MAJOR H. WILBERFORCE CLARKE, R.E.

HE SEXTANT.

BY

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E ASSISTANT ADJUTANT-GENERAL WITH THE NILE EXPEDITIONARY FORCE,
FFICER CHARGED WITH THE DUTY OF TAKING OBSERVATIONS FOR LATITUDE
AND LONGITUDE IN THE UPPER NILE VALLEY, 1884–85.

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THE SEXTANT.

The (nautical) sextant—simple, small, and accurate—is a most useful instrument. Its adjustments are more simple than the adjustments of any other instrument of a like character; and its cost is very little. It has been well called a portable observatory.*

* Instrument.	Weight in lbs. of			Readings of Vernier in seconds	Price in pounds.
	Box and instrument.	Stand.	Artificial Horizon.		
Sextant divided on silver—					
4-inch radius	4	—	5 to 10	20″	£5
7-inch radius	7	—	10	10″	£12
8-inch radius, with platinum arc and gold vernier . .	8		10	10″	£14½
Transit Theodolite—					
4-inch diameter[1]	13½	9	—	—	£23
5 " "[2]	25	10	—	—	£32
6 " "	31	10	—	—	£40
Altazimuth by Casella & Co.—					
3-inch diameter	4	3½	—	—	£20

[1] Without Transit axis, level and lamp.

[2] With " "

* In *Hints to Travellers*, p. 123, Colonel Walker, R.E., Superintendent, Trigo-

Nevertheless, skill in handling the sextant is difficult
acquire. With a theodolite, a man may, the first time he u
it, take the altitude of a star; not so is it with a sextant.

If a man think that he may during a voyage learn its u
he is in error. Virtually, the only celestial body observed
sea is the sun, to take the altitude of which from the visi
horizon is no difficult matter.

The mercurial horizon, the use of which introduces at o
difficulty and refinement, cannot be used at sea; and is
often used (by sailors) ashore.

With the object of helping beginners, by clearly stating
difficulties of sextant-observations, and by showing the way
overcome them, this paper is written.

*Imperfections of the Sextant.**

Before purchasing a sextant, it should be carefully e
mined.

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nometrical Survey of India, says:—"For astronomical observations,
sextant is preferable to a very small altazimuth instrument; for horiz
angles and small depressions, the altazimuth."

An altazimuth instrument of moderate size to be used as a univ
instrument is most convenient and satisfactory. The instrument that I w
recommend is the 6-inch Transit Theodolite by Messrs. Troughton and Si
(138 Fleet Street, London).

The derivation of the word *theodolite* is given below:—

θεαομαι—ὅδος—λιτος.

* Harbord's *Glossary of Navigation*. On the use of the sextant,
student should consult Chauvenet's *Astronomy*, 2 vols., price 31s. 6d.
admirable work.

The joints of the frame-work should be perfect, close and tight; the screws should act well and remain steady when the instrument is shaken.

Imperfect centering may be detected by comparing the distance between two (N.A.) stars measured by the sextant under trial with the same distance observed with a standard sextant, or with a circle; or with the same distance deduced from computation. The error being found for certain places on the arc, the correction for any angle may by proportion be obtained.*

The graduation on the limbs and on the vernier must be flush with the surface of the instrument; the fineness and the distinctness of the cutting examined with a microscope; and the equality of the distances throughout the arc, tested—by successively placing the index of the vernier in exact coíncidence with each division of the limb, till the last division upon the vernier reaches the last division upon the limb. If, in each case, the last division of the vernier does not exactly coincide with a division on the limb, the instrument is badly graduated.

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* Let α = AR of one star; and Δ its polar distance.
Let α' = AR of the other star; and Δ' its polar distance.
Let $(\alpha - \alpha') = m$.

$$\text{Log} \sin^2 (\text{auxiliary arc } x) = \log \sin^2 \frac{180 - m}{2} + \log \sin \Delta + \log \sin \Delta'$$

$$\text{Log} \sin^2 (\text{apparent distance}) = \log \sin \frac{\Delta + \Delta' + x}{2} + \log \sin \frac{\Delta + \Delta' - x}{2}$$

From the apparent distance is deduced the true distance in the same manner as in finding the true distance in longitude by lunar distance.

The glasses of the two (the horizon and the index*) reflectors should be free from veins, with faces ground and polished parallel to each other.

To test the reflectors, look with a small telescope obliquely and separately into each reflector, and observe the image of a distant object.

In every part of the reflector the image should be clear, distinct (not streaky), single, and well defined about the edges.

The glasses of the shades should be of the best quality, each shade should have its two faces ground and polished parallel to each other.

To test the shades, fix the dark glass† to the eye-piece of the telescope; and, without using any of the shades (of the index and the horizon-glass) bring into contact the reflected and the direct image of the sun. Remove the dark glass, and separately set up each shade (of the index and the horizon-glass) and then their combinations.

Should a divergence be observed in the case of a single shade, reject that shade; in the case of a combination of shades, alter the setting of the shades.

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* The index-glass is the glass fixed (at the centre of the sextant) to the movable index arm; the horizon-glass is the glass, half silvered, half unsilvered, through which one views at sea the natural horizon, and ashore the artificial horizon.

† With only the dark glass at the eye-piece of the telescope, there can be no shade error, see p. 11.

If the shades can be neither rejected nor altered in setting, consider the divergence as an error to be determined and to be allowed for.

Adjustments.

(*a*) To place the index-glass (fixed to the movable arm) perpendicular to the sextant-plane.*

Bring the vernier to 60°; hold the sextant (face upwards) in the left hand, arc away from the body; look obliquely into the index-glass,—viewing the arc of the sextant by direct vision to the right, by reflection to the left.

The image and the arc should appear in the same plane as an unbroken arc.

If the reflection of the arc seems to droop from the real arc, the index-glass leans backward; if it seems to rise from the real arc, the index-glass leans forward.

Adjust by the screws that fix the index-glass to the index-arm.

(*b*) To place the horizon-glass (half silvered, half unsilvered) perpendicular to the sextant-plane.

Adjustment (*a*) must first be made.

Place the inverting telescope in the collar and fix the dark glass to its eye-piece; bring the index of the vernier (without

* In the *Manual of Surveying for India* (p. 89), Mr. Troughton says: "The position of the index-glass is not liable to alter, therefore no direct means are supplied for its adjustment."

clamping) to the zero point of the arc; and, observing the sun, move the index handsomely forward and backward.*

The sun's image must pass directly over the sun itself.

If the image be lower, the horizon-glass leans forward; if higher, backward.

Adjust by the screw (or the key) attached to the reflector. In performing this adjustment by this method, it is immaterial whether there is an index error or not.†

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* This may best be done by clamping the index-arm and by moving (by the tangent screw) the reflected image of the sun slowly over the real sun.

† Provided that there is no index error, this adjustment may otherwise be thus performed:—

Place the non-inverting telescope in the collar; set the index of the vernier at zero; hold the sextant horizontally, and, giving it a slight nodding motion, view the sea-horizon.

If the reflected and the real horizon appear as one unbroken line, the horizon-glass is in adjustment.

If not, turn the screw (or the key) attached to the horizon-glass till the horizons are in a straight line.

In some sextants, there are means of setting the horizon-glass not only perpendicular to the sextant-plane, but also parallel to the index-glass, thereby eliminating index error.

Set the index of the vernier at zero and clamp it; fix the telescope in the collar and raise it till the line that separates the silvered from the unsilvered part of the mirror bisects the field of view of the telescope.

Hold the sextant horizontally and view the horizon. If the reflected and the true horizon coincide, well; if not, turn the tangent screw at the back of the horizon-glass till the horizons appear in a straight line. The plane of the index-glass and the horizon-glass will then be parrallel; and there will be no index error.

(c) The line of collimation (the path of a visual ray passing through the centre of the object-glass and the middle part between the cross wires of the telescope) should be parallel to the sextant-plane.

Place the inverting telescope in its collar, and by turning the eye-tube of the telescope set the wires within it parallel to the plane of the sextant; fix upon two distant bright objects (the sun and the moon are the best) when 100° to 120° apart;* bring the reflected image of the one into exact contact with the image of the other.

The angular distance is truly measured only at the middle points between the wires of the diaphragm. Hence, the same degree of divergence should take place at the middle points of the upper and the lower wire (of the diaphragm).

Proceed as follows:—

Bring the darkened image of the sun to touch the moon

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* Loomis (p. 99) says 90°; the Chatham Papers (p. 24) say 120° to 130°. The greater the distance, the more easily is the error discovered.

In the *Manual of Surveying for India* (p. 91), Mr. Troughton says: "The line of collimation is not very liable to derangement."

The position in which the two wires shall be parallel to the sextant-plane is sometimes marked on the eye-piece by the maker. If not, place the index just so far from the zero position (in which the index and horizon glasses are parallel) that the direct image of one object being brought near the top of the field, the reflected image of the other may appear at the bottom; or *vice versâ*. Then one image being brought to the edge of one of the wires, the other image must likewise appear on the same edge of the same wire. Not being there, the eye-piece must be turned by the hand until this condition is fulfilled. The eye-piece and its cell should then be marked.

viewed directly (through the horizon-glass) at the middle of the lower wire nearest the sextant-plane; then, by instantly moving the sextant, bring the point of contact to the middle part of the upper wire farthest from the sextant-plane.

Here contact should also be exact,* the image having overlapped in the centre of the field of the telescope.

If the two images appear to be separated at the upper wire, the object end of the telescope droops towards the sextant-plane; if they overlap, it rises.

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* If not exact, the observed angle is always too great. The following table gives in seconds of arc the excess caused by error of parallelism of telescope :—

Observed angle.	Error of parallelism of telescope.							
	10′	20′	30′	40′	50′	60′	70′	80′
°	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.
10	—	1	1	2	4	6	7	10
20	—	1	2	5	8	11	15	20
30	1	2	4	7	12	17	23	30
40	1	3	6	10	16	23	31	40
50	1	3	8	13	20	29	40	52
60	1	4	9	16	25	36	49	64
70	1	5	11	20	31	44	60	78
80	2	6	13	23	37	53	72	93
90	2	7	16	28	44	63	86	112
100	2	8	19	33	52	75	102	133
110	3	1C	22	40	62	90	122	159
120	3	12	27	48	76	109	148	194

If the two images separate at the upper wire (farthest from the sextant-plane), loosen (in the collar intended to hold the telescope) the screw farthest from the sextant-plane, and tighten the screw nearest to the sextant-plane.

If the two images overlap at the upper wire, loosen (in the collar intended to hold the telescope) the screw nearest to the sextant-plane, and tighten the screw farthest from that plane.*

(*d*) For distant objects, when the horizon-glass and the index-glass are parallel, the zero of the vernier should agree with the zero of the sextant-arc.

If it should not agree, the error is not corrected; but at each observation determined and allowed for.† Hence this comes under the head of errors not of adjustment.

Errors.

(*a*) *The Shade Error*:—

In examining the shades of the horizon-glass and the index-glass (See p. 6), if the reflected and the direct images of the

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* The transference of images from the wire nearest to the sextant-plane to the wire farthest from the sextant-plane, must be quickly effected, or allowance for motion will have to be made.

Instead of the sun and the moon, two stars at least 90° degrees apart may be observed and brought into contact as above described, but this method is a difficult one.

† See foot-note, p. 13.

sun do not remain in contact, the angle through which the index-arm must be moved to restore contact is the error (s) 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 s with the *contrary* sign.

When only a dark glass at the eye-piece of the telescope is used, there is no error. For, if the faces of the glass are not parallel, the rays from the direct and the reflected image are equally affected, and the observation remains unchanged.†

(*b*) *The 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 the reflected image of the horizon into exact continuation of each other. The reading (ϵ) on the arc is the index-error position on the arc proper, negative on the arc of excess. The index correction (to an observation) is (ϵ) with the *contrary* sign.

* The arc of excess is the arc to the right of zero on the graduated limb.

† The dark glass at the eye-piece of the telescope is generally used when finding the index error; and when taking the sun's altitude by means of a mercurial horizon—for the sun seen in the mercury and the image of the sun reflected to the eye from the index-glass and the horizon-glass are almost equally bright.

(2) 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 (viewed directly); observe the reading on the arc proper.

Clamp the index at 30′ on the arc of excess; bring the left limb of the reflected sun into contact with the right limb of the real sun (viewed directly); observe the reading on the arc of excess.

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* When the sun has good altitude, the sextant may be held vertically; but to obtain this correction, it is better to get into the habit of always holding the sextant horizontally.

When bringing the images into contact to ascertain the index error, the tangent screw of the vernier should always be turned in the same direction. Or the index error may be found when the tangent screw of the vernier is moved onwards, and again when moved backwards.

Then, for a lunar distance that is increasing, the index error for the onward motion of the tangent screw would be used; and for a lunar distance that is decreasing, the index error for the backward motion of the tangent screw.

The difference in the index error arising from a forward or a backward motion of the tangent screw is due to the elasticity of the index-bar.

Having clamped the index-arm successively at 30′ on the arc and at 30′ off the arc,—no thought as to which limb is to be observed is required. Simply bring into contact the two images that will appear in the field of the telescope.

By pushing in or by pulling out the eye-piece,—the telescope must be adjusted to *distinct vision*; and this can be truly effected only when the sextant has been raised towards the sun. If perfect vision is not obtained, perfect contact is impossible.

Suppose the readings to be :—

	′	″		′	″
On the arc proper	35	0	On the arc of excess	29	35
„ „	35	5	„ „	29	25
„ „	35	10	„ „	29	20
	105	15		88	20
	88	20		105	15
	6)16	55		6)193	35
Index correction*—	2	49.1		32	15·8

If the observations have been correctly made, the sun's diameter=32′ 15·8″ See *Nautical Almanac*, p. II. of each month. The appearance of the two (the reflected and the real) suns is shown on the opposite page.

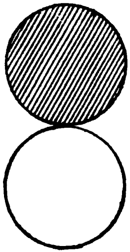
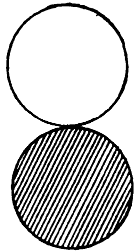
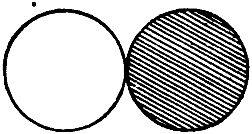
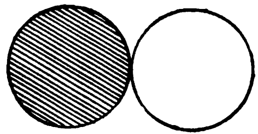
When either a non-inverting telescope, or a simple tube, is used, the appearance is just the contrary to that given. An inverting telescope is, however, generally used.

(3) By a Star :—

Bring into coincidence the direct and the reflected image of the star observed. The reading on the arc proper (or of excess) will be the index correction.†

* If both readings be on the arc (which can occur only when the index error is nearly half a degree), the index correction will be the mean and subtractive; if on the arc of excess, additive.

† The parallax of a 12-inch sextant at half-a-mile distance, is 21″; it is less for sextants of smaller dimensions and for greater distances. Hence for this adjustment, a distance exceeding half-a-mile should be used.

The Sextant, how held.	What kind of Telescope.	Appearance on the Arc Proper.		Appearance on the Arc of Excess.	
Vertically.	Inverting.	 The reflected sun. The direct (real) sun.	The *upper* limb of the reflected sun is in contact with the *lower* limb of the real sun.	 The direct (real) sun. The reflected sun.	The *lower* limb of the reflected sun is in contact with the *upper* limb of the (direct) real sun.
Horizontally.	Inverting.	 The direct (real) sun.	The *right* limb of the reflected sun is in contact with the *left* limb of the real sun.	 The reflected sun.	The *left* limb of the reflected sun is in contact with the *right* limb of the real sun.

To take at sea the altitude of the sun, of the moon, or of a star:—

Set up such shades of the index-glass and of the horizon-glass as may be necessary, according to the brightness of the sun,* place the index-arm, unclamped but not loose, at zero; look through the ring intended to hold the telescope (using no telescope) at the sun (the moon or a star), and, by moving the index-arm, bring the reflected image of the sun (the moon or a star) down to the horizon; clamp the index.

In doing this there is no difficulty.

Then fix the telescope (adjusted to vision), and by the tangent screw make contact perfect.

The sun (the moon or a star) ought to touch that part of the horizon just beneath it. To ascertain this fact, give to the sextant a slow side to side motion, whereby the sun (the moon or a star) will appear to sweep the horizon and touch it at the lowest part of the arc. The altitude then pointed out on the arc will be the observed altitude of the sun's limb (or of the moon or of the star) in contact with the horizon.†

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* If this be not done, injury to the sight may be the result; for stars, no shades are required.

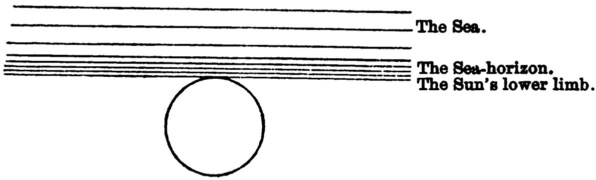
† The meridian altitude of the sun obtained at noon is not necessarily the maximum altitude. See Godfray's *Astronomy*, p. 168.

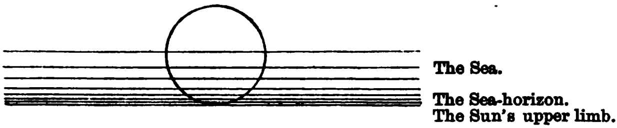
When the declination of the body increases, the maximum altitude will be attained after the meridian altitude; when the declination decreases, before.

Let z = zenith distance of the body.

Let ϕ = latitude.

The sun in contact with the sea-horizon is shown below. When an inverting telescope is used :—





Let d = declination (negative if south).

Let a = hourly change of declination. (See *Nautical Almanac.*)

Let t = seconds of time after or before the meridian altitude when the maximum altitude is attained.

Let y = seconds of arc to be applied to the maximum altitude to obtain the meridian altitude.

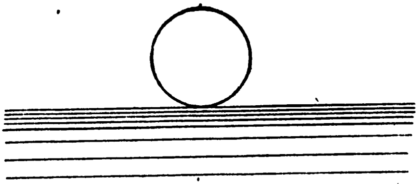
Then $t = \dfrac{a\,(\tan\phi - \tan d)}{\overline{60}^2 \times \overline{15}^2 . \sin 1''}$

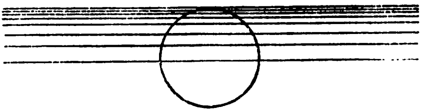
Then $y = \dfrac{2 \sin\phi . \cos d . \sin^2 \frac{t}{2}}{\sin z . \sin 1''}$

At noon, when the sun (viewed through a non-inverting telescope) appears in the horizon-glass to rise above the horizon, the sun is rising; when the sun sinks below the horizon, the sun is descending.

In making an observation, note which way the tangent screw must be turned to increase the altitude.

When a non-inverting telescope is used :—





At sea, the horizon at night is obscured by haze, by fog, or is distorted by uncertain moonlight, hence it is difficult to observe the altitude of a star.

In the twilight, when the sky is clear, the horizon is most favourable for observation.*

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* In his *Navigation*, p. 179, Lieutenant Raper, R.N., says :—

" An altitude observed from the top of a heavy sea will differ considerably from another taken at or below the mean level. From the lower-mast top, the horizon will be better defined, and the variations of the dip by the sea's motion less sensible.

" The height of the eye above sea-level should be ascertained to within two or three feet. When the observer is near the water, the dip changes most rapidly.

" The sea-horizon formed by the eminence of waves should be higher in bad weather than in fair weather.

When the sky under the moon is unclouded, the upper edge of the illuminated part of the sea is the horizon. At other times, it is often impossible to discern the horizon.

When the altitude of the star is near 90°, before attempting to take its altitude, ascertain (by reference to the zenith, or by compass) the precise point over which the star is vertical.

To take the Altitude of the Sun or the Moon in an Artificial Horizon.

In the case of the sun, place a dark glass over the eye-piece of the inverting telescope; but put up no shades.

In the case of the moon, place a green shade in front of the horizon-glass.*

"In all cases in which a telescope cannot be used, a plain tube (without glasses) should be used to direct the sight to the proper point of observation, and to defend the eye from disturbing lights. In this case, both eyes should be kept open.

"The place of the sea-horizon is often doubtful from 1′ to 3′."

When the altitude of the body is more than 60°, it may be observed from the opposite point of the horizon as well as from the point of the horizon immediately beneath it. These corresponding to the mean of the times of observation the apparent zenith distance—

$= \frac{1}{2} \times$ difference of the two altitudes.

Then are eliminated the dip and the index-error.

* By using only a dark glass at the eye-piece, correction for shade error is avoided.

In the case of the moon (a fast traveller), it is convenient to make green in colour the reflection A in the mercury by means of a green shade. Thus it is easy to distinguish between the reflection A and the spectre image B.

Place the inverting telescope in the collar; hold the sextant in the right hand behind the back, out of harm's way; stoop and find the sun (or moon) in the mercury placed in an iron trough on a wooden board on the ground; retire backwards, rising gradually, and keeping in view the sun (or moon) in the mercury till such a distance shall be reached as to make the standing position possible. Take a final look at the reflection A in the mercury of the sun (or moon), and then (the index-arm of the sextant being at zero) direct the sight through the telescope at the sun (or moon). On moving forward the index-arm from zero, the spectre image B of the sun (or moon) will appear. As the index-arm moves forward, move the telescope downward, keeping the spectre image B in view, till finally will be seen nearly in contact in the mercury the reflection A and the spectre image B brought from the sky.

Place a soft cushion on the ground near the mercury; lie down; rest the right elbow on the cushion; look through the telescope at the reflection A in the mercury, and by the tangent screw make contact (between A and B) perfect.*

As the centre of the sun (or the moon) cannot be ascertained, it is necessary to take the altitude of a limb.

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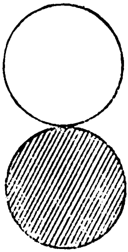
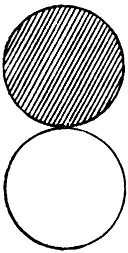
* When the altitude is great, the length of sextant-telescope renders it difficult in a prostrate position to raise the eye high enough to look down the telescope. In such a case, one may may sit cross-legged, or on the sextant-box, but, in this upright position, contact cannot be made with such nicety as in the prostrate position.

The following diagram shows the appearance :—

What kind of Telescope.	Appearance.		
A simple tube, no glasses, or A non-inverting telescope.	B  A	The real sun reflected from the index-glass. The image of the sun seen in the artificial horizon.	The lower limb of the real sun is in contact with the upper limb of the sun's image in the artificial horizon.
An inverting telescope.	A  B	The image of the sun seen in the artificial horizon. The real sun reflected from the index-glass.	Do. do.

When the sun (or the moon) is rising, it is proper to take the upper limb, the spectre image B of which constantly tries to *approach* the reflection A in the mercury; when the sun (or moon) is sinking, it is, for the same reason, proper to take the lower limb.*

The motion of the approaching and of the separating of images is shown in the following table.

—	Altitude.	
	Increasing.	Decreasing.
Contact formed at the lower limb of the sun (or moon).	Images separate	Images overlap
Contact formed at the upper limb of the sun (or moon).	„ overlap	„ separate

In taking an altitude, it is proper to wait for contact. Thus, if the altitude of the sun's approaching limb is $a°$, take successively the altitude—

if rising.		if sinking.
at $a°. 10'$		at $a°. 40'$
at $a°. 20'$		at $a°. 30'$
at $a°. 20'$		at $a°. 20'$
at $a°. 40'$		at $a°. 10'$

* In taking equal altitudes of the sun (a.m. and p.m.) for time, if the sun's upper limb have been taken in the morning, it will be proper to take the same (upper) limb in the afternoon.

In the case of the moon when not full, the altitude of the rounded part of the moon, whether it be the lower or the upper limb, must be taken.

To take the Altitude of a Star in an Artificial Horizon.

This operation is not easy: only by practice and by skill can it be done.*

Exactly the same process is followed as in the case of the sun or the moon; but to make the process more easy, the spectre image B of the star in the sky may be brought nearly into coincidence with the reflection A of the star in the mercury by looking at the star with the naked eye (no telescope being used) through the collar intended to hold the telescope and through the horizon-glass. When this shall have been done, the inverting telescope may be fixed in the sextant, and *coincidence* made perfect.

When two bright stars are near together, there is ordinarily danger of confounding one with the other: by this method, the danger is averted.

The sextant must be clean and also the mercury; at the same time, it is astonishing what—even with the dirtiest mercury—an expert observer will do.

Only bright stars can be taken. A faint star at a fair altitude may be visible to the naked eye; yet, with the sextant, to take its altitude may be impossible.

Up to 60°, the greater the altitude of the star, the less is the difficulty of observation. A foreground of desert hue enhances the difficulty, and so does very bright moonlight—in which the star's light is often quenched.

* The taking of altitudes of stars may be facilitated by previously calculating the altitudes and setting the index to the calculated altitude.

In his work on Hydrographical Surveying (p. 184), Captain Wharton, R.N., says that it is next to impossible to observe stars with a sextant unfurnished with a stand.*

In this I do not agree with him. Lying down, it is perfectly easy to take with precision and nicety the altitudes of stars.

The sextant-stand costs nearly as much as the sextant itself, is very heavy, and is difficult to fix in the proper position with

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* The procedure is as follows :—

Place the sextant and the sextant-stand on *its stool,* so that one of the three legs (supporting the stand) shall be at right angles to the meridian and on the right of the observer. Set the vernier to a few minutes less than the estimated double altitude of the star.

Move the stool (with the sextant and the sextant-stand on it) so that looking over the sextant-telescope, the reflection A of the star in the mercury may be seen. At this reflection A, point the telescope; tighten the screw that fixes the handle of the sextant on the bearing of the sextant-stand; work the sextant right and left on the stand pivots, and the spectre image B of the star will soon dash across the field of view.

Bring the two images into proximity ; place the right hand on the screw at the end of the stand-leg that has been arranged at right angles, and the left-hand on the tangent-screw of the sextant. Work these two screws till the images (A and B) of the star coincides.

Captain Wharton says :—

The sextant-stand should be lacquered, not bright; the foot-screws should have large heads, easily grasped; the bearing that carries the sextant should be accurately fitted into the socket in the handle, and should be very slightly conical—if too conical, it is liable to jam ; the counter-balance should balance the sextant without the screws at the end of the pivot being set up too taut.

A small three-legged stool, fourteen inches high, with hollows for the foot-screws of the sextant-stand, to prevent their slipping, and hollows for the dark glasses, should be provided.

The observer should have a similar stool.

respect to the artificial horizon. Further, the sextant-stand itself requires a stand on which to stand.

In taking the meridian altitude of a star, take care to be in time; see that the tangent-screw has plenty of run; note which way it must be worked to increase the altitude. This is no case of waiting for coincidence. The motion of the star near the meridian is slow; and therefore the star can be easily followed by the action of the tangent-screw till it culminates.

The observer must recollect that, in consequence of the inversion of the telescope, the ascending star will appear below the reflection A in the mercury and the descending star will appear above the reflection A.*

The altitude recorded on the arc of the sextant must be corrected for index error, and then be divided by two—to obtain the "observed altitude."

This "observed altitude" must be corrected for—

Refraction – Parallax + Semi-diameter + or – Dip (at sea only)	in the case of the sun, the moon, or a planet.
Refraction Dip (at sea only)	in the case of a star.

The result is the true altitude.

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* The appearance cansed by the inverting power of the telescope should be studied. In the *Nautical Almanac*, it is thought worth while, in the case of Jupiter's Satellites, to give the appearance caused by this inverting power.

With an artificial horizon, no altitude greater than 60° or less than 15° can be observed.*

Error in the glass roof of the artificial horizon may be eliminated by reversing it and taking a second observation.†

The reflection A and the spectre image B of the star being viewed in mercury through the telescope, if the sextant be slightly oscillated right to left, the reflection will remain steady, the spectre image will move to and fro. Thus may be known the spectre (B) of the star from the reflection (A) of the star.

To eliminate errors for incorrect estimations of index error, and of refraction, combine (or balance) observations by taking pairs of altitudes north and south of the zenith, or east and west of the meridian.

Altitudes taken at greater intervals of time than five minutes should not be grouped together to form a single observation, as the arithmetical mean of the altitudes will not (on account of the varying rate of motion in altitude) correspond with the arithmetical mean.‡

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* The writer has taken an angle of 67°.

† Reverse after each set of three or of five altitudes. Use the roof only when necessary. When taking equal altitudes for time, do not reverse.

‡ The change of altitude in a very small portion of time depends on the latitude and on the azimuth of the body; the second difference (variation in change of altitude) which becomes conspicuous in a long interval, depends upon the altitude.

If a series of altitudes be observed at equal intervals of time, the difference will give 2nd differences and even 3rd differences.

When the 2nd difference is insensible,—½ the form of two altitudes or ⅓ of

In practice, the intervals of time at which altitudes are taken are not exactly equal, and errors of observation will often conceal the 2nd difference.

When altitudes can be obtained only at considerable intervals, it is proper to deduce a separate result from each.

In two cases the 2nd difference of altitude disappears:—

(*a*) When the object is E. or W.

(*b*) When its motion is vertical.

The elevation of the observer has no effect on the altitude taken from mercury.

Even in the case of the moon, an elevation of a mile does not produce a change of 1″ in the horizontal parallax.

Lunar Distances.

Direct the telescope of the sextant to the fainter object. If the fainter object be to the right, hold the sextant face downwards.

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three altitudes, or $\frac{1}{5}$ of five altitudes, corresponds to the middle of the time occupied by the observation. When the 2nd difference is considerable, the arithmetical mean is in error as follows:—

(*a*) The half of the sum of the two altitudes at the beginning and the end of the interval differ from the altitude proper to the middle instant of the interval by $\frac{1}{8}$ of the 2nd difference proper to the whole interval.

(*b*) The third of the sum of the three altitudes at the beginning, the middle and the end of the interval differs from the four altitudes by $\frac{1}{12}$ of the whole 2nd difference.

(*c*) The fifth of the sum of five altitudes at four equal intervals by $\frac{1}{16}$ of the 2nd difference.

The distance between the moon and the sun, a planet, or star, increases when they are to the west of the moon, and decreases when they are to the east of the moon.*

The illumined rounded limb of the moon must be brought in contact with the sun (or the star), even if to do so the moon's image be made to pass beyond the sun (or the star).

When the *nearest* limbs of the sun and the moon are observed, make them overlap if receding, leave a small space if approaching, and wait for contact.

When the *farthest* limbs of the sun and the moon are observed, do just the reverse.

At sea, in taking the distance between the sun and the moon, the observer should fix himself in a corner, or should lie on his back (head supported on a cushion†) on the deck.

Great practice is necessary for successfully measuring the distance, and the application of innumerable small corrections render extraordinary care and skill necessary.

A good observer rarely makes an error of half a minute in the lunar distance.

At sea, the power of the telescope should not exceed 9;

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* See *Nautical Almanac*, pp. xiii. to xviii.

See that the tangent screw of the index-arm has plenty of run onward or backward, as the case may be.

† A box 16″ long × 10″ wide × 9″ high, with a soft cushion resting on it, serves well.

when there is much motion, or the moon is near to the sea, a power of five is more satisfactory. Ashore, a power of twelve may be used.

The difference between the true and the apparent lunar distance depends on the correction of altitude, and is affected by every minute variation of those corrections.

The most rapid change of distance being 1° 48′ in three hours, the effect of 1′ error of distance is 25′ of longitude.*

Hence the height of the barometer and the thermometer at the time of observation should be noted.

A stand constructed to hold the sextant while taking lunar distances is a thing greatly to be desired. Stands as at present constructed are unfit for the purpose. Such a stand should be able to hold the sextant in any position, vertically, horizontally, inclined, and in reverse positions (face downwards).†

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* With a transit theodolite lunar distances cannot be taken. Hence, when the transit theodolite is used, longitude is taken by zenith distances of the moon, by which method an error in the moon's altitude produces an error thirty times as great in the resulting longitude. But many not expert in taking lunar distances can with precision take altitudes (with a transit theodolite, or with a sextant). For the mode of taking them, see Chauvenet's *Astronomy*, vol. i. pp. 382–393.

† In his treatise on the Sextant, 1858, p. 121, Mr. Simms says:—"As a comfortable position is essential to anything like accuracy in observation, the operator should be furnished with a chair, having a back inclined at 45° to the vertical, and arms sufficiently high for the support of the elbows when the telescope of the sextant is directed between 30° and 40° from the horizon. With such a convenience there will be little difficulty in observing a lunar distance even with a considerable amount of motion."

In taking lunar observations, the order, if there be only one observer, should be:—

(*a*) According to the *Manual of Surveying for India*, p. 608:—*

Several lunar distances.
A zenith distance of the moon.
" " lunar star.
Several lunar distances.
A zenith distance of the lunar star.
" " moon.
Several lunar distances.

(*b*) According to *Hints to Travellers*, p. 53:—†

Read thermometer in air.
Adjust horizon-glass (if necessary).
Take two pairs of observations for index error.
Take three altitudes for time, star East.
" " " West.
" five lunar distances, star East of moon.
" " West "
" three altitudes for time, star West.
" " " East.

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* The Astronomer Royal. Observations (*a*) are in addition to those for time and latitude.

† Captain Galton. Observations (*b*) are in addition to those for latitude. The reader will note that no altitudes of the moon or of the lunar star are here directed to be taken. Star-altitudes for time are taken east and west to eliminate instrumental errors.

Take two pairs of observations for index error.
Read thermometer in air.
„ barometer.

Lieutenant Raper, R.N., says :—

Observe in order the altitude of the body farthest from the meridian, the altitude of the other body, and the distance.* Conclude in the reverse order.

One altitude (precision in which is unnecessary) will be sufficient at each time.

The time by watch is to be noted at each of all these observations.

Observe the moon's true bearing; if she is near the zenith, observe instead the bearing of the lunar star. With barometer and thermometer at hand, the altitudes should be not less than 5° or 6°; with barometer and thermometer not at hand, not less than 12° to 15°, especially in very hot (or cold) weather.

The observed distance is liable to error due to want of parallelism of the telescope; to error due to making the contact above (or below) the centre of the field; to error due to irradiation.

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* The reason is that the outer body preserves for a longer time than the other uniformity in its change of altitude; consequently, its altitude may be reduced to an intermediate time by simple proportion with less error than the altitude of the other body. These observations are in addition to those for latitude and for time.

The effect of an error of a few minutes in the altitudes is insensible; an ill-defined sea-horizon is no great detriment; in computing altitudes precision is unnecessary.

The effects of general errors and of observation errors may be reduced by observing equal distances on opposite sides of the moon; for the errors will be opposite kinds. The true longitude will not, however, be the mean of the two erroneous longitudes, unless the moon changes at the same rate her distance from the two bodies.

Stars East and West of the moon should be observed.

If the index-correction of the sextant is uncertain, the errors produced in the computed Greenwich time, and consequently in the longitude, having different signs for the two observations, will in the mean nearly disappear.

Further, if the distances are nearly equal, the eccentricity of the sextant will affect nearly equally each distance, and will, therefore, be nearly eliminated at the same time with the index error.

The altitudes of the moon and the lunar star (or the sun) should be observed at the same instant as the lunar distance. If this is not possible, they should be observed immediately (within ten minutes) before and after, and interpolated for this instant.

It may be advisable to omit the observations of the altitudes, and thereby gain time to multiply the observations of the lunar distances.

At sea, where an immediate result is required with the least expenditure of time and labour, the altitudes should be observed.

The lunar distances should exceed 45°.*

To take the Angular Distance between the Sun and the Moon.

Between the index-glass and the sun set up such shades as may be required. Without using the telescope, direct to the moon the sight through the ring (intended to hold the telescope) and through the unsilvered part of the horizon-glass; and move the index-arm until the sun's image comes nearly in contact with the nearest illumined rounded edge of the moon.

Fix the inverting telescope (adjusted to vision); place the wires parallel to the sextant-plane; and (by the screw) raise the telescope to the unsilvered part of the horizon-glass.†

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* Remarks by Mr. Thomas Wright of the *Nautical Almanac* Office. In his *Navigation* (p. 284), Lieutenant Raper speaks of a lunar distance of 20° only.

For the reduction of lunar observations, consult:—

(*a*) Chauvenet's *Spherical and Practical Astronomy*, vol. i. (the price of vols. i. and ii. is 36s.). Trubner & Co., Ludgate Hill.

(*b*) Read's *Navigation and Nautical Astronomy*, 10s. 6d. Elliot Stock, 61, Paternoster Row. With this book is required Riddle's *Tables* Simpkin, Marshall, Stationers' Hall Court.

(*c*) *Reduction of Lunar Observations*, by Admiral Sir C. Shadwell, 4s. 6d. J. D. Potter, 31, Poultry.

(*d*) Riddle's *Navigation and Nautical Astronomy*, 11s. 6d. Simpkin, Marshall & Co.

(*e*) Simms' *Treatise on the Sextant*: an exhaustive work.

† This screw is intended to raise the telescope so that the field of view may be bisected by the line on the horizon-glass separating the silvered from the unsilvered part. When thus bisected, the object seen by reflection and the object seen by direct vision are equally bright.

Direct the sight through the telescope to the moon; make contact perfect, either by turning the tangent-screw or by waiting; move the sextant slowly around the axis of the telescope, whereby (the sun appearing to pass by the moon) contact will be perfectly made.

The point of contact should be as near as possible to the centre of the field of view.*

Manifestly, by day, when observing the sun and the moon; and by night, when observing the moon and a lunar star—it is better to raise the telescope, so that the fainter object may be as clearly seen as the brighter object.

* In the *Nautical Almanac*, pp. xiii. to xviii., of each month, are recorded the angular distances of the moon from the sun and from the nine lunar stars, —bright stars nearly perpendicular to the horns of the moon.

When a *Nautical Almanac* is not at hand, and it is necessary to choose a star for longitude-observation, the following table may assist in the selecting of a proper star:—

Name of Lunar Star or Planet.	Least Distance.				Greatest Distance.			
	E.	p.	W.	p.	E.	p.	W.	p.
α Piscis Australis (Fomalhaut)	36°	181	37°	216	107°	178	104°	213
α Pegasi (Markab)	25	181	24	198	90	180	104	213
Pollux	20	213	19	212	103	198	104	215
α Leonis (Regulus)	23	213	20	214	111	198	81	215
α Arietis	23	217	27	216	105	214	103	213
α Tauri (Aldebaran)	25	217	28	212	102	214	98	213
α Virginis (Spica)	22	215	22	18	104	212	81	19
α Aquilæ (Aṭ-ṭair)	40	37	35	214	102	34	89	217
α Scorpii (Antares)	25	19	22	36	96	16	70	37
The Sun	22	19	16	18	131	16	135	15

This table is taken from the *Nautical Almanac*, 1884, to which by page (p.) reference is made.

Having fixed the inverting telescope, the observer should lie on the ground (on his back or on his side, as may be convenient), his head (and, if necessary, a part of his shoulders) being supported on a small box, a portmanteau, a bag, or a cushion.*

To take the Angular Distance between the Moon and a Star.

Between the index-glass and the moon set up a light shade (to diminish the light of the moon). Without using the telescope, direct to the star the sight through the ring (intended to hold the telescope) and through the unsilvered part of the horizon-glass; move the index-arm until the image of the moon is seen near to the star (viewed directly). Fix the inverting telescope (adjusted to vision); place the two wires (in the telescope) parallel to the sextant-plane; by the screw, raise the telescope to the unsilvered part of the horizon-glass.

Direct the sight through the telescope to the star; make contact perfect either by turning the tangent-screw or by waiting; move the sextant slowly around the axis of the telescope

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* In his *Treatise on the Sextant*, p. 122, Mr. Simms says: "The number of lunar distances taken in a set should be 10 in bad weather, 5 in good weather; the intervals should not much exceed 1½ minutes, otherwise the mean will be vitiated. Should there be other observers besides the observer of the lunar distances, they should not await any signal from the observer of the lunar distance, but should, while he is recording an observation, each quickly observe an altitude, taking the time from the watch of the lunar distance observer.

whereby (the illumined rounded limb of the moon appearing to pass by the star) contact will be perfectly made.*

Let A be the star, and B the moon,

then A B represents the distance between the star at A and the moon's nearest limb at B. B′ is the image of the moon brought from B into contact with the star at A.

Let B be the moon, and C the star,

then B C represents the distance between the star at C and the

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* The instructions here given are similar to those given for the distance between the moon and the sun; but the difficulty of taking the distance is greater.

Greater, too, is the difficulty when the fainter object is to the right, for then the sextant has to be inverted. In this case, the position is often one of painful constraint. See p. 27.

When the moon is not full, there is no danger of the wrong limb being taken; when the moon is nearly full, consult p. xii. of each month in the *Nautical Almanac*, where the Greenwich time of full moon is given; when the moon is full, take care to record correctly whether the nearest or the farthest limb has been taken. Weigh fully the appearance caused by the inverting power of the telescope.

moon's farthest limb at B. B″ is the image of the moon brought from B into contact with the star at C.

The sextant-box should be well made, secured with brass screws and clamps, and furnished with a stout leather strap and brass buckle, whereby it may be slung on a man's back.

In the sextant-box, besides the sextant and its telescopes, should be spare index and horizon glasses folded in wool and secured in fitting recesses; and a piece of chamois washing-leather wherewith to clean the sextant. In it means should be provided for securely keeping the sextant with the index-arm clamped in any position; and for holding the telescope adjusted to vision.

The sextant itself should be as light as possible. A sextant however heavily built will bear violence no more than a sextant lightly built. When it comes to measuring a few seconds of arc in a lunar distance, a heavy sextant is a vexatious and injurious burden to the observer.*

To put Wires in the Telescope of the Sextant or other Instrument.†

Cut holes two inches square in a strip of cardboard three inches wide; catch a garden spider, place him on the card-

* Captain Stokes, R.N., informs me that some years ago he had an aluminium sextant—very light, very costly—made at Paris. To this sextant, however, he preferred a 7-inch sextant by Troughton.

Neither do Messrs. Troughton and Simms and Messrs. Elliott and Co. keep aluminium sextants; nor do they appear ready to make them.

† Captain Wharton, *Hydrographical Surveying*; and the *Manual of Indian Surveying*.

board, and shake him off. As in falling he casts his web, twist it on the cardboard so as to cross the holes.

Take the diaphragm from the telescope; scrape off the old balsam, lay the diaphragm on a table, and place a drop of Canada balsam on its edges.

With the help of a microscope, place the cardboard across the diaphragm so that the web shall lie in the notches cut in the diaphragm.

It may otherwise thus be done :—

With spirits of wine clear the diaphragm and the nicks; place the diaphragm on a surface slightly raised; select a silk fibre, to each end of which append a small ball of wax; fit the fibre into the nicks and let the balls hang free to tighten the fibre. When the required number of wires is placed, fix them (with drops of laudanum, or with any other adhesive fluid) to the diaphragm.

*To Silver Sextant-glasses.**

Lay a piece of tinfoil (that should exceed the surface of the sextant-glass by a quarter of an inch on each side) on a smooth surface (the back of a book); rub it out smooth with the finger; add a bubble (size of a small shot) of mercury; rub the mercury over the tinfoil until it spreads itself and shows a silvered surface; gently add sufficient mercury to cover the leaf so that its surface may be fluid. Take a slip of paper (the size of the tinfoil); lay the paper on the mercury, and on

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* *Hints to Travellers.*

the paper the sextant-glass well cleaned. Pressing gently on the glass, withdraw the paper-slip; turn the sextant-glass on its face on an inclined plane, to let the mercury run off. After twelve hours, remove the edges; and after twenty-four hours, varnish with spirits of wine and red sealing-wax.*

The Artificial Horizon.

This may consist of a plate of polished metal, or of darkened glass made horizontal by means of screws.

The instrument is portable, but unsatisfactory in its results.

The artificial horizon by Staff Commander George, R.N., made by Messrs. Gould and Petrie, No. 181 Strand, consists of a disc of glass floating on mercury in a vessel that it nearly fits. A very small trough thus used gives as wide a field of view as a large trough used in the ordinary way. The reflection of the glass causes its under surface to be optically raised, and therefore the edges of the trough cut off proportionately less of the field of view.

When people are walking near, and during wind, it is very steady. Very low altitudes may be observed with it, because the reflection from the upper surface of the glass becomes so bright as to reinforce the reflection from the mercury below.

When the mercury is pure, its surface clean, and the glass

* The observer should practise first on common bits of glass. A better plan is to have in the sextant-box, folded in cotton-wool in secure recesses, spare index and horizon glasses ready silvered.

of the best workmanship, this horizon gives excellent results.* Otherwise, errors of 2½ minutes in the half of the observed altitude may occur.

Before introducing the mercury, cleanse the trough from dust.† When setting the glass afloat, place a piece of paper or of thin silk on the mercury, and upon it the glass.

Then carefully withdraw the paper (or the silk) from under the glass.

The Mercurial Horizon.—Altitudes taken from uncovered mercury are thoroughly reliable. Errors introduced by the glass-roof may be partly eliminated by reversing the cover between each pair of observations. For this purpose, one of the faces of the glass-roof should be marked.

The iron trough (to hold the mercury) should be not less than 3¼ inches inside length, because the convex border of the mercury is useless, and the surface of the central portion is fore-shortened to the observer.

A board 18″ × 12″ × 1″, whereon to place the trough and the glass-roof on the ground, should be provided. If the board be

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* To test the accuracy, direct a telescope furnished with cross-wires downwards to the mercury; and with the cross-wires, intersect the reflection of some well-defined point many yards distant. Reverse (or disturb) the mercury. When it has come to rest, observe whether the cross-wires still intersect the reflection of the same point.

† A wooden scraper fitting close to the inner breadth of the trough, will remove the scum. The scum adheres to the wood.

covered with thick soft cloth, the glass-roof will sink into it and thus exclude wind.*

Every care must be taken to see that the glass-roof is wind-proof; some glass-roofs have a slit along the ridge whereby wind gets to the mercury.

Captain Wharton, R.N., recommends the use of a stand for the artificial horizon; but I am opposed to its use.

If one is to have a stand for the sextant, a stand for the sextant-stand, a stand for the horizon, and a stool for the observer, it will be better to discard the sextant and to take up the transit theodolite.

A stand for the artificial horizon is quite unnecessary.

The artificial horizon box should be well made, secured with screws and brass clamps, and furnished with a stout leather strap and brass buckle. The hooks and the lock and key should be of the best.

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* When taking equal altitudes for time (forenoon and afternoon), the observer should have on both occasions the same face of the glass-roof opposite to him. What is desired is not correct altitudes, but equal altitudes.

In his work on *Hydrographical Surveying*, Captain Wharton, R.N., says:—

"The trough should rest on an iron plate, to which should be screwed iron battens to prevent wind from getting underneath the glass-roof.

"The stand for the mercurial horizon consists of two parts. The lower part is a plate with three short legs, on which it firmly stands.

"The upper is pierced by three large-headed screws, that serve as legs, these fit into slight hollows in the lower plate. By adjusting these screws, the horizon laid on the upper plate can be levelled.

Inside the box should be a wooden scraper, of such a size as to fit close to the inner breadth of the trough, for the removing of scum, and a piece of chamois (washing) leather for the cleansing of the mercury.

The Lamp.

A good light is indispensable for reading the vernier by night.

A signal lantern, with the axis of the reflector or lens inclined a little downward will suffice.

In *Hints to Travellers*, an oil lamp with a large wick is recommended.

In these days, probably the best of all lamps would be an electric lamp. Such a lamp, with generating apparatus, may be obtained for about £5 at the Electric Apparatus Company, Charing Cross, London.

The Stars.

To make use of stars, to know them, a map is necessary. Without a map and without careful observation of the heavens it is impossible to recognise stars.

For practical use, the best work is a book by Rosser, price *7s.* 6*d.*, published by J. Murray & Son, entitled, *The Stars, how to know them, how to use them.* The book being studied, the subjoined remarks may be of service :—

The following stars form a right-angled triangle:—

1. α Boötis (Arcturus), α Coronæ Borealis (Alphecca), and α Serpentis (Unuk).
2. α Boötis (Arcturus), α Virginis (Spica), and α Leonis (Regulus).
3. α Boötis (Arcturus), α Virginis (Spica), and α Scorpii (Antares).
4. α Scorpii (Antares), β Libræ, and α^2 Libræ.
5. α Scorpii (Antares), α Coronæ Borealis (Alphecca), and 12 Canum Venaticorum (Cor Caroli).

The following stars form an equilateral triangle:—

1. α Lyræ (Vega), α Aquilæ (Altair), and α Ophiuchi.
2. α Orionis (Rigel), α Arietis (Hamal), and α Columbæ (nearly).
3. α Arietis (Hamal), α Ceti (Menkar), and the Pleiades.

The following stars form an isosceles triangle:—

1. α Tauri (Aldebaran), β Tauri, and the Pleiades.
2. α Tauri (Aldebaran), γ Tauri, and the Hyades.
3. α Boötis (Arcturus), α Virginis (Spica), and β Libræ.

α (Markab), β (Scheat), and γ (Algenib), all of Pegasus, with α Andromedæ (Alpheratz), form a body like the body of the Great Bear; and β and γ (both) Andromedæ with α Persei (Mirfak) form a tail like the tail of the Great Bear.

The Lunar Star, α Leonis (Regulus), 1° magnitude, is an inconspicuous star not easily recognised. By the followin directions it may be known :—

1. α Boötis (Arcturus), α Virginis (Spica), and α Leon (Regulus), form a right-angled triangle.
2. α Boötis (Arcturus), β Leonis (Denebola), and α Leon (Regulus) are in one line.
3. A line through the pointers α β, Ursæ Majoris, will pas between α Leonis (Regulus) and β Leonis (De nebola), Regulus being westward.
4. A line from α Ursæ Majoris drawn 20° west of β Urs Majoris will point to Regulus.
5. A line from α Orionis (Betelgeuse) drawn 1½° north o β Canis Minoris will point to Regulus.
6. A line through δ, γ Ursæ Majoris will pass throug γ^1 Leonis and α Leonis (Regulus).

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