PORTABLE INSTRUMENTS FOR MEASURING ANGLES.(*)

QUADRANT WITH SPHERICAL LEVEL FOR FIXING ONE'S POSITION IN A BALLOON.

A quadrant with spherical level, invented by the Ingénieur Hydrographe FAVÉ, was described in an article published in the *Hydrographic Review,* Vol. V, N° 2, Nov. 1928, pp. 171-177.

This quadrant is manufactured by the firm of Albert LEPETIT (late "Maison LORIEUX, HURLIMAN et BERTHELEMY"), 6, rue Victor-Considérant, Paris.

By an oversight this address was not mentioned in the article published.

COUTINHO SEXTANT.

(From documents supplied to the I. H. B. by the Portuguese Delegation at the First Supplementary International Hydrographic Conference).

This sextant with level was invented specially for Aerial Navigation by the Portuguese Admiral Gago COUTINHO, for use on the flights which he made in 1921 from Lisbon to Madeira and in the first transatlantic flight, Lisbon to Rio-de-Janeiro, in which he took part with Captain Sacadura CABRAL.

This sextant and the tables for aerial navigation, prepared in advance, enabled them to pick up the rocks of St. Paul which are only 18 metres above sea level and less than 200 metres long, after a flight of 1700 km. It was also by means of these aids to navigation that these hardy navigators found the Island of Fernando Noronha (5 km. in length) without any difficulty.

The fault common to all instruments using an artificial horizon for observing the altitudes of heavenly bodies, from aircraft, is that they are based on the apparent vertical. This vertical, for the observer in an aeroplane (as in all other movable positions, whether in a ship or in a carriage), is only a dynamic direction, inclined out of the true vertical by the centrifugal force caused by the rotary movements of the aircraft, which are chiefly around a

(*) Under this general heading some descriptions of new instruments, chiefly suitable for measuring angles in aeroplanes, are given. These articles are a continuation of those which appeared in "*Hydrographic Review*", Vol. V, N° 2, November, 1928.

vertical axis, on account of the irregularity of the course which cannot always be straight and frequently follows a curve.

This irregularity is inevitable because of compass errors, the short length of aircraft, irregularity of wind, etc., and also on account of the movements given by the aviator to the lateral planes in order to maintain equilibrium.

The angle of deviation from the vertical, while it is due to rotation around a vertical axis, is given by the well-known common formula :

$$\tan \Delta = \sin a \frac{V^2}{gr}$$

where a represents the angle between the course and the azimuth of the observed heavenly body ; V represents the speed ; r represents the momentary radius of rotation around a vertical axis ; g represents the force of gravity (9.8 m.). The formula shows that the angle of deviation from the vertical is at its maximum while the star is on the beam and, assuming that in practice the instantaneous radii of rotation may be reduced to one sea-mile, the following values for the deviation are obtained :

Craft at a speed of 10 miles per hour..........	5'
» » of 20 » » »	19'
» » of 60 » » »	3°

However accurate the instrument may be it will never succeed in surmounting this source of large errors, as the standard plane of reference for measuring altitudes of heavenly bodies on board aircraft does not absolutely depend on the perfection of the instruments employed, even if observing with an ideal instrument giving absolutely accurate altitudes.

In order to surmount this difficulty, the obvious course is to steer as carefully as possible on a distant object, to steer the aircraft's head on to the star one is observing and, lastly, to take one's observations in groups which, when meaned up, will eliminate this error as far as possible. Under these conditions the observations should be taken when, in the observer's judgment, he has learnt that, in practice, the vertical is least affected by centrifugal force.

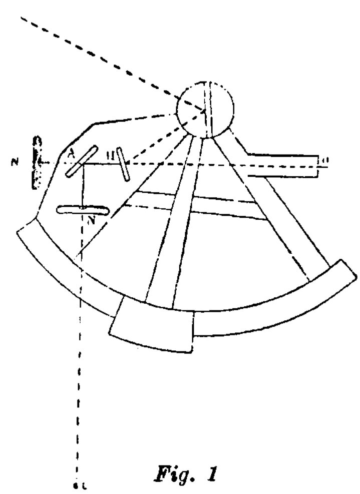


Fig. 1

Before undertaking his preliminary flights over the Tagus and Lisbon, and ever since June 1919, Commander Gago COUTINHO undertook to study and perfect a sextant of the type usually employed on board ship to which, *without affecting its value for observations with the sea horizon,* was fitted a small bubble level (of limited sensitiveness) whose image, reflected by means of a small mirror placed behind the small horizon mirror, appeared behind the unsilvered portion of this latter mirror, which is to the right of the silvered portion, in which the images of the stars to be observed are reflected as usual.

In the diagram shown, *O* is the hole in the sight vane through which one observes the image of the star reflected by the horizon mirror *H*. This mirror is unsilvered on the right-hand side and through it appears, reflected by the auxiliary mirror *A*, the image *N'* of the bubble of the level *N* whose radius of curvature *N C* is made equal to the distance *ON'*. The image of the heavenly body reflected in the small horizon mirror will appear over the image of the bubble reflected in the auxiliary mirror. Now, once adjusted on the centre of the bubble, the line of direction of the sight vane remains thereon, quite independent of any movement of the instrument in the horizontal plane, and as the distance between the eye-piece and the reflected image of the bubble is made equal to the radius of curvature of the level, it follows that the images of the heavenly bodies will also remain over the image of the bubble whatever be the position of the instrument. This being a fundamental principle in the sextant, it was essential that it be retained.

Therefore it is not a case of making three objects coincide, as is the case with the theodolite, (zero, bubble, and the image of the heavenly body) but merely to bring two objects together as with the ordinary sextant (horizon line and star).

A small level, perpendicular to the plane of the arc of the sextant, and visible in the field of the eye piece, enables observations to be taken in an almost vertical plane, as is done on board ship with the ordinary sextant by swinging the reflected image along the horizon, which is not easy seeing that a main rectilinear level has been adopted for the instrument. Without this supplementary arrangement this operation would not be possible.

Numerous experiments, carried out during many hours' flying over observation stations of known geographical positions, have shown that this sextant, under favourable conditions, such as are met with in the steadier atmosphere of the open sea, with a well-trained observer, allows astronomical observations to be taken whose probable error for each single altitude observed is only $\pm$ 10', the probable error for a mean of 7 observations should not be much over $\pm$ 3', which is quite satisfactory for aerial navigation.

Certain observations, made on land to verify the accuracy of the instrument in the absence of errors resulting from the dynamic vertical, have revealed, for each single altitude taken, a probable error of $\pm$ 3'. Captain Jorge DI CASTILHO, in the Atlantic flight which he carried out from Guinea to Fernando Noronha, made advantageous use of this type of sextant during his flight, which lasted no less than 12 hours of darkness.

The firm of C. PLATH, Nautical Instrument makers of Hamburg (Stubbenhuk 25, Hamburg 11), constructed this sextant to Admiral COUTINHO's own specifications and with regard to this, the Engineer Joaquim SALGADA expressed himself as follows in an interesting article on *Rapid Methods of Aerial Navigation* which he wrote at the end of 1928 in "*Sciencia y Industria*", Nos 32 and 33; and which points out the most recent improvements made in this instrument by the constructors. Information appertaining to these fittings can also be found in a special pamphlet issued in May 1928 by the firm of C. PLATH of Hamburg:

The sextant made by PLATH is notable at first glance owing to the fact that it is provided with a left-hand grip, contrary to the arrangement usually provided. This peculiarity was intended to leave the right hand free to write down the readings without putting down the sextant. It is necessary, therefore, to have a certain amount of practice before successfully using this sextant, but it is easy to become accustomed to it.

Another advantage of this arrangement, which has not been considered yet but which is nevertheless of importance, is that the graduations of the scale read from left to right, *i.e.* in the natural direction, which simplifies reading off. With the original model of the sextant invented by Admiral Gago COUTINHO, as well as with two models made in France and in England, it was not possible to take observations using the articifial horizon, the level and the telescope because, in focussing the telescope on the sun, it was impossible to see the level (which was only 30 c/m away) clearly. Consequently, use was made of a sight vane with a small opening with which the sun could be observed perfectly, but it was impossible to observe stars with the exception of those of the first magnitude and these latter only in clear weather.

These various shortcomings were explained to the PLATH firm, which solved the problem by employing a telescope of which the central portion of the object glass is fitted with an auxiliary lens, which regulates the focal distance of the whole for a distance corresponding to that of the level. Thus it is now possible to see the star and the level clearly at the same time and to observe stars of the second and even of the third magnitude quite easily. This was a great improvement to the sextant.

The sextant with spirit level is a two-fold instrument. With it angles can be measured either to the sea horizon or by means of the level itself. The apparatus is of the same shape as an ordinary sextant; the spirit level and the auxiliary mirror are behind the support of the small mirror.

Figure 2 représents the general arrangement of the sextant and of its levels.

A is the central mirror, or large mirror.

B is the small mirror, or horizon mirror.

BL represents the spirit level which is visible to the observer by means of the reflecting mirror *C*. In accordance with the laws of optics, the bubble of the spirit level appears to be in a vertical position with regard to the observer and to move upwards and downwards.

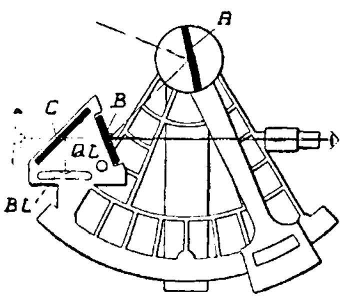


Fig. 2. — Diagram of Admiral Gago Coutinho's Sextant.

QL is the cross level (attached perpendicularly to the plane of the sextant) which indicates to the observer that his sextant is approximately vertical.

The two levels are fixed behind the silvered portion of the small mirror in such a way as to leave the unsilvered portion free for observation beyond the silvered portion.

A transparent slit is left in the silvered portion of the small (or horizon) mirror, see Figure 3.

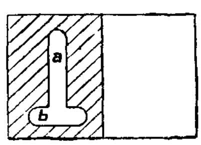


Fig. 3.

Transparent slit in the small or horizon mirror.

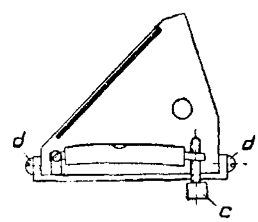


Fig. 4.

Observation level : radius $r = 22$ $^{c}/_{m}$, is adjusted so as to give a coincidence for every position. For balloons a larger radius = 36 $^{c}/_{m}$, is given, which corresponds to 6 $^{m}/_{m}$ for each degree of division.

The course of the bubble of the level *BL* is seen through "*a*", and through "*b*" the cross level is seen. The position of the level *BL* can be adjusted by means of the screw *c*, (Fig. 4), the horizontal position of which can be altered so that, after correct adjustment, the centre of the bubble will be at the same height as the horizon, assuming that the sextant has no index error so that the sextant reading may be zero.

The adjustment of the instrument is carried out at the works by means of a collimator. When it is necessary to readjust the spirit levels, either for fitting a new level or for any other reason, and if the apparatus for this purpose is not available, the adjustments are carried out as follows :

The larger mirror is adjusted in the usual manner for perpendicularity to the graduated arc. Then, having set the instrument to zero, the small mirror is adjusted either by means of the sun or a star, or a very distant land object, by means of the mirror adjusting screws, to make it parallel to the big mirror.

For adjusting the two mirrors, the transparent slit or a regular astronomical telescope is used. When the mirrors have been adjusted for perpendicularity to the plane of the sextant and for parallelism to each other, the adjustment of the spirit level is taken in hand. For the correct position of the level the horizon should cut the centre of the bubble when it is half-way along its line of movement.

The sea horizon, when clear, is the best object to use for adjusting the bubble, but care must be taken that the observer be not much above sea level but as close as possible to the horizontal plane passing through the object on which the adjustment is being made.

It is clear that the bubble error will be cancelled when two stars diametrically opposed are taken, as was done on board the *Argos*.

To replace the horizon spirit level, the screws *d* (Fig. 4) and the base plate with the level holder, which is fixed to its back, are removed. The telescope with its special appliances is fitted so that the optical axis passes through the transparent portion of the mirror. The securing screw must therefore be put in the countersunk portion on the support.

The field of vision of the eye-piece is so wide that a portion of the horizon is visible beyond the spirit level through the unsilvered portion of the horizon mirror (small mirror).

The level moves up and down as the regulating screw is turned and it must be so adjusted that the horizon cuts the centre of the level (Fig. 4).

The optical axis of the telescope should pass through the unsilvered slit in the mirror. The countersunk portion of the support is so fitted as to ensure this coincidence.

The axis of the unsilvered slit should pass, during the observation, either through the section ot the mirror or through the transparent portion of the mirror so that observation can be equally well made through this slit onto the horizon or onto the level.

The holder for the sight-vane attachment (Fig. 5) is fitted with two slots (*f*) and (*e*). The slot (*f*), being the nearest to the attachment, is used when an observation to the bubble is going to be taken and the further slot (*e*) when the sea horizon is used. The adjustable screen which is placed beneath the casing of the level serves to regulate the lighting of the latter.

The level and the lenses of the special telescope are calculated so as to give correct altitudes whatever the position of the level may be, either with the sun or with a star in coincidence with the bubble of the level, therefore there is no necessity to have any special mark at the centre of the level.

The same applies when the vane is employed.

The lenses of the special telescope also are of particular design (and are patented), and give an equally sharp view both of the level and of the star observed.

For securing the telescope in its collar (Fig. 5) the body of the telescope has a tube extension which is clamped to the collar. This tube contains a WOLLASTON prism which will be referred to later.

The fact that the images of the star and the bubble remain together when the sextant is moved depends on the adjustment of the distance between the telescope and the unsilvered slit in the mirror. When the position of the telescope is altered, it must be moved in its collar until the images of the bubble and of the star remain together when the sextant is raised or lowered; the same must be done when placing the transparent slit.

In doing this, care must be taken that the cross wires of the telescope are parallel to the sextant, *i.e.* to the trajectory of the observation (horizon) bubble and, consequently, the eye-piece slit should be normal to the plane of the sextant.

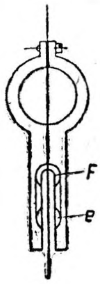


Fig. 5. — Telescope collar.

Fig. 6. — Eye-piece.

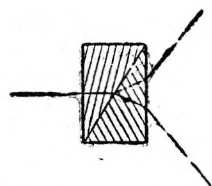


Fig. 7. — Prisms.

To avoid parallax error a special eye-piece is supplied fitted with a special slit for the eye. The sight vane is fitted with a slit at the end of which is a circular orifice (Fig. 6). This arrangement facilitates the finding of a star, but for the actual observation the slit itself should be used to avoid errors due to parallax.

When it is desired to obtain the coincidence of the images of the bubble and of the sun, one image will be superposed over the other and render it invisible by its brightness; this led to the introduction of a WOLLASTON prism which is shown in Figure 7.

It is composed of prisms of different angles of refraction; thus objects seen through them appear doubled. The prism and its frame are fitted in the inner tube of the object lens of the telescope or in the tube of the vane attachment. The correct position with regard to the plane of the sextant is obtained by turning it in a groove and it is secured therein by a screw. The figures below give a greatly magnified impression of the effect caused by the prism. One of the prisms is cut to such a shape that the two sun discs are

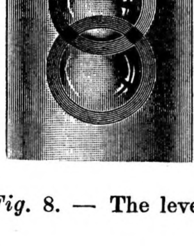


Fig. 8. — The level.

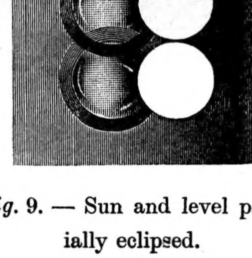


Fig. 9. — Sun and level partially eclipsed.

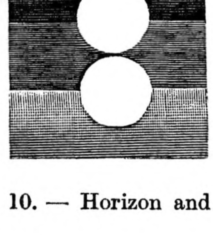


Fig. 10. — Horizon and Sun.

almost touching. For the stars, their images should be equally distant from the centre of the bubble and on each side of it (Fig. 8).

The spirit-level sextant is manufactured with two kinds of arc. For land work it is preferable to read off on a drum, but for aircraft work it is more convenient to have a rapid movement of the arm with vernier reading. The arc is therefore constructed either for drum reading (Fig. 11) or for vernier reading (Fig. 12).

For night observations, the bubble and the vernier are illuminated by electric lamps.

In the handle (Fig. 13) is a detachable cell, a push-button to light the vernier, an arrangement to light the spirit levels and an arrangement for altering the resistance which enables the lighting of the bubble to be adapted to the darkness or otherwise of the night and which breaks the circuit when the lever is put to "obscurity" in order that the cell may not run down.

On long distance flights a spare cell is carried, but the lamps can also be connected up to the main lighting system on board; in this case, however, the cell must be removed from the handle.

A special wire fitted at one end with a plug for the current and at the other end with two insulated terminals serves to connect up the apparatus to the main circuit. As the voltage of the main is generally 12, the above wire is supplied with a supplmentary resistance to lower the pressure to 1.2 volts.

The lamps are of the ordinary commercial type.

The cells are of cylindrical shape like those used for pocket electric torches

The sextant is supplied in a round aluminium case.

Besides the special eye-piece and the sight vane, the firm supplies an astronomical telescope for ordinary observations, keys for adjusting the mirrors and the levels, a spare cell, a spare lamp, etc.

There is a special arrangement for securing the instrument box on board aircraft, making it easy to remove the instrument and return it to its box.

The radius of the arc is 150 m/m.

The small mirror appears longer, perpendicularly to the arc, than those of ordinary sextants ; this is necessary for the provision of a slit for the spirit levels.

The bubble is illuminated from below; by day by means of a small white celluloïd articulated reflector which reflects daylight; by night the light is supplied by a small electric lamp provided with a rheostat which fits into a fixed carrier behind the extended portion of the arc which carries the levels.

The hinged arm of the reading-glass carrier is also fitted with a small electric lamp to light up the arc for reading off at night.

In the model fitted with a micrometer the reading glass need not be used for reading off.

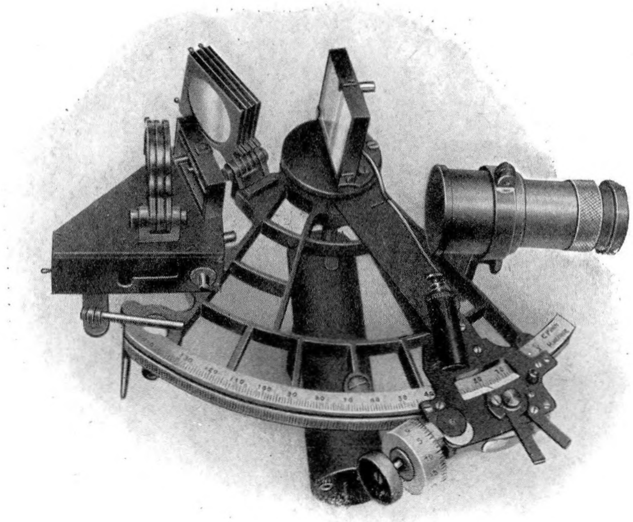


Fig. 11.
The Admiral Gago Coutinho-Plath sextant for direct observation fitted with micrometer screw reading.

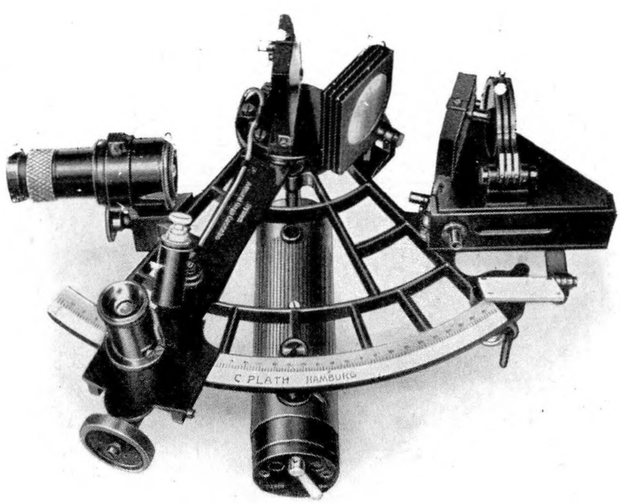


Figure 12.
The Admiral Cago Coutinho-Plath sextant for left-handed observation with vernier reading.

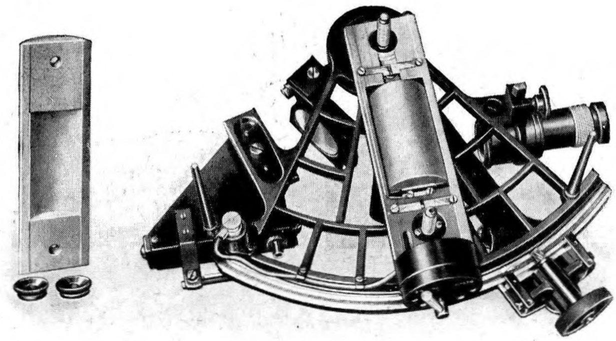


Fig. 13.

The Admiral Gago COUTINHO-PLATH sextant with the handle opened.

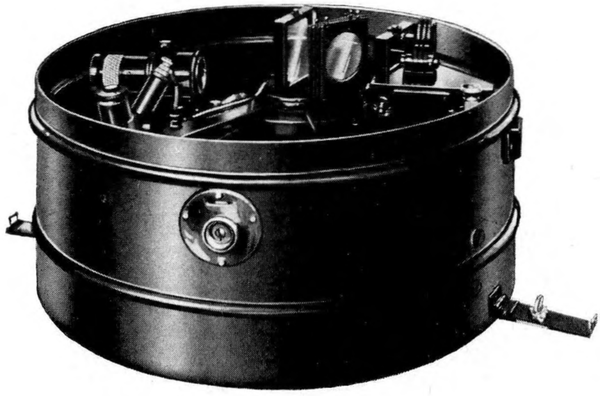


Fig. 14.

Sextant case containing sextant and showing arrangement for securing on board.

O.P.L. BUBBLE OCTANT.

The O.P.L. Octant with bubble level is manufactured by the Société d'Optique et Précision de Levallois, 86, rue Chaptal, Levallois-Perret, France.

The principle of this instrument is shown in detail in Fig. 1.; the various parts are fixed to a rigid frame which constitutes the body of the instrument.

The spherical level *N*, of radius *R*, is supplied with a system of illumination which illuminates the bubble *B* and which causes it to have the appearance of a bright spot.

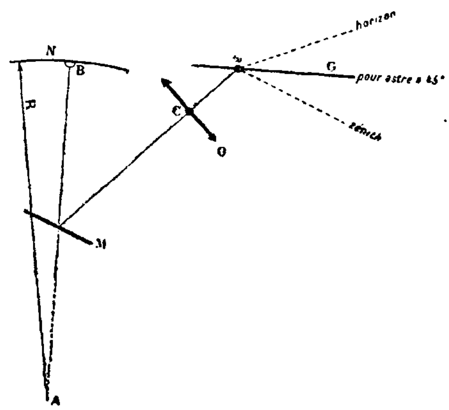


Fig. 1.

An object glass *O* of optical centre *C* and of focal length *R* receives the light rays which emanate from the bubble *B* of the spherical level, which is apparently luminous, and which are reflected by the mirror *M*. The collimated image of this bubble is reflected by a transparent mirror *G*, which can be revolved around the axis ω by the observer.

If a slight angular movement be given to the whole apparatus in the plane of the figure, it is clear that as the bubble moves along the surface of the spherical level, the line *BA* will be always vertical; if the mirror *M* turns through an angle α the ray of light reflected by it will turn through an angle of 2α and then will reach the mirror *G* which has turned through an angle $-\alpha$. The ray reflected by this mirror will be deviated through an angle -2α thus returning to the original direction.

Thus, so long as the bubble remains in the working zone of the level, the movements of the frame in the plane of the figure, which must be assumed to be vertical, have no influence on the direction indicated by the bubble.

The error, due to the plane of the Octant not being absolutely vertical, is, as in ordinary sextants, proportional to 1 — cosine of the angle of inclination; in practice it is much smaller than the error in reading off; if the inclination be about 2° or 3°, which it is easy not to exceed, the resultant error, which is *O* at the zenith, is less than a thousandth of the altitude at 45° altitude.

With this instrument it is possible, by turning the mirror *G* round the axis ω through an angle of 45° (or one-eight of a circle) to observe any heavenly body between the horizon and the zenith, hence the name, "Octant à bulle" which is given to this instrument.

DESCRIPTION OF THE APPARATUS.

It is assumed that the bubble acts as a source of light. Figures 2, 3, and 4, show the method employed by day or by night, to make the bubble appear as a luminous circle.

Lighting by Night. — The filament of a small electric lamp *L* (Fig. 2) is put in the centre of a spherical vacuum worked into a portion of the

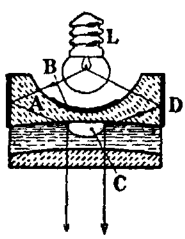


Fig. 2.

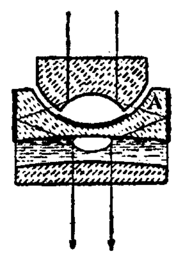


Fig. 3.

glass *A* ; a screen *B* protects the bubble *C* from the direct rays of the light. The rays of light given out by this lamp are reflected at *D* by the silvered partitions of the piece of glass, strike the bubble as parallel rays, and thus cause a very brilliant ring.

Lighting by day. — It is advantageous to make use of the sunlight by day. The lamp and its socket are replaced by a cylindrical portion of glass *A*, into which a spherical hollow *S* is cut (Fig. 3). The sun's rays are reflected by the sphere *S*, then, as before, on the silvered cylindrical partition *D*. The result of this arrangement is to create an apparent sun in the neighbourhood of the centre of the sphere *S*. The lighting of the bubble is satisfactory so long as the sun is at least 15° or 20° above the horizon. In order to maintain a good light after it falls below this altitude, there is stuck onto the upper face of the piece *A* a small right-angled reflecting prism *PP* (Fig. 4) which acts from its two ends but which, to simplify construction, is made in one piece and fixed on a diameter of the piece *A*. The axis of the prism is normal to the frame of the octant and is so arranged as to face the sun

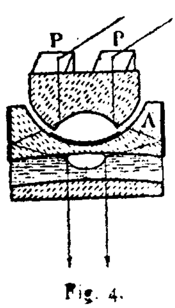


Fig. 4.

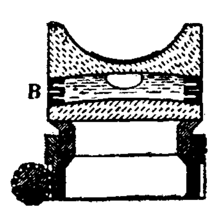


Fig. 5.

always while it is being observed. It is fixed permanently to the piece *A* and does not get in the way when the sun is high above the horizon.

Diameter of the bubble. — Experience has shown that, even in air-tight levels, the diameter of the bubble varies with alterations of temperature, especially when a liquid rich in alcohol or ether is employed. The makers have therefore devised a level with a deeply grooved container *B* (Figure 5), which being thus rendered slightly elastic, is capable of expansion and contraction. A tangent screw *V*, worked from outside the casing of the octant gives a rotary movement to a drum *C*, which screws up and down in the frame, thus compressing the grooved container or allowing it to expand. By means of the drum, the lower lens of the level *L* (Fig. 5) can be lowered or raised by some fractions of a millimetre and the bubble thus given the desired size. For observing the sun or the moon, the bubble should have a slightly greater diameter than that for a star, say about 35 or 40 m/m. It may be smaller for observing a star, but should not fall below certain limits so as not to lose its brightness. The fact of being able to regulate the diameter of the bubble has much increased the accuracy of observations.

The light rays reflected from the bubble fall on the mirror *M* (Fig. 6), They are directed by the object glass *O* onto the transparent mirror *G*. This is shown in the figure in a central position, corresponding to that for observing a star of 45° altitude.

The positions G_1 and G_2 of the mirror correspond to the limits of observation, the horizon and the zenith.

Shade glasses can be inserted at *V* to tone down the brightness of the observed heavenly body, or at *V'* to lessen the brightness of the bubble during night observations; the brightness of the bubble is also controlled by a rheostat which acts on the lamp.

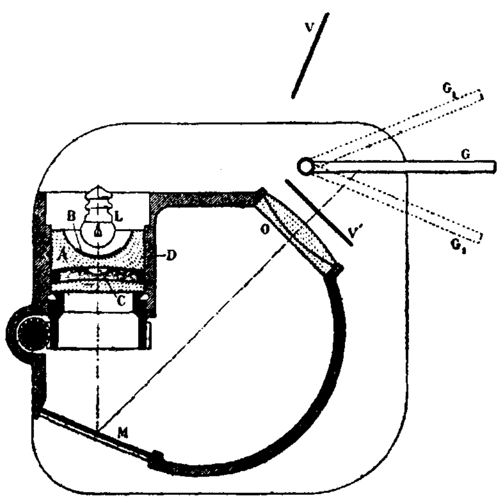


Fig. 6.

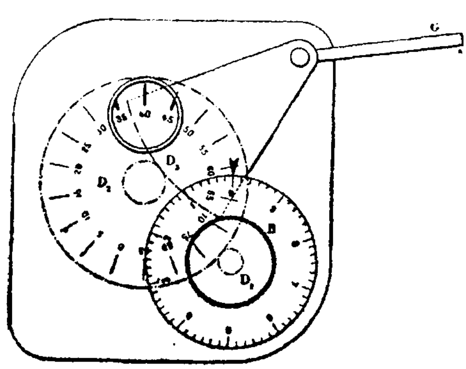


Fig. 7.

It is the position of the mirror *G* which enables the altitude of the required body to be measured The movement of the mirror (Fig. 7) is controlled by the milled head *B* which is fitted with a two to one reduction gear consisting of the toothed wheels D_1 and D_2 and the toothed sector D_3.

The toothed wheel D_2 carries a disc, divided into divisions of 5^0 each, the figures of which are read off through a window.

In octants designed for aerial navigation, the milled head *B* is divided into ten divisions of one degree which are subdivided into six divisions, each of which thus corresponds to 10' of arc. It is possible to estimate to one-fifth of these divisions which gives an accuracy of about 2' of arc; in the octants for use at sea the division may be finer.

On the opposite side of the octant is a projection which serves as a handle and which contains the battery for the lamp for taking night observations:

The circuit is closed by pressing with one of the right hand fingers on an oscillating rod.

The principal parts of this octant are of aluminium, its total weight is under 1000 grammes. The frame measures about 11 c/m each side.

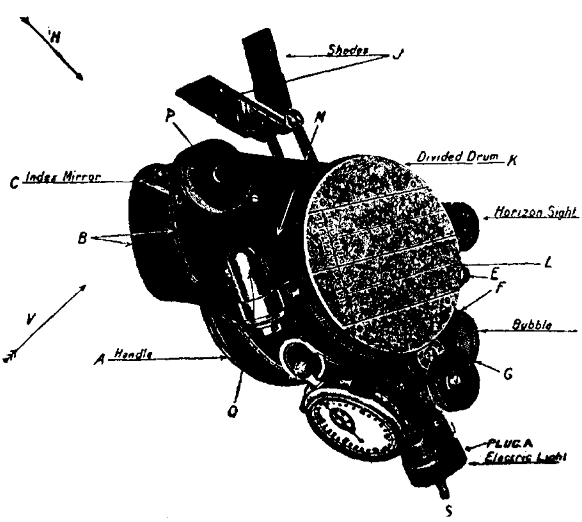
These dimensions are very convenient for observing.

THE R.A.E. BUBBLE SEXTANT.

This instrument is made by Henry HUGHES & SON, LTD. 59. Fenchurch Street, London, E.C. 3, and the information here given is extracted from the booklet on on Instruments for Aerial Navigation by A. J. HUGHES, O.B.E., recently published.

The purpose of the Bubble Sextant is to enable the altitude of a heavenly body to be measured when the horizon cannot be seen.

To deal with this situation, resort may be had to some gravity control device to give the vertical, such as a short pendulum or bubble; the difficulty that arises here is that any such instrument is necessarily affected by the acceleration of the machine, whether longitudinal or athwartships. Neverthe-



BOOTH BUBBLE SEXTANT

Fig. 1.

less, by using the mean of a number of observations with such a device, it is possible to reduce the resulting error within manageable limits.

In the R.A.E. Bubble Sextant, the vertical is given by the position of a bubble in a spherical level which is capable of being illuminated for night use. The principle on which it works is illustrated.

The eye must take up either of the two positions shown. The lower position is the best for star sights, and the upper position for observations of the sun, although theoretically there is no reason why either position should not be used for any or all observations.

The lens is chosen to have a focal length equal to its optical distance from the bubble, and the curvature of the upper surface of the latter is also equal to this distance, so that the bubble is always in focus and will appear to move with the sun or star if the instrument should rock in the hand, and this greatly facilitates observations.

When using this instrument on an aeroplane, it is found that the greatest accuracy is attained when observing forward or aft.

Extraordinarily good results have been obtained with this type of sextant, both in aerial and marine work.

METHOD OF HOLDING INSTRUMENT.

In all cases the instrument is held in the left hand by grasping the wooden handle or drum *A* and the two side plates *BB* are held approximately vertical. The plain glass mirror *C* should be on the side nearer the observer, and the short tube *D* should be on the side away from the observer and pointing in an approximately horizontal direction.

(1) *FOR TAKING SOLAR OBSERVATIONS WITHOUT HORIZON SIGHTS.*

The lamp *E* should be pushed home (except in some cases where the illumination of the bubble is then insufficient, when it may be pulled out to its furthest limit).

The eye should look down into the instrument in the direction of the arrow *H* through the plain glass *C* and a bubble will be seen if one exists; if not, a bubble should be formed, and its size regulated by using two milled screws *F* and *G*.

Observe the sun by reflection at the surface of the plain glass *C*, having suitably disposed the adjustable sun-shades *J* so that the rays from the sun pass through one or both of them before being reflected; the appearance of the sun will be that of a bright green circle.

By rotation of the graduated drum *K* by the right hand the sun's image can be brought central with the bubble, whose size may be varied by use of the adjusting screw *G*. (It is better to have a large bubble than a small one, as in the latter case it may disappear altogether during an observation).

The bubble will appear to oscillate both up and down and from side to side; when setting the drum *K* the bubble should be kept as near the centre of its field as possible (though the instrument is so designed that a correct reading will be obtained even when the coincident images of sun and bubble are some way from the centre).

It is very important to see that the bubble is free, *i.e.* not touching the side of its cell, when an observation is made.

When what is considered to be a satisfactory observation has been made, the time should be noted within a few seconds and entered on the white disc *L* provided on the instrument, and the reading of the instrument at the mark *M* gives the altitude, which should be entered in the proper column on the white disc *L*. The engraved numbers are degrees, and the small divisions 10' of arc; intermediate readings must be estimated. About six such readings should be taken as quickly in succession as possible, and the mean of the times and mean of the altitudes should be taken for each such set.

(2) *SOLAR OBSERVATIONS WITH HORIZON SIGHT.*

If a fairly reliable horizon of haze or cloud, or a spurious horizon exists, the horizon sight may be used.

Previously to taking a solar altitude, the height or depression of the "horizon" is taken from the mean of some half a dozen readings in just the same way as described above for obtaining the sun's altitude, *i.e.* the "horizon" line is made by reflection at the mirror *C* to appear to bisect the bubble and the reading taken and noted. After taking the mean of six readings, the bubble may be dispensed with for a time.

The lamp *E* is pulled out to its fullest extent, when a view of part of the horizon will be seen in the field of view, and holding the instrument much as described before, it is possible very accurately, and in one observation only, to bring the "horizon" into coincidence with the sun's centre by rotation of the drum *K*. If the previous horizon computation was positive (+), the true sun's altitude is obtained by adding it to the latter reading; if negative (—), by subtracting.

In taking the altitude from the horizon, the latter should be kept as nearly as possible centrally across the field, and the sun's disc made to appear as nearly as possible in the centre of the field.

(3) *STELLAR OBSERVATIONS AT NIGHT.*

In this case, the leads *S* at the bottom of the instrument should be connected to the terminals of a two-volt battery; the sun-shades *J* must be set so as not to interfere with direct sight through the plain glass mirror *C*; the lamp *E* must be pushed in as far as it will go.

A bubble is formed in the manner already described, and will be seen by illumination of the lamp. Inside the wooden drum *A* by which the instrument is held will be found a metal milled ring, by rotation of which the illumination can be regulated within wide limits — in general, the light required will be in the vicinity of the smallest amount possible.

Hold the instrument above the head so that the eye can look directly through the plain mirror *C* in the direction of the arrow *V* at the star whose altitude is required; by varying the position of the instrument and suitably rotating the graduated drum *K*, the field of the bubble can be seen and brought gradually up to the star. The illumination must now be adjusted by turning the milled disc inside the wooden handle *A*, so that the star and bubble can be comfortably seen at the same time. The drum *K* should then be rotated so as to secure coincidence of the star with the centre of the bubble. (*N.B.* — This is not the centre of the white patch lying in the bubble image).

The reading is taken in the same way as for solar observations and entered up, together with the time and mean of six or more observations taken.

For reading the altitude on the drum *K*, a small lamp *Q* is provided with a switch *P*. The turning of the latter so that the arrow points to *ON* will cause the illumination, when necessary, of the figures to be read on the drum. The same lamp switched outwards will illuminate the tablets for recording purposes.

NOTES. — (1) The instrument should be kept in its box when not in use, and when out of the box should not be subjectect to any jarring or impacts. Above all, the plain mirror *C* should never be touched.

(2) The graduations on the drum (from 3° to 80°) are in two revolutions. In the first revolution the figures are on the left-hand side and in the second revolution on the right hand. It will be obvious which figure is correct as a casual inspection will show whether the required altitude is, say, 30° or 70°.

(3) The leads *S* are attached to a plug *R* which may be removed during the daylight observations, if necessary.

(4) Experience alone will teach the motion of the hand necessary to bring the bubble and sun or star image into the central part of the field of view, and a little practice on the ground will generally assist in reducing the time taken over the observations; after repeated use the action will become almost automatic.

TO FORM A BUBBLE.

The bubble is controlled by the two milled screws *F* and *G* and they should be unscrewed until quite free, and the larger one just off that part of the bubble gear on which it is fitted. Now screw on the larger milled screw about 1 1/2 to 2 complete turns, and then screw up the smaller milled screw until a slight resistance is felt.

Holding the instrument in the left hand in the observing position, screw up the smaller milled screw a little more, then roll the instrument forward until the short tube *B* points downwards and returns to the observing position.

This sequence of operations should be repeated until, after returning to the observing position, a bubble is seen in the field. In most cases, when screwing up the smaller milled screw, the last little bit before obtaining the bubble, a click will be heard, but not always.

The bubble, when formed, is nearly always too large for observing purposes and will require to be regulated. It can always be made larger by screwing up the smaller milled screw and can usually be made small enough by unscrewing the same.

Sometimes the latter method of regulation is insufficient, and in that case, after unscrewing the smaller milled screw until it is free, the observer should screw up the larger milled screw until the bubble becomes small enough; the smaller milled screw should then be screwed up until it just begins to affect the bubble and the final adjustment made by the smaller milled screw.

THEORY OF THE BUBBLE.

The bubble chamber and expansion box are filled with liquid pentane and sealed. The large milled screw is screwed a little way on to the outside of the expansion box and clears the threaded tube upon which the small milled screw works.

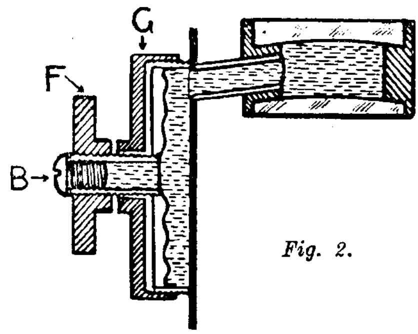


Fig. 2.

The action of screwing up the smaller milled screw is first to cause it to seat against the larger milled screw (when the first slight resistance is felt), and then to pull out the diaphragm of the expansion box.

The liquid pentane has to fill the extra space produced by pulling on the diaphragm, and does so by a small part of the liquid evaporating into gas; in this way the bubble is formed.

On unscrewing the smaller milled screw, the mechanical pull on the diaphragm is released, and the liquid and the gas bubble are compressed by the diaphragm bending to return to its original position; under these circumstances, the gas of the bubble is condensed to liquid and the bubble disappears quickly or slowly, according to the exact conditions of pressure, temperature, springiness of the diaphragm, etc.

SPECIAL CAUTION.

When the instrument is not actually being used in taking observations, the bubble must be released, and the observer must see that both milled screws are free.

R.A.E. SEXTANT, Mk. VI.

In this instrument the bubble and unsilvered index mirror, which are such prominent features of the Mark V Sextant, are retained while adapting them for use on a divided arc.

The bubble gear unit is a complete independant unit which can be swung out of position when not required for use. Spare bubble units can be supplied and readily interchanged. The unit consists of the same bubble chamber and expansion box as before, fitted to an aluminium body carrying two rustless steel mirrors and collimating lens so arranged that, whenever the bubble is free to move about below its curved retaining glass, the mirrors and lens throw a beam exactly horizontal as if coming from the horizon.

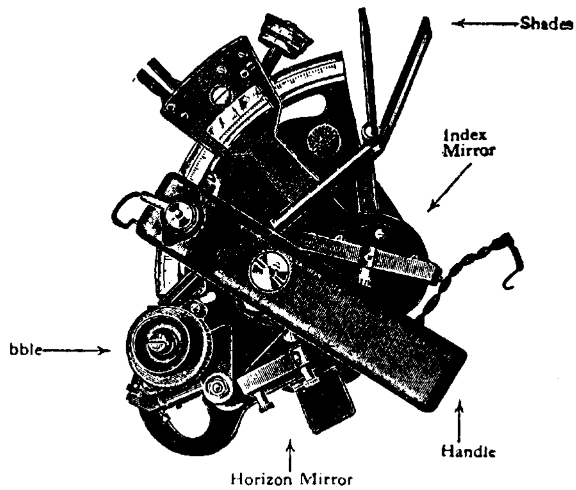


Fig. 3.

A fixed fully silvered horizon mirror is used and the unsilvered index glass is mounted on the index arm as usual, and three shades mounted on doubly pivotted arm are available.

The bubble is illuminated at night by a lamp, the brightness of which is controlled by a rheostat and the arc can be illuminated by another lamp controlled by a switch.

The instrument is held very differently from the marine sextant as the index arm is pointing upwards and forwards instead of downwards.

The instrument is divided to read to single minutes and may be used on a the natural horizon, or with the bubble horizon at will, by merely swinging the bubble gear in and out of position.

The interchangeable bubble gear is removed in a few minutes by unscrewing the nut indicated in the figure and removing it together with the washer immediately below it. On turning the sextant over so that the underside of the limb is uppermost a spiral spring connecting a pin on the bubble gear to another pin on the limb will be seen; this spring should be unhooked and removed and the bubble gear may now be gently pulled off its bearing pin which is the one from which the nut and washer were removed. On remounting carry out the operations in reverse order.

The adjustments and connections of the instrument are in no way affected by the replacement of a complete set of bubble gear as described above, provided that the new set of gear has been properly adjusted by the makers before fitting.

AMICI-MAGNAGHI REFLECTING CIRCLE.

(Royal Italian Navy Regulation Model.)

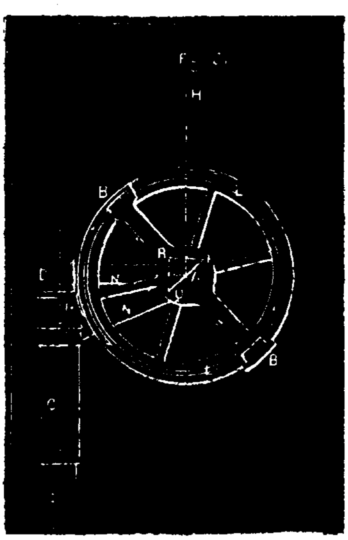
Ever since the invention of reflecting instruments, attempts have been made to replace mirrors by prisms; thus in England, Caleb Smith constructed, after Hadley's specifications, octants fitted with prisms instead of mirrors.

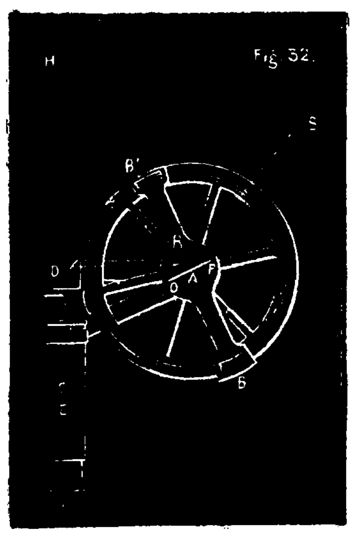
But the prisms fitted in similar places to the mirrors did not much assist towards observing. The difficulty of accurate manufacture and, in those days, of obtaining perfectly homogeneous lumps of glass, was probably the cause of prisms having been abandoned in favour of mirrors; it was only later that attempts were made to take advantage of the greater clarity of images reflected in prisms and of the greater angles which they enable the observer to take.

After the specifications of Professor Unéus (Die Geometrischen Instrumente), Steinheil constructed a prismatic circle (Prismenkreis) in 1830. But earlier, in Italy, J. B. Amici had invented an instrument with prismatic reflectors, very similar to the one which was later put on the market by Steinheil. His first attempts date back to the year 1820. Amici was compelled, in the course of time, to modify the primitive apparatus adopted by him and by Steinheil to make the instrument more handy (*).

PRINCIPLE OF AMICI'S CIRCLE.

The telescope is secured on a metal mounting to which is fixed a small prism whose edges are at right angles to the plane of the mounting, and whose reflecting hypotenuse is at an angle of 45° to the line of collimation of the telescope.





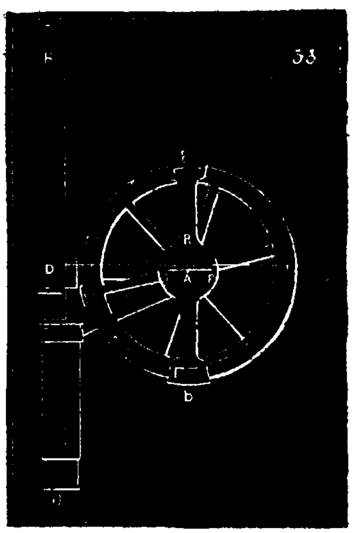
(*) This historical information was taken from the treatise "*Gli Strumenti a riflessione per mesurare angoli*" published in 1875 by Commander G. B. Magnaghi, Italian Hydrographer.

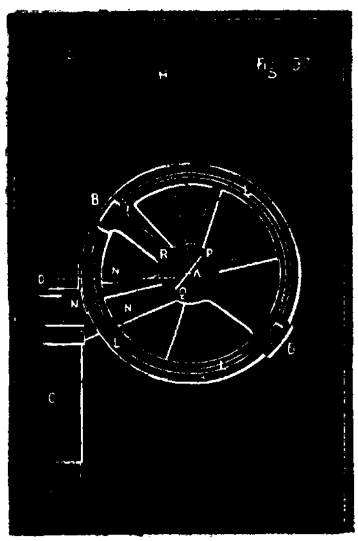
The altitude of the prism is adjusted so as to allow the direct light rays to pass through to the upper half of the object glass of the telescope (Fig. 31).

The mounting also carries the divided circle, excentric with regard to the telescope, at the centre of which the moving arm is pivoted. At the centre of the moving arm is a larger prism whose hypotenuse passes through the centre of the circle and whose two faces are perpendicular to the plane of the circle. The ends of the moving arm terminate at two points diametrically opposite a graduated arc of the circle and thus give two readings, which enable the position of the prism to be determined with excentrical error eliminated. The reading (*C*) which is produced until the hypotenuses of the prisms are parallel, like the sextant, makes the direct and reflected images of the same distant object (*H*) coincide in the field of the telescope.

To measure the angle between two objects, one must look through the telescope direct at, for example, the left-hand object (*H*) moving the moving arm in the direction of the arrow until the image of the right-hand object (*S*), reflected by means of the turning prism and the fixed prism, appears in conjunction with the left-hand object in the field of the telescope. Supposing *S* to be the mean of the readings obtained at each end of the moving arm after doing this, then the required angle $\delta = S - C$ (Fig. 32).

As in the sextant, the movable prism turns through an angle equal to half the angle measured.





In the position shown in Fig. 33, in which the hypotenuses of the prisms form an angle of 45° with each other, the angle between the objects whose images coincide in the field of the telescope is a right angle. Beyond this, one should not turn the moving arm in the same direction in order to measure angles over 90°, but the moving arm must be moved back in such manner as to get the reflection from the other face of the prism not yet made use of, (Fig. 10). Then continuing to move the arm in the direction of the arrow one can measure angles up to 180° and even above (196°). The annexed figures show diagrammatically the movement of the central ray.

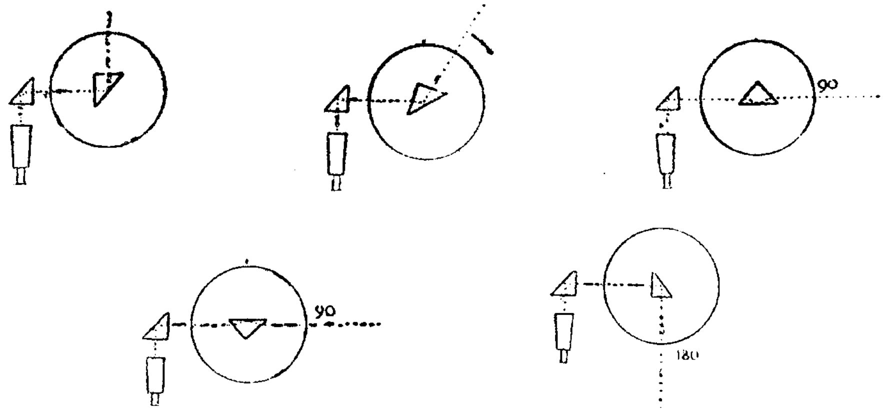


Fig. 10.

While the angle is about 90° the field of the instrument is sufficiently large to enable one to observe in the two positions of the moving arm.

With this instrument one can also observe the reflected image of the left-hand object, but in this case the field of measurement is fairly limited, about 16°.

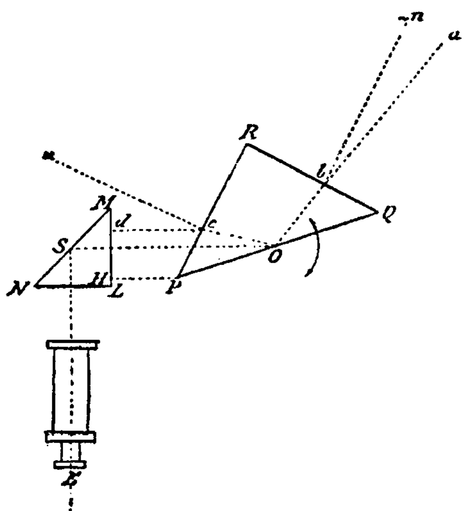
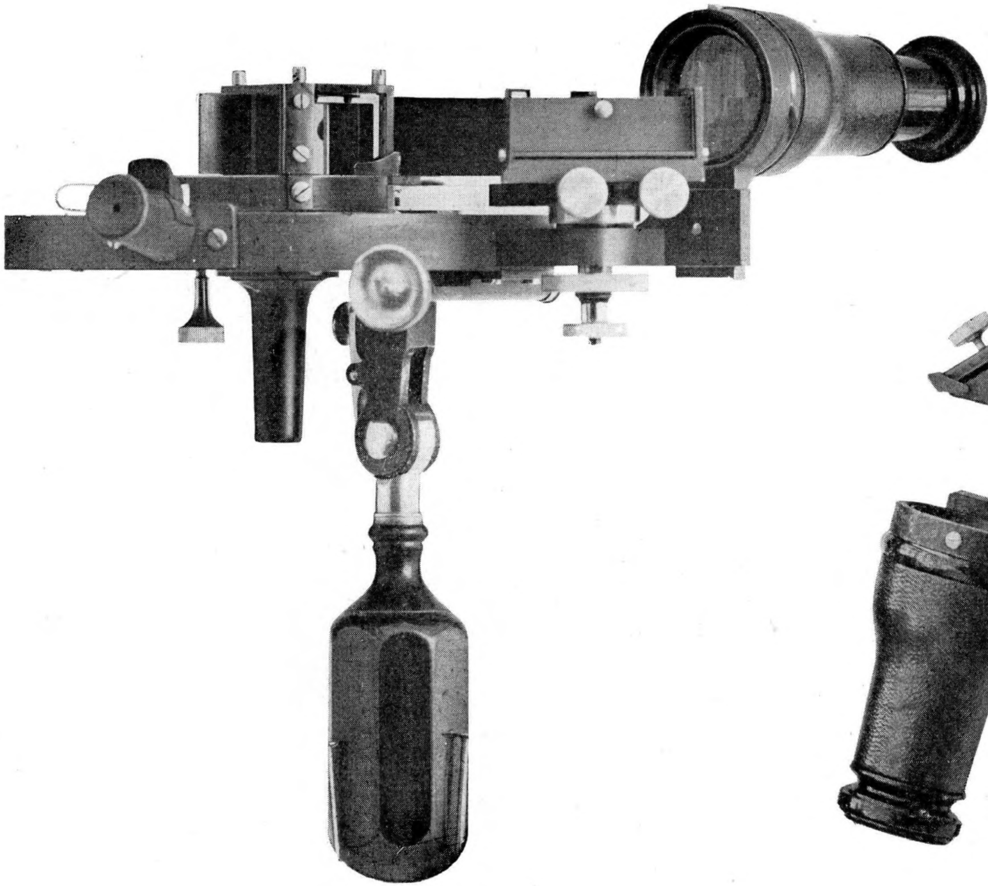
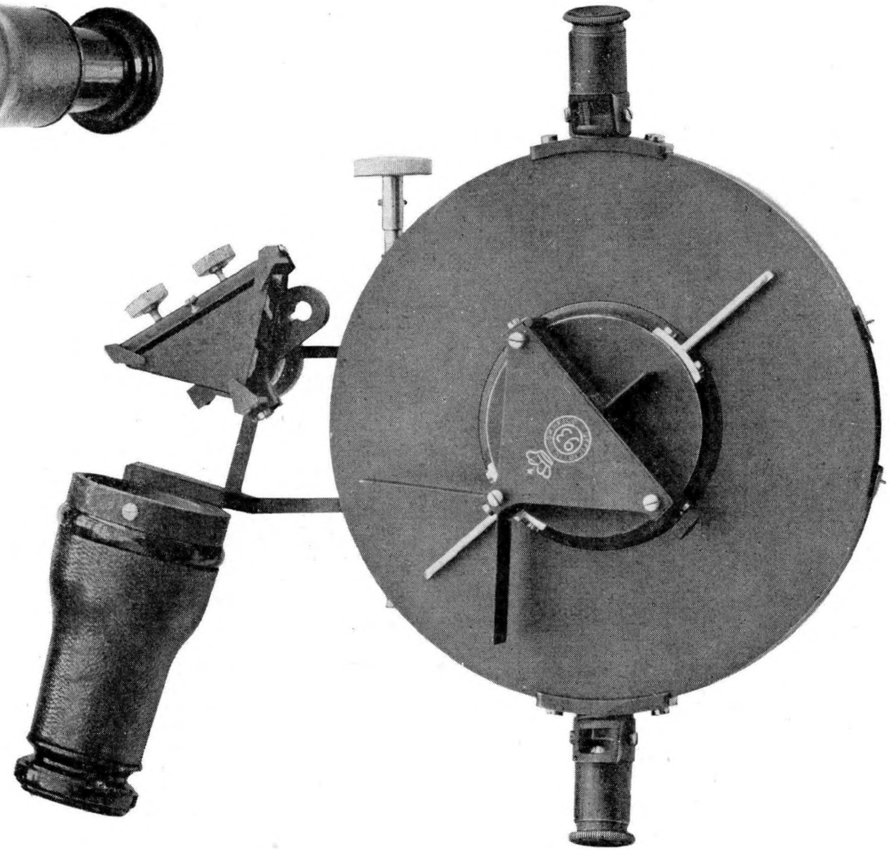


Fig. 11

With regard to the clearness of the reflected image, if one considers the face *ML* of original impact of the small fixed prism, it is evident that for angles of 0° and 180° that face receives the beam of light reflected by the central prism on the whole of its surface. On the other hand, in the case of angles in the neighbourhood of 90°, the beam reflected by the central prism only meets one of the halves *MI* or *IL* of the face of original impact of the fixed prism. In effect, the clearness of the reflected image will be at its maximum for angles of 0° and 180° and will get less until it reaches its minimum in the neighbourhood of 90°.

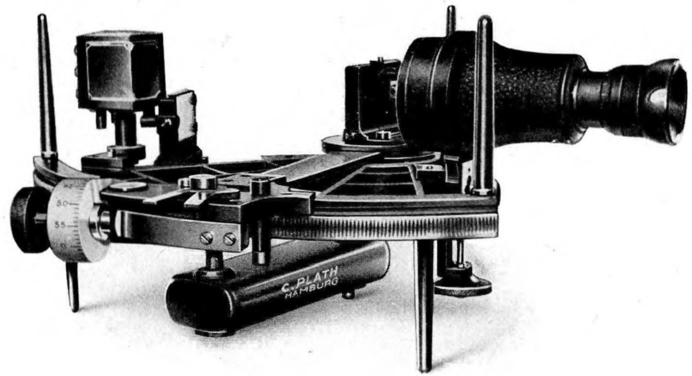
The divided circle can be moved with regard to the mounting in such a way that the Amici circle has all the advantages of a repeating circle like





Amici-Magnaghi
Reflecting Circle.

Cercle à réflexion.
Amici-Magnaghi.



Plath Sextant

with pentagonal prism.

Sextant Plath

à prisme pentagonal.

Borda's repeating circle and, in between 0° and 16° and between 164° and 180°, even enables us, as we have seen, to repeat the observations from left to right.

The theory concerning the errors of the AMICI circle is explained in detail in the previously mentioned work of Commander MAGNAGHI, and particularly those which arise from slight inequalities in the acute angles of the prisms. These correspond in a sense, to the error in a sextant resulting from the two mirrors not being parallel to each other, but the resultant errors are less. For instance, if the difference between the acute angles of a prism is 20", the greatest error due to this inequality will reach 9.4". But, nowadays, prisms can easily be made whose error is in every case negligible.

According to Commander MAGNAGHI'S specifications, the Istituto Idrografico of the Royal Italian Navy constructed an instrument with prismatic reflectors which, while still retaining the respective positions of the prisms and telescope of AMICI'S circle, was a considerable improvement on it as regards accuracy and handiness.

The annexed photographs and plans represent the most recent AMICI-MAGNAGHI circle made to the order of the Italian Surveying Service by the San Giorgio S. A., Sestri Ponente and the Filotecnica, Milano. This instrument was on view at Monaco during the International Hydrographic Conference of 1929.

The graduated circle is completely covered and protected by a metal case.

The divided arc is much reduced in size having a radius of only 6 c/m.

The graduation marks are not cut in the plane of the circle as in most sextants, but along its edge, in such a way that, regarding the circle as a cylinder, the divisions are cut in its side, being always normal to the plane of rotation.

The two verniers, diametrically opposite, are cut on a similar cylinder, placed beneath this graduation and readings are very easily taken by means of the two microscopes perpendicular to the cylindrical surface of the graduated circle. They are fitted with a small illuminating prism. The markings of the vernier are arranged to read off to 20" so that the probable error in reading off will be $\frac{10''}{\sqrt{2}}$ that is, about 7".

There is no special adjustment for the large prism once it has been cut to the proper proportions. It is carried on a drum at the centre of the moving arm. The graduated circle itself is grooved and is connected to the central pivot by means of 5 metal radii.

The mounting of the central prism is fitted with two small arms which give the prism its fast rotary motion. The friction screw, which is on the lower part, clamps the verniers to the circle, and the horizontal tangent screw which is at the side of the small prism gives them a slight movement.

The mounting of the prism carries on a continuation of its faces two small shades to tone down the light rays which are not entirely reflected by the hypotenuse of the large prism.

The small prism is mounted in the frame-work in a rather special manner, and can be moved in two ways: one around an axis parallel to the plane of the instrument to adjust its angles as regards perpendicularity to the plane of the circle, and the other around an axis perpendicular to the plane of the circle to reduce as far as possible the error of the instrument. On the rear face of the small prism are the two opposite screws which act on a lever carrying the prism and which cause this second movement.

The large milled wheel and the brake underneath the mounting of the small prism adjust, by means of an excentric, the angle of inclination of the small prism.

The edge of the arc is divided into 720 equal divisions. In the surveying circles which are exclusively used for measuring horizontal angles between land objects, coloured shades are not fitted and the handle is vertical. The instrument thus constructed has great advantages over the sextant; with it, angles up to 180^o can be taken and it gives a clearer and lighter image. It allows one to eliminate in reading off the errors of parallax and of unequal graduations.

Its advantages and its extremely accurate construction thus make the AMICI-MAGNAGHI circle a truly remarkable instrument.

SURVEYING SEXTANT WITH PENTAGONAL PRISM.

In addition to numerous sextants for navigation and aeronautics, the firm of PLATH, Hamburg, constructs a special sextant for hydrographic requirements.

This special sextant fitted with a pentagonal prism, is distinghuished by the maker under the name of "Pentaquintant". The limb has a radius of $150 \frac{m}{m}$. The arc is divided to 1/1 degrees. The alidade has a micrometric device divided to 1/1 minutes. It is mounted on the limb by a tangent screw and is fitted with disengaging gear for rapid angular movements. To the body of the instrument are fixed three points serving as a tripod which allows the instrument to be placed on a flat surface without disturbing the adjustment of the mirror of the telescope or of the pentagonal prism.

By using the pentagonal prism, the range will be enlarged about 90^o.