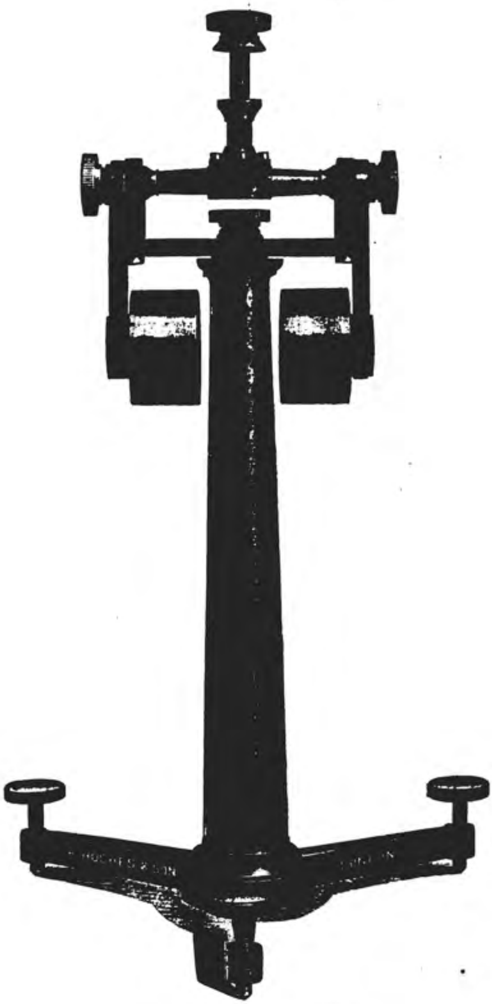


ZENOMETER.

centre of the horizon glass. By moving the index beyond the 90° small angles are measured below the water-line, angle of depression. By means of tables using the height of eye as a base, distances up to two cables can be obtained quite accurately.

The Sextant Stand.—The accuracy of sextant observations is greatly increased by means of a stand, so constructed that when attached to it the sextant can be fixed in nearly any required plane. The disadvantages of the sextant stand are its weight, bulb and expense.

The stand consists of a vertical brass pillar, supported by a tripod standing on three adjusting screws, the points of which rest on the ground or table on which the stand is placed. The head of the stand consists of a cap fitted on the top of the pillar carrying a stout cross bar with two brackets, in which the



SEXTANT STAND.

horizontal axis turns. Attached to each end of this axis are the counterpoise weights and in the middle of the axis is fitted the spindle which carries the sextant.

In the improved forms, the counterpoise weights can be adjusted to any weight of sextant and the horizontal axis is attached to a circular base plate which can be clamped and slow motion imparted to it by a tangent screw.

Knorres Level.—This is a small attachment to the sextant which is very useful in observing stars with an artificial horizon and a stand. It consists of a small spirit level attached to the index arm, and so adjusted that the bubble will play when the two images of a star reflected from the sextant glasses and from the artificial horizon respectively coincide in the field of the telescope.

The Artificial Horizon.

This is a highly reflecting plain surface in a truly horizontal position. Mercury or any viscous fluid protected from the wind can be used.

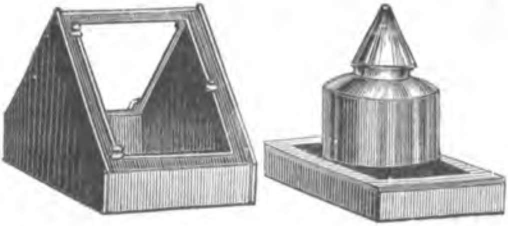
The angle between an object and its reflection from the artificial horizon is double the altitude of the object from the observer's sensible horizon, therefore if the former be measured with the sextant and the reading halved, the result is the observed altitude of the object.

Suppose a ray from a star be reflected from the mercury of an artificial horizon to the eye, the direct rays from the star to the eye will fall in the direction of the dotted line. The small place between the eye and the mercury is insignificant in comparison with the distance of the star, therefore the rays falling on the eye and on the mercury respectively may be considered parallel. The reflected image of the star will appear to the observer in a continuation below the mercury of the straight line between the eye and the artificial horizon.

Now the angles of incidence and reflection ***A*** and ***B*** are equal, the opposite angles ***B*** and ***C*** are equal.

$\therefore AC = 2B = 2A$ and since the rays from the star to the mercury and from the star to the eye are practically parallel, the angle $D = A + C = 2A$.

The most reliable form of the artificial horizon is the shallow trough containing mercury covered by a roof in which are framed

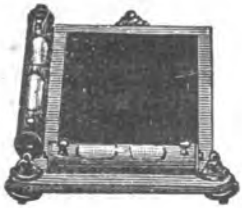


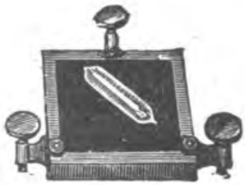
two carefully ground plates of glass whose planes are approximately at right angles to each other and at an angle of about 45° to the surface of the mercury. The glasses should be parallel and marked with the certificate of the National Physical Laboratory. A bottle of mercury is supplied with this instrument.

A new form of horizon has been introduced into the Royal Navy, which consists of a shallow trough of metal gilt. This is amalgamated after getting the surface absolutely clean and free from grease, by wetting it with a few drops of dilute sulphuric acid and then rubbing into it a drop of mercury until the whole surface is bright, when a very small quantity of mercury added will flow evenly and form a horizontal surface. The drop is wiped off with a broad camel hair brush. A bubble is supplied with this form as the trough is mounted on three adjusting screws.

Captain George's horizon consists of a circular iron trough containing mercury on which a disc of glass with parallel faces floats. It is portable and convenient to use, but unless care be exercised when placing the glass on the mercury, and unless the latter be fairly pure and clean, rather large errors, quite unsuspected by the observer, may be introduced. Before floating the glass, a piece of thin paper should be placed on the mercury, the glass should then be put on and lightly pressed while the paper is carefully withdrawn.

These horizons are fitted with a glass lid which screws on the top of the trough, and a circular cistern is attached into which the mercury runs when not in use. Three levelling screws are also fitted to the frame. The chief advantage of this horizon is that the whole surface of horizon is available for observation.





Another form of horizon consists of a plane mirror which is adjusted horizontally by means of a spirit level, such an instrument being very cheap and portable.

The Paget Artificial Horizon for Attaching to the Sextant and use in a Sea-Way.

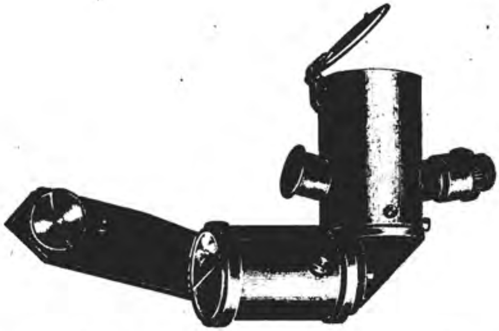
The Paget Artificial Horizon, as now made in its improved form, possesses many advantages over the various swinging and balance horizons at present used. It is not affected by vibration, wind does not disturb it, and any of the sextant telescopes can be used with it, thereby enabling an observation of greater precision to be obtained. It can be used to great advantage at night for stellar altitudes, a small electric lamp with pocket battery being provided for the purpose of illuminating it. It is readily attached to the sextant by a single thumbscrew and can be quickly removed.

The construction of the instrument is a short, curved spirit level tube, mounted in a brass tube with a prism above to throw the image of the bubble into and cause it to appear to move vertically up and down the field of the telescope through the clear half of the horizon glass. A lens in an adjustable tube in front of the prism throws the bubble into focus with whatever telescope is used. A small hinged reflector at the bottom of the horizon illuminates the bubble in daytime and the electric lamp is used at night. The fine cross or horizon wires are fixed across the level tube, and an adjusting screw is provided at one end of the level tube with which the bubble can be compressed or enlarged to just occupy the space between the upper and lower wires. The instrument is fitted with adjusting screws in the event of its being injured or put out of order. A spare level is also sent, and can be readily fitted when required.

To Use the Horizon.—Fix it securely on the sextant with the clamp screw, focus and screw in telescope to be used. Set the bubble and wires focus sharp, angle the reflector at bottom of tube so that the level is illuminated, or, if at night, attach the electric lamp and accumulators. See the bubble is the correct size (the space between the two wires) or adjust it to this by the screw.

Have the sextant approximately level and bring the sun or star down into the centre of field of telescope; then concentrate your attention on holding the sextant perfectly steady for a second or two with the bubble exactly between the upper and lower wires, and if the sun or star is not in contact on the centre wire or horizon, move the tangent screw what you think sufficient to make contact and steady again.

To test the instrument in clear weather by the sea horizon :—The sextant being in the usual adjustment and the horizon attached, set and clamp the index to zero, then hold the sextant so that the centre horizon wire and the sea horizon are in a line



together; the bubble should rest in contact on the lower wire; then if it does not, turn the tangent screw so that the sea horizon and horizon wire coincide with the bubble resting in contact on the lower wire.

The reading of the sextant then gives the error which must be corrected for the dip and refraction and applied as a constant error in all subsequent observations.

The Gyroscope Collimator Invented by Admiral Fleurais.

This instrument is used in connection with an ordinary sextant, the observation being taken as with the sea horizon by bringing the image of the observed body in a field of vision in which a horizontal grating of a special kind allows the observer to ascertain the position of the sensible horizon and the angular distance of the image from it. At the centre of an air-tight case is fixed a small hemispherical cup of hard material, the diameter of which is 1″. This supports the pivot of the gyroscope, the latter having the shape of a spherical segment, the centre of which is coincident with the point of the pivot while its centre of gravity is a little below this point about ·02″. This segment is hollow, so as to combine lightness with a large moment of inertia with regard to the axis. Along its equator, in a groove, are placed little vanes, by means of which the gyroscope is set in motion by the inflow of air from the apertures in communication with the atmosphere when air is pumped on the case.

On the top of the gyroscope is the optical apparatus giving the sensible horizon. This consists in a plano-convex lens and a field grating placed at the opposite extremities of a same diameter, the grating, which is a succession of equidistant transparent lines perpendicular to the axis of rotation, on a black background, being at the focus of the lens.

The axis of the optical system is in the same horizontal plane as the line of sight of the observing telescope, the case having two windows facing each other along the line of sight, so that the light of an electric lamp, or of the sun reflected—in the latter case in a small mirror fixed on the case—can pass through the latter and be received by the telescope whenever the axis of the optical system fixed on the gyroscope is coincident with the vertical plane through the collimation line of the telescope; this occurs at every half-revolution. As the normal speed is about 100 revolutions per second, a persistent image of the grating is observed in bright lines on a dark background, on which the image of the observed body can be brought down.

When a top so supported is made to revolve round its axis, this axis describes a cone of decreasing amplitude, and a point on it will describe a closing spiral. If the eye is at about the level of the pivot and in a fixed vertical plane through it, the axis will be seen to oscillate on each side of the vertical, exactly as a pendulum, the amplitude of the oscillations decreasing gradually. By decreasing the distance of the centre of gravity from the pivot, or increasing the speed of rotation, the time of a cycle of precession can be increased, so as to minimise the influence of the motion of the vessel. We have thus a short pendulum with the time of oscillation of a very long one. This motion of precession is really made up of a succession of minute loops, similar to the loops described by the earth in its rotation, but, with a sufficient speed of rotation, these loops are too small to be detected by the eye, as it is the point of the pivot, and not the centre of gravity, which describes them.

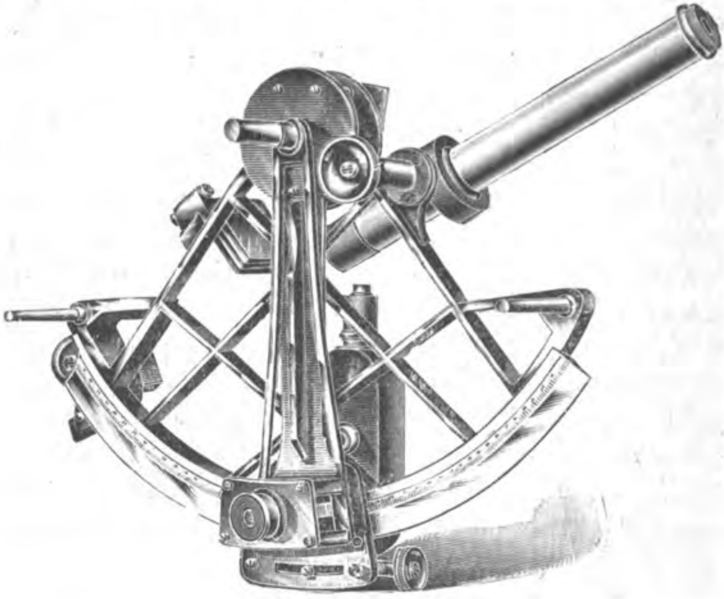
When the axis of the gyroscope is vertical the middle of the dark space of the grating is the trace of the sensible horizon in the field, a constant instrumental error, made up of two parts (*a*) the instrumental error of the sextant itself, and (*b*) the collimation error of the gyroscope being allowed for. The axis, however, is rarely vertical and its spiral motion will give a balancing motion to the line of the grating. When the axis of rotation is in the plane of the sextant, the lines are horizontal and parallel to a spider thread in the telescope, perpendicular to the plane of the sextant, the centre line being below or above the plane of the sensible horizon according to the position of the axis, inclined towards or from the observer. As the gyroscope rotates the lines become slightly inclined to the horizontal, becoming horizontal again after half a cycle and so on. If we only consider the rotating when its lines are horizontal there is then at the succeeding positions of the gyroscope at which this occurs a vertical oscillation of the lines, while the reflected image of the observed body will be comparatively steady and seem therefore to oscillate vertically with regard to the grating. A little spring acted upon by a lever allows a slight pressure to be exerted upon the gyroscope to give it the necessary inclination for this precessing motion.

When the gyroscope has attained its full speed the air tube is closed, and two or three strokes of the pump are given, so as to produce a certain vacuum (about 6 cms. of mercury) shown by the gauge fixed on top of the case. The case is then closed, the pump disconnected, and the instrument is available for a period of time of about half an hour.

The image of the observed celestial body being brought down on the image of the grating, its position with regard to the centre line is observed at each reversal of its motion, when the grating is horizontal. A little practice will enable the observer to estimate the tenths of the intervals between the consecutive lines. The time corresponding to each separate observation of the image is taken by an assistant.

The Quintant.

Instruments capable of measuring up to 144° are termed quintants. After 120° in an ordinary sextant the relation between the index and horizon glass becomes such as to



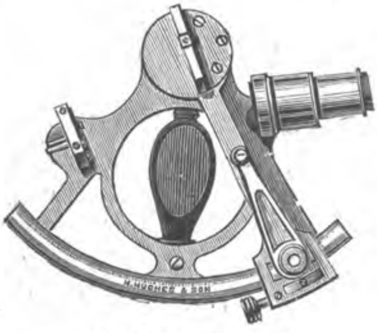
THE QUINTANT.

render observations impracticable. By placing the telescope holder close up under the index mirror and shifting the horizon glass to the extreme end of the arc so as to make the angle formed by the centre line passing through both mirrors and that passing through the horizon glass and the axis of the telescope as acute as possible, the index bar is given a freer range and a larger angle can be measured.

The index and horizon glasses are very successfully fitted on the back of the instrument and the legs in front, that is on the side of the arc, this being a great convenience in setting down or taking up the instrument and also allowing of the magnifying arm being fitted at the same centre as the vernier. This instrument is specially adapted to artificial horizon work and measurements of large angles generally.

Sounding Sextant.

This is a special form of sextant for use in surveying. It chiefly differs from the observing sextant in being generally lighter and handier; in having the arc cut only to minutes and in having a very large telescope. The index and horizon

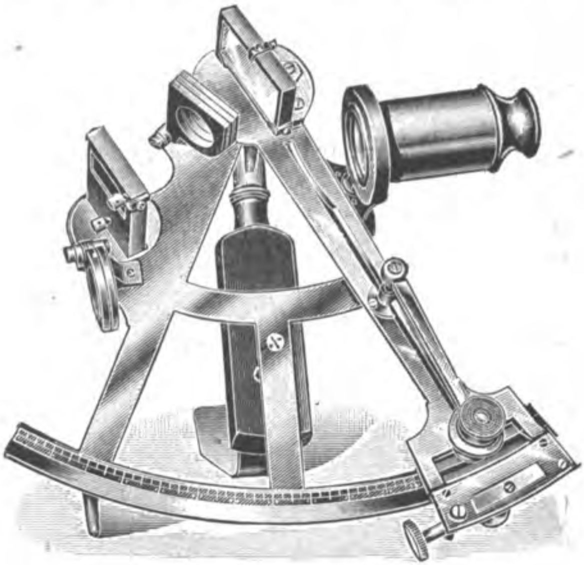


SOUNDING SEXTANT.

glasses are made very large and the shade frames omitted. A shade head and blank head are supplied with the sextant.

The Night Octant.

The Night Octant is of similar construction to the sounding sextant with very large mirrors, the sides omitted and with telescope, but the arc is divided to 10″, as the instrument is intended to be used for taking star observations only.

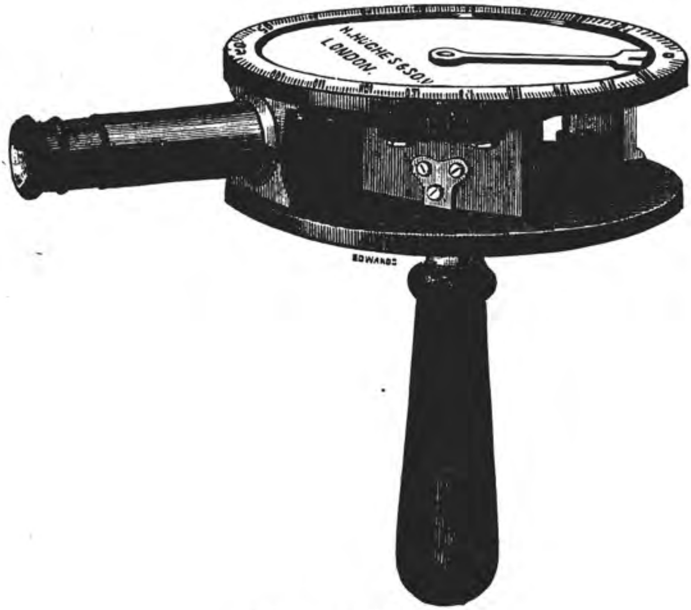


NIGHT OCTANT.

Angle Sextant.

This is a very simple form of instrument designed and solely intended for use in taking shore angles, boat survey work, and keeping station in fleet. It can be set and instantaneously read off to $\frac{1}{8}$ of a degree without the use of tangent screw, clamp vernier or magnifying glass, and can be placed about the deck or elsewhere without fear of damage.

It consists of two circular metal plates $5\frac{1}{4}$ inches in diameter, these are framed together and between them are mounted the index and horizon glasses. The former, $1\frac{3}{4} \times 1\frac{1}{4}$ inches, has fixed to it a pinion wheel which gears into a smaller one on the index arm, these wheels, being made 6 – 1, give a slow steady motion to the index glass when the index arm is moved by hand. The circle is divided into 120°, each of which is subdivided to quarter degrees and can be read to half that at a glance. The telescope has a clear aperture of an inch and slides in out of the way when not in use, or a plain blank sight can be substituted quite satisfactorily as in the pattern adopted by the British Admiralty. The wooden



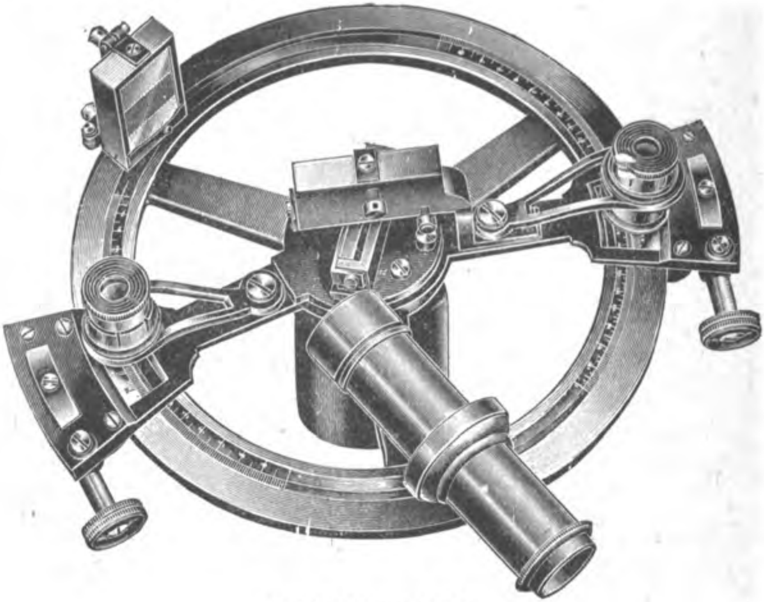
ANGLE SEXTANT.

handle underneath unscrews and the whole affair goes into a sling leather case. Its advantages for the work specified as compared with the sextant are cheapness, less liability to injury, larger field of view and quicker reading.

The Double Sextant.

The Double Sextant was designed for taking three points and other shore bearings.

This instrument consists of a whole circle with a 5 or 6-inch arc, fitted with two indices, two index mirrors with one over the other in the middle of the circle. The horizon glass is placed on the edge of the circle and is silvered top and bottom with a clear cut in the middle to observe the central object. The indices are fitted with clamp and tangent screws and read to 10″. A handle is fitted in the middle of the circle over the centre work. Captain Lecky has described this instrument in his *Wrinkles*.



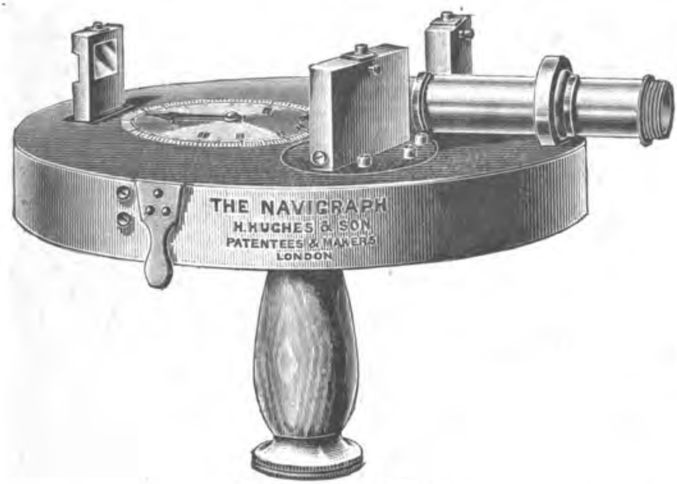
DOUBLE SEXTANT.

The double sextant can be used for harbour survey and river work and has proved a most valuable instrument in all work where speed, accuracy and portability are required.

The Navigraph.

The navigraph is a novel and ingenious combination of the sextant and station pointer, and a development of the Paget angle sextant which we brought out a few years since, and was adopted by the Admiralty for use on all His Majesty's ships.

The improvement and advantage of the navigraph are that an officer can take with it and plot the two angles required for positioning the ship without reading or transferring to a second instrument, and thereby obviating an element of error, besides the saving of time. The instrument consists of a circular metal case or box of 8″ diameter. It is provided with two index mirrors, so that it can be used to measure angles either to the right or left hand; a horizon glass, which can be shifted between two stops, so as to reflect into either of the two index glasses, as may be required. A telescope collar with a blank and a prospect telescope are provided, the two index glasses, being mounted on



THE NAVIGRAPH.

geared wheels, are moved by means of the milled head-screw at the lower part of the handle of the instrument. This gives a slow motion and obviates the need of a tangent screw. A small radial arm inside the case is mounted in gear with the index wheels, and moves over the actual or natural angle observed. A transparent xylonite disc 8 inches diameter is provided, which fits inside the navigraph case; there is a small notch on its edge which engages with a projection on the radial arm and carries the disc round with it when the instrument is being used.

A slot or aperture is cut out of the lower plate of the case and lines drawn on the disc with a lead pencil along the bevelled edge of this are truly radial from its centre and record the actual angles observed. This aperture is wide enough to allow of a distinguishing mark or number being written against each line drawn on the disc if necessary. A circular dial plate and index hand are fitted on the top plate of the instrument to indicate when required the angle being taken.

One side of the transparent disc has a prepared surface on which the pencil lines can be drawn, and when finished with these are readily erased with a piece of india-rubber. The usual adjustments are provided on the mirrors.

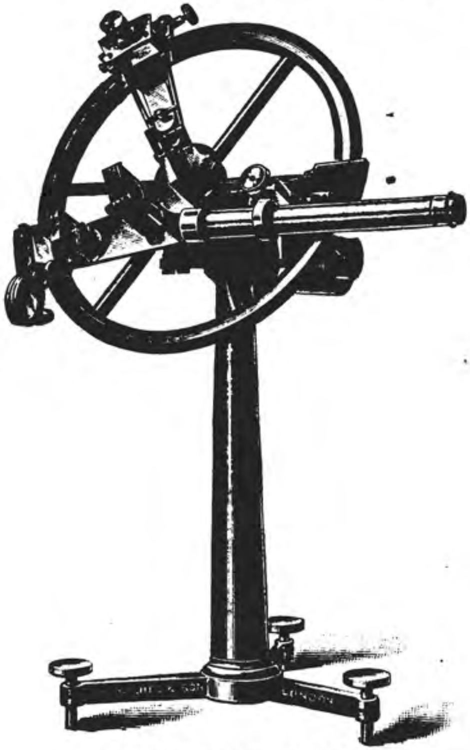
Three radial or station pointer arms, with a centre pricker, are also provided with each instrument, which readily locks on to the disc and extends it range as may be required.

The Goniograph.

This is an instrument designed by Lieutenant Pott, R.N., for the purpose of observing two angles simultaneously and plotting them on the chart direct. It is known as the double reflecting goniograph and is in all respects a double sextant and station pointer combined. The goniograph is held in the hand like an ordinary sextant and as soon as the angles are taken, the handle is unscrewed and the instrument put down on the chart where it can be manipulated exactly as a station pointer would be. It is certainly a precise though somewhat cumbrous instrument.

Reflecting Circles.

The simple reflecting circle differs from the sextant in having the arc extended to a complete circle and the index arm produced beyond the index glass to the other side of the circle and having a vernier at each extremity. By taking the mean of the readings of the two verniers, the errors caused by eccentricity are eliminated. In the repeating reflecting circle the horizon glass, instead of being fixed to the frame of the instrument, is attached to an arm along with the telescope and revolves about the centre of the instrument. This arm carries a vernier at its extremity. The arc is graduated from 0-720 right-handed. By reversing the plane of the instrument two sets of readings can be obtained. In Troughton's reflecting circle three verniers are attached to the arms which carry the index glass and two



REFLECTING CIRCLE.

handles are fitted for convenience. In holding the instrument in a reverse position the prismatic reflecting circle constructed by Piston & Martins, of Berlin, differs from the reflecting circle by the substitution of a glass prism for the horizon glass. The prismatic instruments are more favourable to the production of distinct images at high altitudes, and angles of all magnitudes can be measured.

The Dip Sector.

This is an instrument designed by Troughton for measuring the dip. It consists of a small arc or sector with vernier attached to the arm on which is placed the index glass. The horizon mirror is placed by the side of the index glass exactly at right angles. The telescope is fitted parallel to the index arm at zero and a diagonal mirror or prism is employed to observe the reflected image in the horizon glass.

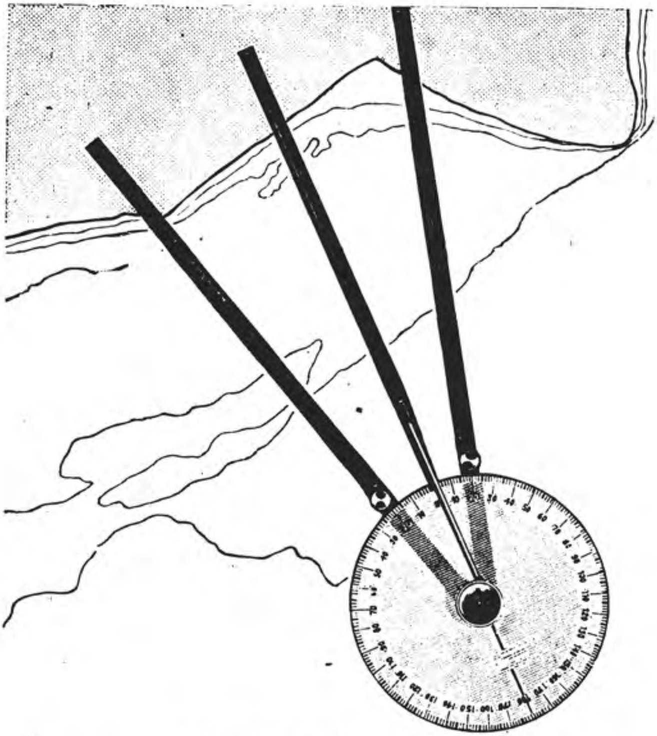
To use the instrument, it is held vertically. Observe the true horizon and by moving the index bring the reflected image into coincidence with the direct object. Note the reading, which differs from 180° by twice the dip.

The Station Pointer.

The Station Pointer is a very useful adjunct of the sextant for coasting or nautical surveying. It consists of three brass arms mounted radially to the centre of a divided circle. The centre arm is fixed at zero, the two outer arms, one left and one right, move round the circle, and can be clamped at any angle from the centre leg. The circle is divided to half degrees, and the divisions are cut on the brass or on a silver arc let into the brass, in which case verniers are supplied to read to minutes, with a tangent screw for setting the arms more exactly. The diameter of the circle is usually 6 inches. The centre is made with a large hole in the middle to allow of the exact position of the centre point being marked with a pricker or pencil. The arms are chamfered, and it is most important that two should meet together and the other arm be as close as possible to zero. Lengthening pieces are supplied and a magnifying glass for reading the vernier.

A full description of the principle and use will be found in the Admiralty Manual on the station pointer. There are a number of very cheap and useful forms of station pointer.

Cust Station Pointer, which consists of a sheet of transparent xylonite on which a graduated arc is engraved. The register angles are drawn on this with pencil with the angle reversed, and the plate, being turned over so as to bring the pencil lines in contact with the paper to obviate parallax, is used as a station pointer.



THE STATION POINTER.

The X Y Station Pointer is used in the examination rooms of the Board of Trade for masters and mates, and consists of three arms mounted with a transparent xylonite disc in place of a metal circle. This is a very simple and handy station pointer.

Mooney's Patent Rhumposcope.—This instrument consists of a station pointer circle with three radial and movable arms, which can be set and clamped to any bearing or angle. This is mounted on a transparent compass plate with the central clamping screw. This plate is divided with three compass circles of degrees and also with parallel lines or ordinates. These latter are for the purpose of positioning or setting the plates exactly true north and south and east or west by the meridian or parallel lines on the chart.

To Use the Instrument:—Have the compass bearings of three known objects which are marked on the chart, set and clamp the three radial arms on the compass ring to these three bearings; then place the instrument on the chart and move it about until the three radial or bevelled edges lie exactly over the three objects or places on the chart. The position of the ship or yacht can then be marked by a fine pencil point through the centre hole of the transparent plate, and, the transparent plate being set true north and south by means of the parallel lines, the difference between the north point of the compass ring and the north point of the degree circle on the transparent plate is the total error of the compass and the course the vessel was on when the above bearings were taken. The fresh course of the vessel to the next point can then be laid and read by unclamping and setting one of the radial arms over this point or place.

Star Globe.

A Star Globe was introduced a few years ago by Lieut. English, R.N., and has been steadily coming into use amongst navigators. The globe is about 5 inches diameter pivoted in a brass ring or meridian at the North and South Poles. The brass meridian is graduated from 0° at the celestial equator to 90° at either pole. The degrees on this meridian corresponding to the latitude must be brought directly under the zenith, or its complement on to the horizon. In north latitude the North Pole must be elevated, and in south latitude the South Pole.

On the equinoctial or celestial equator of the globe the hours of time are marked in Roman figures from the first point of Aries which is o hours to 24 hours, to the eastward right round the

STAR GLOBE.

globe. To find the sidereal time at any desired moment the right ascension of the mean sun (R.A.M.S.) (see right hand column of page II. each month in the *Nautical Almanac*) accelerated for the mean time at Greenwich (M.T.G.) at the time of observation, must be added to the mean time at ship (M.T.S.)

or the right ascension of the apparent sun, must be added to the apparent time at ship (A.T.S.), which is practically the same as that derived from M.T.S.

STAR GLOBE.

Having thus found the sidereal time required, turn the globe round till this time on the equinoctial comes directly under the brass meridian. The instrument is now set for the time and latitude and every star is in its proper position above the horizon and its altitude and true bearing can be measured by the graduated and vertical circles. This globe is made by Messrs. Carey, London.

A larger globe 9 inches diameter, designed by Captain Magnac of the French Navy, and is mounted in a simpler way by Messrs.

Henry Hughes & Son, Ltd., London. It consists of a brass horizon divided in degrees and a brass half meridian also divided in degrees mounted perpendicular to a brass ring revolving inside the horizon circle. The globe is inside these, resting for support on a hollow block at the bottom of the box, allowing it to be freely moved and set to any required position.

When thus set, the meridian ring can be revolved so that its divided edge cuts the star required, whose altitude and azimuth are then read off.

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