PRACTICAL

MARINE SURVEYING.

BY

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PREFACE.

THE need of a suitable text-book on Marine Surveying for use at the Naval Academy has been felt for several years by the officers engaged in teaching that subject.

Having been engaged exclusively in surveying work for six years previous to my assignment to duty at the Naval Academy, I was requested by the Head of Department of Astronomy, Navigation, and Surveying to prepare a text-book on Marine Surveying to take the place of the one then in use.

After considerable thought, I agreed to undertake the task, and the present volume is the result; and it is earnestly hoped that it may be of value, not only as a text-book for the Academy, but to others who may be without experience in surveying work.

With very few exceptions, all the methods that are explained have been used in actual practice and found to work satisfactorily.

The method of reducing the "broken base" and the plan of having more than two parts when necessary are believed to be original with this work, as is also the method of calculating distance from the mast-head angle.

Chapter V, on the Projection, was specially prepared for this work by Lieutenant Commander Asa Walker, U. S. N.

In the chapter on Astronomical Work I have described the method of establishing positions by the use of the sextant and artificial horizon, as those instruments are to be had on board of every ship and would have to be used in making a small survey.

The transit instrument is the instrument *par excellence* for latitude and time determinations, and no outfit for an extended surveying expedition is complete without one.

For the method of plotting angles by means of chords I am indebted to Wharton's *Hydrographical Surveying*, and I have received much valuable assistance from the U. S. Coast Survey Reports, from which the cuts of several of the instruments were also taken. The theodolite represented on page 2 is the latest pattern by Fauth & Co. of Washington. The cuts of the Y-level and surveyor's compass were kindly furnished by Messrs. W. & L. E. Gurley of Troy, N. Y., makers of these excellent instruments.

I have attempted to cover all the points that may arise from the beginning to the end of a marine survey and make the whole process as clear as it really is simple and straightforward, and in conclusion I would say that in Marine Surveying, while good instruments are a prime necessity, yet the very best instruments will not give accurate results without a careful, conscientious, and painstaking attention to all the details which play so important a part in this work.

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U. S. NAVAL ACADEMY,
ANNAPOLIS, MD.,
September, 1889.

CONTENTS.

PRACTICAL MARINE SURVEYING.

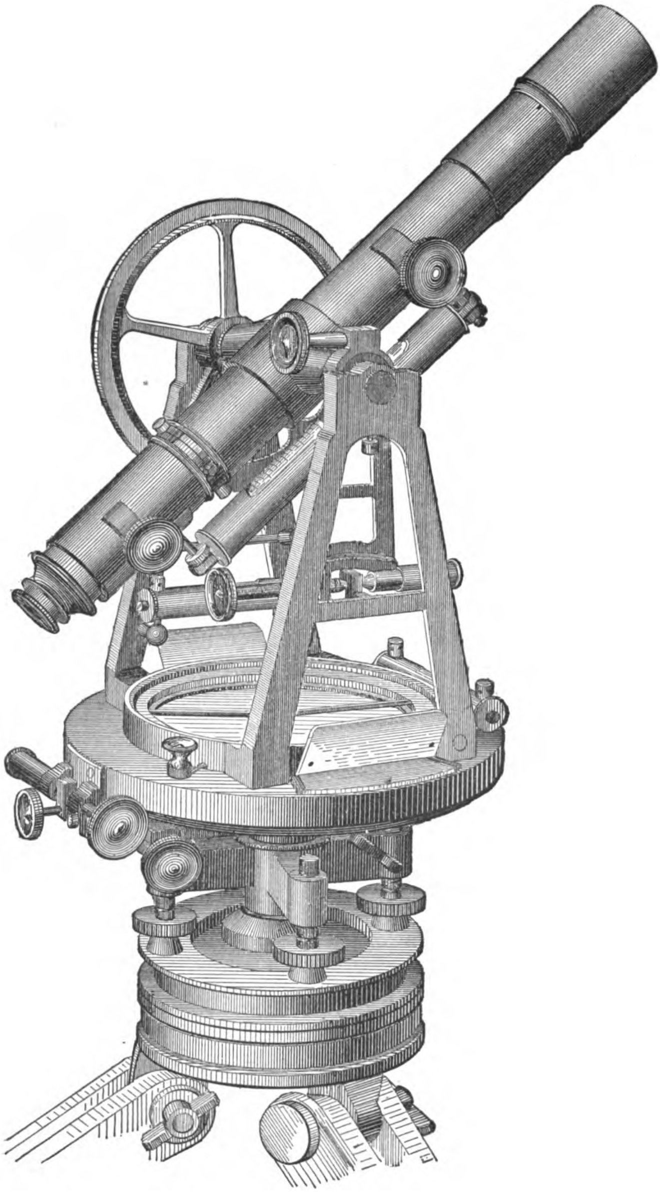
CHAPTER I.

INSTRUMENTS.

1. THE instruments of most frequent use in a nautical survey are the theodolite and sextant for measuring angles, and the three-arm protractor for placing them on the projection. In connection with the theodolite the heliotrope is used to enable stations that are beyond the power of the telescope or otherwise indistinct to be angled upon.

The details of the construction of theodolites vary with different makers, though all are manufactured on the same principles.

2. A theodolite consists of a telescope of moderate power fitted with a horizontal axis, which enables the line of sight to be moved in a vertical plane, supported by standards on the upper of two plates, one or both of which are capable of revolution about a vertical axis, and which have clamps and slow-motion screws fitted for controlling their motions. The lower plate is graduated from zero to 360° right-handed, and the upper plate carries one or more verniers by which the angular space on the lower plate passed over by the upper one is measured. The vertical axis is supported by a metal frame-work fitted with levelling-screws, by which its position may be



7-INCH REPEATING THEODOLITE WITH VERTICAL CIRCLE.

changed. Attached to the upper plate are two levels at right angles, by means of which and the levelling-screws the verticality of the axis may be assured. A magnetic needle is mounted in a suitable case in the centre of the upper plate, between the standards of the telescope; and there may be a graduated circle attached to the horizontal axis of the telescope in a vertical plane, with a vernier on the standard, for measuring vertical angles, in which case a clamp and tangent-screw are also attached to axis. Within the telescope, in the common focus of the eye-piece and objective, is placed the diaphragm, a ring of metal having two fine threads or wires attached to it, crossing its plane at right angles to each other. This diaphragm may be revolved about the optical axis of the telescope, and may be moved in any direction at right angles to this axis by means of four screws attached to it.

In order to place a theodolite in proper condition for observing it must be adjusted as follows:

3. To place the axis of the azimuth circle vertical or the plates horizontal: Plant the tripod on which the instrument is to be mounted firmly on the ground, pushing the feet into the soil if it is soft, and place the instrument on top of it. Turn the azimuth circle until one of the levels—the most sensitive, if there is any difference—is parallel to the line joining two opposite foot-screws, and by them bring the bubble to the centre of the tube. Turn the circle through 180° and, if the bubble is not in the centre, correct half the error by the foot-screws, the remainder by the screws attached to the level. Turn the circle to the first position and adjust the level again, and repeat until the level is in perfect adjustment. This result will be much facilitated by placing the level at right angles to its first position and bringing the bubble to the centre by the other foot-screws, after having made the first adjustment of the level by its screws and then continuing the adjustment as described. Now place this level at right angles to its original position and bring the

bubble to the centre by means of the foot-screws, and then bring the bubble of the other level to the centre by the screws attached to it. The levels being adjusted, the axis is placed vertical by bringing both bubbles to the centre, one of the levels being parallel to a pair of foot-screws; and the correctness of the adjustment is tested by the steadiness of the bubbles when the circle is turned slowly in azimuth through a complete revolution.

4. Next adjust the threads of the telescope to the common focus of the eye-piece and objective. Move the eye-piece in or out until the threads are most distinct, and then move the eye-*tube* or the object-glass in or out until a distant object is clearly seen, and bisect it with the vertical thread. Move the eye sidewise, and note if the object remains bisected. If it does not, the adjustment is not perfect. If the object seems to move to the same side of the thread as the eye, the eye-piece must be drawn out slightly and the object-glass refocussed. If it moves the other way the eye-piece must be pushed in slightly.

5. The vertical thread is placed in a plane perpendicular to the horizontal axis of the telescope by bisecting a sharply defined object and turning the diaphragm until the thread continues to bisect it, when the telescope is moved in altitude, bringing the object alternately to the top and bottom of the field of view.

6. To adjust the line of collimation of the telescope: The line or axis of collimation is an imaginary line from the optical centre of the object-glass perpendicular to the axis of rotation of the telescope.

The line of sight is the line passing through the optical centre of the object-glass and the middle point of the vertical wire. To be in adjustment, these two lines must coincide. To effect this adjustment, having made those already described, point the telescope at some sharply defined object and read the circle. Transit the telescope, i.e., revolve it on its horizontal axis through 180°, and by means of the graduation turn the telescope through 180° in azimuth. If it points to the same object, the adjustment is good; if not, read the angle on the circle and then point at the object and read its angle. The difference is twice the error. Turn the telescope back half the difference, and by means of the screws on the diaphragm bring the thread on the object. Repeat this operation to see that the adjustment is good, and then a final test may be made thus: Point at any object in sight and perfect the intersection. Transit the telescope, and notice what object is on the wire in that direction, to the rear. Turn the telescope in azimuth through 180° and bisect the original object, and then transit again and see if the same back object is on the wire, as it should be. If it is not, the amount it is off is four times the collimation error, and only $\frac{1}{4}$ of it should be corrected by the diaphragm. It will be seen that this test is most useful as any error is quadrupled.

7. Should the telescope happen to be lifted from its supports and the horizontal axis shifted end for end, the adjustment is very simply made. Point at any object and clamp the plates. Reverse the axis and correct half the deviation with the azimuth-screws, the other half with the diaphragm-screws.

8. On most theodolites the axis of revolution of the telescope is made perpendicular to the azimuthal axis by the instrument maker, and there is no provision made for adjusting it. If, however, there is a screw for moving one of the Y's, the axis is made horizontal by using a small striding level, resting upon its extremities. Level the plates and place the level on the axis. Bring the bubble to the centre by means of the Y-screw. Turn the theodolite through 180° without removing the level and bring the bubble again to the centre, half by the Y-screw and the remainder with the level screw. Perfect the adjustment by repetition. If there is no level available, place an artificial horizon in front of the telescope in such a position

that by looking in the mercury through the telescope the reflection of some distinct elevated object may be seen and bisected. Clamp the plates and then point towards the object. If it is on the wire, the axis is horizontal. If the wire is to the right of the object, the right end of the axis must go up, etc.

9. The horizontal axis may be adjusted without using any auxiliary instruments. Point at a distinct elevated object and clamp the plates. Turn the telescope down, and note what mark at the foot of the object—below the level of the theodolite if possible—is on the wire. Transit the telescope, point at the upper object and then at the lower one, as before. If the same mark is on the wire at the last pointing as was at the second, the axis is in adjustment; if not, half the error must be corrected with the Y-screw. The theodolite must be carefully levelled during this adjustment.

10. The theodolite is now ready for use. By taking half the observations in astronomical work "telescope direct," and the other half "telescope reversed," i.e., turned in azimuth 180° and transited, or in terrestrial work taking each set direct and reversed, the angles are corrected for any remaining defects of adjustment and for eccentricity. Vertical angles should always be taken telescope D. and R. as the mean eliminates any error in placing the zero of the vertical arc.

11. A small theodolite, 5″ circle, called the "Bureau theodolite," it being the Bureau of Navigation pattern, is very useful in harbor and coast-line work. It has but one movable plate, no vertical circle, reads to minutes, and is levelled by four screws acting on the end of the vertical axis, which is fitted with a ball-and-socket joint. The telescope has an object-glass 1″ diameter, and signals may be observed up to about 10 miles.

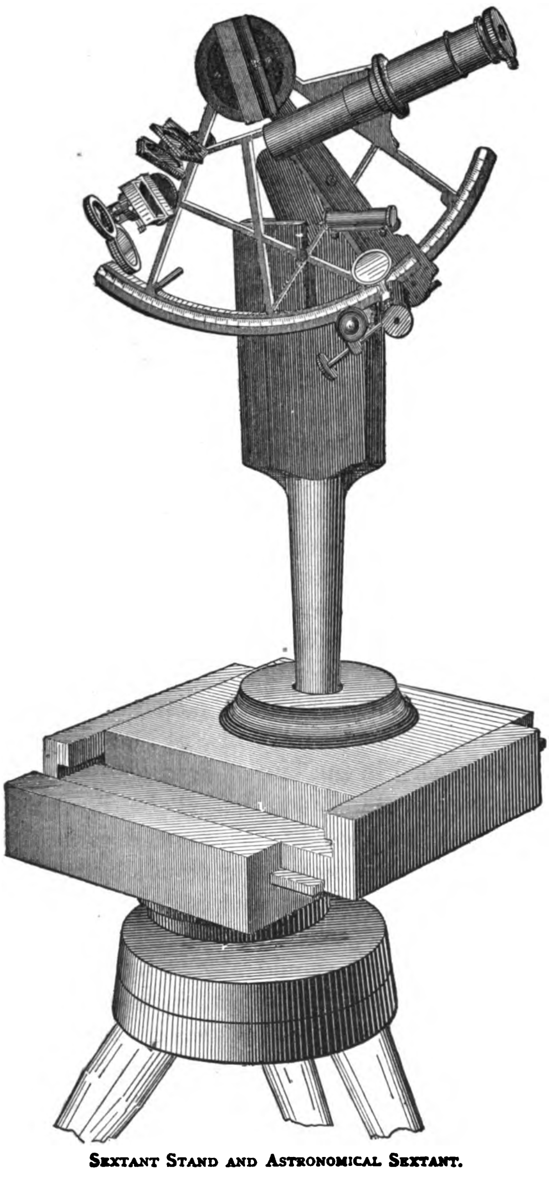
It usually has but one vernier, which is under the eye end of the telescope, so that angles may be observed and read very rapidly with it. The telescope may be reversed, but angles cannot be repeated with it.

12. The construction and adjustments of the sextant need not be described here, being well known. The use of the sextant for measuring horizontal angles, though a little novel at first, is soon acquired, and presents no special difficulty.

For hydrographic work small light instruments are desirable, reading to half-minutes, and capable of measuring angles up to 135°, and having a terrestrial telescope with a large object-glass in place of those usually supplied. When sextants are to be used in boat-work a spare set of mirrors should be supplied with each instrument, so that they may be replaced without delay when those in use become clouded from dampness.

13. In astronomical work special superior sextants are used. They are accurately graduated and tested for eccentricity, have large telescopes fitted with diaphragm, and have a spirit-level on the *arm* at such an angle that when the bubble is in the centre and the telescope pointed to the artificial horizon the image of the same star is seen in the mercury as is seen reflected by the two mirrors. The colored shades are not used in artificial horizon work, but instead a colored eye-piece is screwed to the telescope. This eye-piece contains a revolving disk having four shade-glasses in it, and one blank hole, any one of which may be placed in the line of sight as desired. This is of special advantage in cloudy weather, as the direct and reflected suns may always be kept at the same degree of brightness when partially obscured by passing clouds by turning the disk without delaying observations, and without risking the loss of any contact of a set.

14. A sextant stand should always be used in shore-work with the sextant on account of the increased accuracy of observations and comfort of the observer. A very convenient stand may be made as follows: a circular block of wood, 2″ thick, 6″ diameter, has hinged on its under side three legs about 1′ long, and fixed on its upper side a peg 1½″ diameter, 2″ long. Over this peg fits a *head* made of three pieces about



Sextant Stand and Astronomical Sextant.

8″ square, the lower one having a socket to fit the peg, the centre piece sliding in grooves in the lower and the upper piece sliding in the centre one at right angles to the direction it slides in the lower. The upper piece has a socket in the centre in which rests the support of the sextant. This is shaped like a tuning-fork, and the handle of the sextant slips into the hollow of it with a slot for the bar by which the handle joins the sextant, to fit in. The friction in this slot keeps the sextant in any desired position, and the sliding head allows the whole to be moved so as to keep the heavenly body in view in the horizon. In reading, the sextant is lifted with the fork; and after reading, if replaced carefully, the two images will reappear in the field.

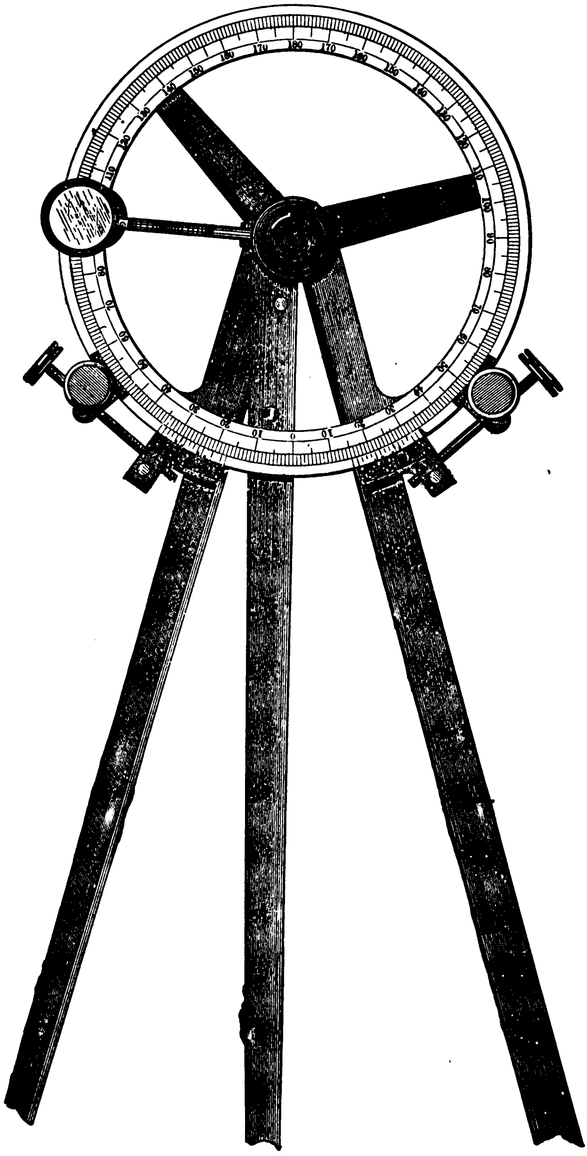
15. A stand for use with the artificial horizon will be found very useful in preventing vibrations of the mercury from wind, and, in A.M. observations, in keeping moisture from penetrating to the inside of the roof and condensing on the glasses. It is made of a piece of inch board, well-seasoned, about 6″ × 10″ with four sharp legs about 3″ long on the corners, of wood or metal, and has a rectangular groove on its upper surface about ¼″ deep, in which the roof fits snugly. The legs are forced into the ground by pressure of the foot, and a smooth, level, clean, and firm rest is formed for the horizon, which greatly assists, when decanting the mercury, in keeping out sand and dirt, and when set up effectually keeps out wind. A sheet of felt or fearnaught tacked to the board serves equally well, and also deadens any slight jars from persons moving in the vicinity during observations. If one side of the stand is placed in the meridian at the commencement of night observations no time will be lost in placing the horizon correctly when changing from N. to S. stars, and *vice versa*.

16. The three-arm protractor consists of a graduated circle having three radial arms revolving on the centre of the circle in a parallel plane. One is rigidly connected to the circle,

the others are movable, and have verniers, clamps, and tangent-screws attached so they may be set and secured at any desired reading on the circle. The arms have each one edge perfectly straight, and these edges, if produced, always pass through the centre of the circle, no matter in what positions the arms may be placed. The centre of the hub is hollow and a disk of glass with a fine hole in its centre fits therein so that at any time the central point may be marked on the chart on which the instrument rests. On one side of the centre arm the two edges of the fixed and movable arms may be made to coincide, or the angle between them made zero. On the other side the angle is limited by the construction of the instrument. 10° to 13° are usually the smallest possible angles.

17. The instrument is ready for use when the verniers have been adjusted. Close the two arms until the edges coincide and clamp the movable one. See that the edges coincide throughout their length, and then move the vernier until its zero coincides with the zero of the circle, and screw it securely in that position, noting also that the highest mark on the vernier also coincides with a mark on the circle. With a straight-edge draw a long line on a sheet of paper. By means of the adjusted vernier set the arm 180° from the centre arm and place the extremities of the arms on this line, and note if the centre of the instrument is on the line. Unless the graduation is bad, it will be, if the vernier was properly adjusted. Now keep the fixed arm on the line, turn the adjusted arm away from it, and bring the third arm with its edge on the line. See that the ends of these arms and the centre of the instrument are on the line, and then set the second vernier to exactly 180°. The accuracy of the graduation may be tested by laying off a series of angles by means of chords, as will be described presently, and measuring these angles with the protractor.

18. The use of the protractor for laying off angles that have been observed from a plotted position needs no explanation.



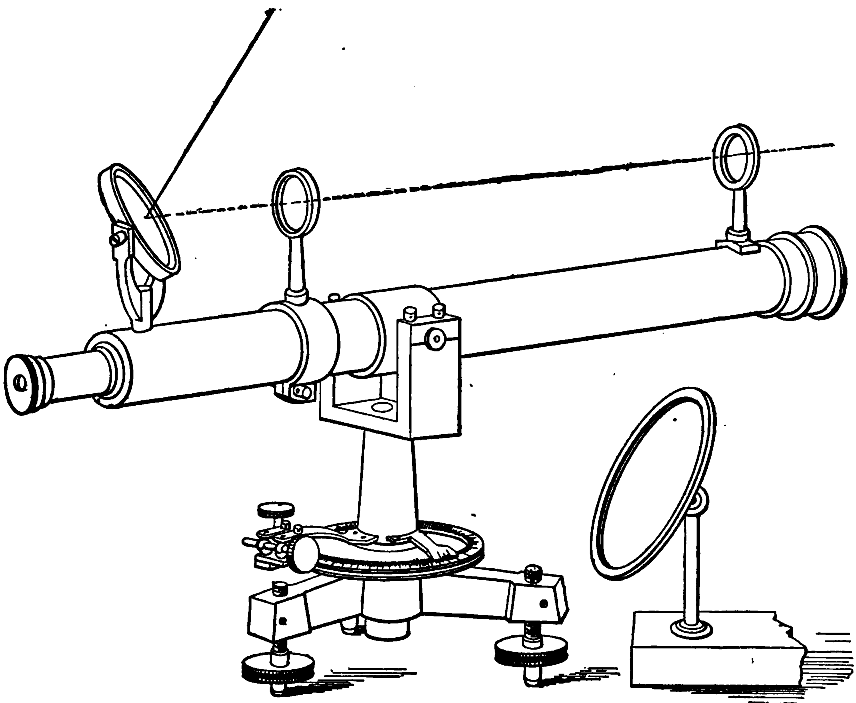
Three-arm Protractor.

In sounding-work its main use is in the graphic solution of the three-point problem. Two angles having been observed from an unknown point between three known stations, the arms are set to the observed angles—the right arm to the angle to the right of the central station, and the left arm to the other.

Place the protractor on the chart and slide it about until the three edges pass through the centres of the points representing the observed stations. The centre of the instrument is then at the point on the chart corresponding to the position occupied, and this point is marked with a pricker, or needle, through the central hole. This pricking through is much facilitated by the use of a small cylinder of brass, which fits the central hole and has a plunger with a fine sharp point accurately fitted in its centre, and by tapping this plunger the centre is accurately marked.

19. The heliotrope, used in connection with the theodolite, consists of a telescope about 20″ long, about 1½″ object-glass, having a diaphragm with two threads at right angles. Attached to the tube of the telescope near the eye end is a small circular mirror about 1½″ diameter, having motion about two axes—one perpendicular to that of the telescope, the other perpendicular to the first. Near the object end of the tube is a ring set perpendicular to the axis of the tube. The centre of the mirror and centre of this ring are on a line parallel to the line of sight of the telescope. There is a wood screw attached to the centre of the telescope, with a hinge joint by which it may be fastened to a stump, block of wood, or a signal. A second mirror is supplied to be used when the sun is more than 90° from the station to which the flash is to be sent. In use, the instrument is screwed to a stump or block of wood at the station to be observed upon, and the telescope directed towards the observer's station, which is bisected by the cross wires. The back mirror is then turned until the light spot falls on the front ring. This spot is circular, and is a little larger than the

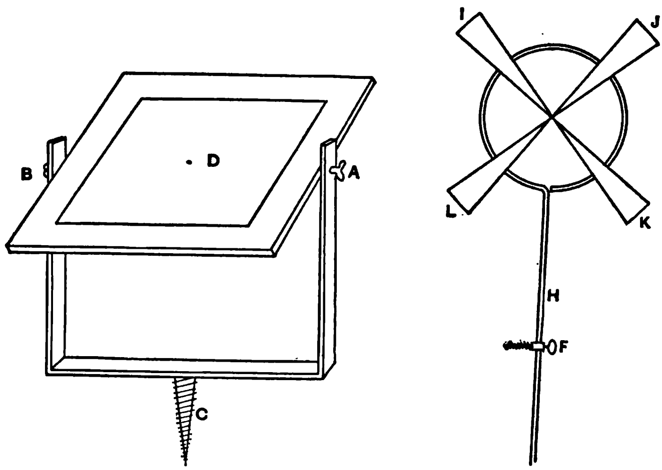
hole in the front ring, but smaller than the outer circumference of it, and the mirror is adjusted so that the ring is illuminated equally all around the hole. The flash is then in the right direction, and is kept so when the sun changes its position by



HELIOTROPE.

turning the mirror so as to keep the ring and light spot concentric. The heliotrope represented in the cut is one in use in the Coast Survey and is more elaborate than the one described, having a second ring near the eye end, which casts a shadow on the other, and having the graduated circle which permits of its use for measuring angles.

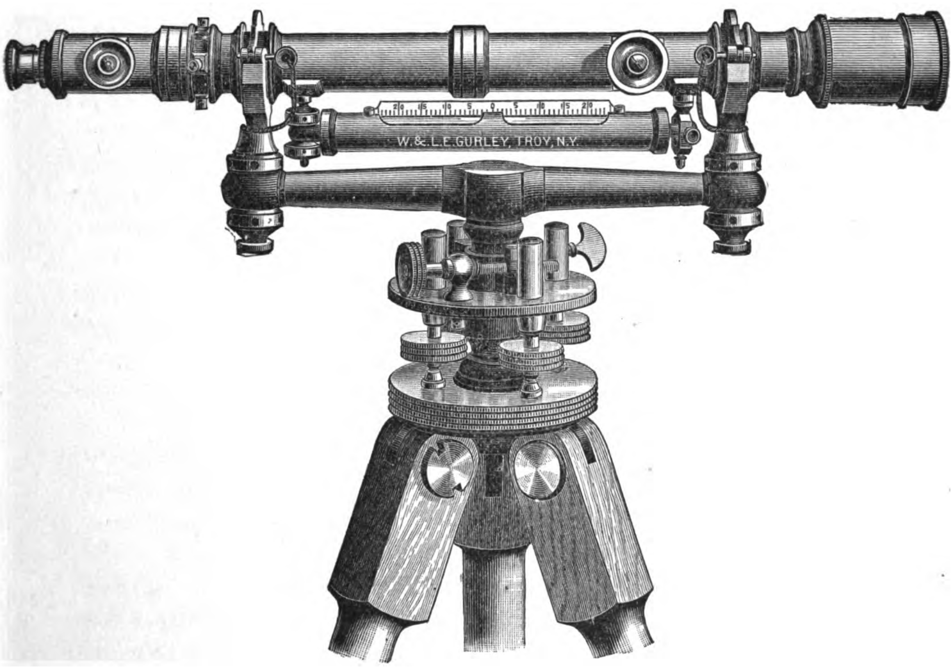
20. In the absence of this instrument a substitute may readily be made on board ship which will fulfil all the requirements. Fit an ordinary mirror with a yoke as shown in the sketch, having pivots at *A* and *B* and a wood screw at *C*. In the centre of the mirror at *D* scratch a hole about $\frac{1}{8}''$ diameter in the amalgam, and cut a hole in the back of the frame so this



spot may be looked through. Also make of round iron a ring with a handle as in the sketch, and secure to it four pieces of cardboard or tin about 6″ long and 1″ wide at the ends, wedge-shaped, *black*. Fit also a collar *F* with a wood screw and set-screw. To use this set up the mirror over the proper point, and, looking through *D* at the observing station, drive a stake in range with it about 3 feet from the mirror, to which screw the collar *F*. Put the rod *H* through *F* and clamp it when the centre of the circle is in line between the centre *D* and the observing station. Turn the mirror until the slips *I*, *J*, *K*, *L* are each equally illuminated from the centre, and the flash will be in the right direction, and may be kept there by slight motions of the mirror. The best plane glass possible should be used, or the rays will be dispersed before travelling far. The yoke may be made of iron $\frac{3}{4}''$ wide by $\frac{1}{4}''$ thick, and the ring of $\frac{1}{4}''$ round iron about $6''$ in diameter.

THE LEVEL.

21. The level used in measuring small differences of elevation is called the Y level, and its appearance is shown by the figure.



20-INCH Y LEVEL.

The requirements of the level are that the line of collimation shall be truly horizontal, and when turned on the vertical axis shall move in a horizontal plane.

To adjust the level it is first necessary to make the line of collimation parallel to the bottoms of the collars. Set up the instrument, and with the level down point at some object and bisect it with the horizontal wire at the intersection of the two wires. Revolve the telescope in the collars until the level is up, and if the object is still bisected the adjustment is made for that wire. If not, by means of the screws on the diaphragm move the wire half-way back to the object, and bisect it by means of the levelling-screws. Revolve the telescope and repeat the operation until the adjustment is perfect. At the same time adjust the vertical wire as in a theodolite. (Art. 7.)

Next make the plane of the level on the telescope parallel to the line of collimation. Clamp the instrument and bring the bubble to the centre by means of the levelling-screws. Lift the telescope from the Y's and turn it end for end. Bring the bubble to the centre, half by the foot-screws and half by the nuts on the ends of the level. Repeat until the adjustment is perfect. Revolve the telescope slightly on its axis, and if the bubble runs to either end of the tube, adjust it by the screws which bear against the *sides* of the tube so as to bring its axis into the plane of the axis of the telescope.

The last adjustment is to make the axis of collimation perpendicular to the vertical axis of the instrument.

Place the telescope parallel to one pair of diagonally opposite foot-screws, and bring the bubble to the centre by means of these screws. Turn the telescope through 180°, and note if the bubble remains in the centre. If it does not, half the error is corrected with the foot-screws and half with the nuts on the ends of the level bar. Repeat this operation, and then test the adjustment by placing the telescope in two directions, at right angles to the one first used, and note also if the bubble remains in the centre when the telescope is turned on its vertical axis through a complete revolution.

The instrument is prepared for use by setting up on its tripod and levelling. Place the telescope parallel to a pair of foot-screws and bring the bubble to the centre. Place it parallel to the other pair, and do the same. Then if the instrument has been properly adjusted it is ready for use.

REPAIRS TO INSTRUMENTS.

22. Should the cross wires of a theodolite become damaged or broken in any way they may be replaced as follows: Remove the diaphragm by withdrawing the four screws which hold it and slipping it out of the telescope tube. Carefully scrape away the balsam which held the old threads, and four radial scores will be seen on the face of the ring. Look about on shore among the bushes for a spider's web. Having found it, select one of the finest threads, and, having moistened the balsam remaining in the scores, place the ring against the selected thread so that it lies in two opposite ones; and then, pressing on it, break the web on either side, and repeat this operation for the other thread. If a common spider can be found, place it on a card having a hole in the centre about 2″ square, and shake it off. It will spin a web in falling, and by revolving the card this thread is made to cross the aperture in the card several times, and the threads may be fastened to the diaphragm as explained above.

23. It is always well to be able to resilver the glasses of sextants in case of any accidents to them. In boat work they are very often ruined by dampness.

Take a piece of tin-foil free from holes, about a quarter of an inch larger, all around, than the glass to be silvered. Place it on a piece of glass about 4″ square, and rub it out smooth with the finger. Put a small drop of mercury on the foil, and rub it with the finger until it spreads over the entire surface, giving it a silvery appearance, being careful to get none *under* the foil. Put on carefully a few more drops of mercury until the entire surface is fluid. Having previously made the glass perfectly clean, place it on a piece of tissue-paper whose edge just covers the edge of the foil, and slide the glass carefully from the paper to the tin-foil, keeping a gentle pressure on the glass to keep out bubbles; and if any appear under the glass, slip it around on the mercury until they are worked out at the edges, or pick it up, wipe it, and slip it on again. When it has a good surface, place another piece of glass on top of the mirror and turn the whole set over, so that the first glass laid down may be on top. Lay the set on a slightly inclined surface, place a strip of tin-foil against the edge of the piece on the glass, to draw off the surplus mercury, place a small weight on top and set aside to dry. After five or six hours the surplus tin-foil may be removed, and the next day a coating of varnish made of spirits of wine and red sealing-wax may be put on the back of the mirror. For a horizon glass the foil must be cut with a clean edge, and the glass slid over it until it is only half covered by the amalgam. Too much time must not be lost in putting on the glass after the mercury is put on, or the tin-foil will be eaten through and spoiled. The mercury that is drawn off from the foil must on no account be returned to the bottle of clean mercury, or the whole will be ruined for an artificial horizon.

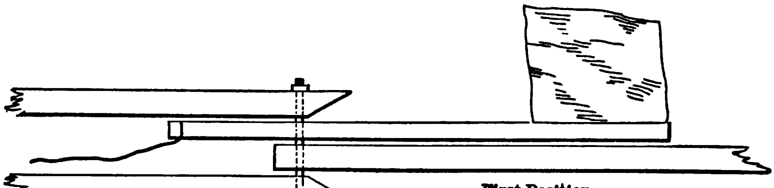
CHAPTER II.

CONSTRUCTION OF SIGNALS.

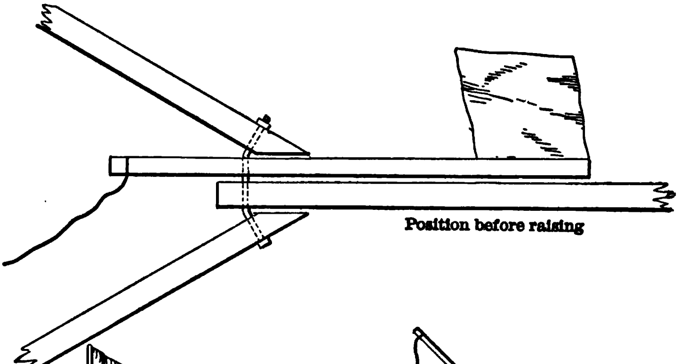
24. THE signals used in marking the positions located in a survey are of the greatest variety both as to construction and material.

For large signals, however, the standard construction is the tripod, surmounted by a pole and flag, which is constructed as follows:

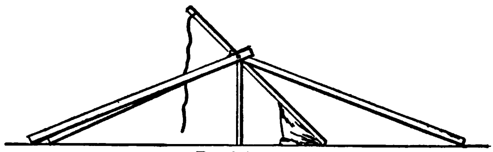
25. For a good-sized signal, legs about 24′ long may be used, of 3″ × 3″ scantling, and a pole 16″ long of 2″ × 3″ scantling. For covering, inch boards 6″ wide and about 16′ long will be found a convenient size. Provide a bolt of ½″ round iron with square head and nut on the other end, 13″ between heads, and plenty of nails, 8- or 10-penny. Prepare these pieces on board ship by boring a ⅝″ hole in the three legs about 6″ from one end and a similar hole in the pole about 5′ from one end. Bevel the ends of two of the legs as shown in the sketch, and secure a flag of sheeting about 6′ × 9′ on the flag-pole. On arriving at the position at which the signal is to stand, place the two bevelled legs together with their heads over the centre of the station and the third leg with its head between their heads, but extending in the opposite direction, and place the pole with the hole abreast the three heads. Put the bolt through one bevelled leg and the square head one, then through the pole, and lastly through the other bevelled leg and put on the nut. Secure a line to the short end of the flag-pole, and



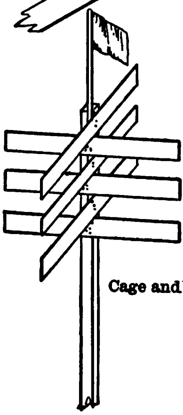
First Position



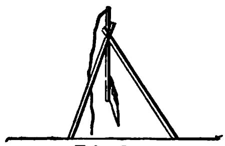
Position before raising



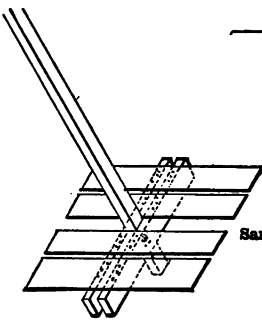
Partially raised



Cage and flag



Tripod up



Sand anchor

spread the heels of the outer legs about 15′ apart. (This will bend the bolt a little.) Three or four men now take hold at the bolt and raise it straight up about 5′, and put a stick of wood under it to hold it up. Let one man go to the heel of each leg, two to the middle one, and have those at the outer legs hold the ends on the ground. Lift again on the head, and the two men on the middle leg carry its end towards the centre, pushing up towards the head, and the tripod will be erected. It will be very easy now to move the feet of the tripod so they will be equally separated, and the head will be over the centre of the station. In raising the tripod, care must be taken that it does not fall over sidewise.

26. Place the heels about 15′ to 20′ apart, in an equilateral triangle, with one face inshore, so that one face will show up and one down the coast. If the tripod is in an exposed position, it must now be anchored securely. A good sand anchor is made by nailing two pieces of scantling 3′ long on either side of the ends of the legs, at right angles to them, and nailing three or four short pieces of board on these cross-pieces. Dig a hole about 3′ deep for each leg and fill in on top of the anchors with sand or rocks. Next nail a board across each face of the tripod about 6′ above the ground. By means of the line on the flag-pole swing it into a horizontal position, and secure the line to one leg for a time. Board up the two offshore faces, making the spaces equally wide with the boards; and when within about 6′ of the top, swing the flag-pole vertical, and secure it by a short brace from its heel to each leg of the tripod, and then continue the boards to the top. Loose the flag, and whitewash the outside of the tripod from the top down.

27. Fourteen boards 6″ × 16′ will be enough for two sides of a 24′ tripod, with two pieces across the inshore side. If desired, a cage may be nailed on the upper end of the pole instead of a flag, and whitewashed before being placed vertical.

This cage is made of 6″ wide boards about 6′ long, nailed at right angles to the pole and alternately to each other, as in the sketch. If the soil is such that the legs may not be buried, stakes may be driven alongside each heel and spiked to it, or guys may be secured to each leg and set up to rocks, trees, or stakes. For tripods, bolts should be of ½″ iron up to 24′ legs, and above that of ¾″ iron, and should be two inches longer than the total thickness of wood they must pass through.

28. Sometimes a skeleton tripod is put up to support a flag over a station and allow of its occupation by theodolite at the same time. In this case the first boards are put on all around, and another set as high as may be reached by standing on these. It will be found a great convenience to nail pieces of wood about a foot long to one leg to form a ladder to climb the signal. Flags are made of yard-wide sheeting stitched together in as many widths as desired. For a 40-foot tripod three widths each of six yards long, making a flag 9′ × 18′, were used.

29. Signals are distinguished by putting different-colored flags, or by putting black stripes with white, either horizontal or vertical. White, black, and red muslin are the colors most used. In securing the flag to the pole, the best method is to take a couple of laths, roll a few inches of the head of the flag about them, and nail them to the pole. Should it be desired to erect a tripod without a bolt, the two outer legs must have their heads securely lashed together, the heels being spread, and the third leg loosely secured to this crotch with a lashing that may not slip on *that* leg. Great care must be taken to leave plenty of slack in putting on this lashing, or it will jam and carry away before the head of the tripod is high enough. The flag-pole must be lashed on after the tripod is up.

30. The sizes of scantlings necessary for legs are 2″ × 3″ up to 16′, 3″ × 3″ up to 24′, 3″ × 4″ up to 32′, and 4″ × 4″ beyond that. Legs longer than 40′ should be obtained in special sizes, according to the time the signal must stand and the amount of boarding put on it. With three 40′ legs and by splicing a 2″ square pole 25′ long to 12′ of 3″ × 3″ scantling for flag-pole, a signal having the flag 67′ above the ground was built; this height being necessary to enable the flag to be seen over a high table-land in order to cut in an observation spot in a river bottom.

31. Smaller signals which are not required to be seen a great distance may be made of a single pole with a cage or flag on it, buried about 2′, and supported by braces or guys a few feet above the ground. In wooded countries small saplings make fine poles, and may be used as braces. Poles may also be spiked to tree stumps, and in some cases a long pole with flag projecting from the top of a tree has been used. Driftwood is often met on the beach sufficient to build signals for miles. Barrel staves make good cages. On the summit of a hill a cairn of stones built about a short pole makes an excellent signal. All these are to be whitewashed to increase their visibility; and isolated rocks, points of bluffs, and trees, when whitewashed, make excellent signals. In rocky soil a pole with flag may be stepped in a shallow hole and supported by three spun-yarn guys set up to rocks or stakes about the pole, the heel being secured by piling rocks about it. A barrel filled with earth and whitewashed makes a good signal in many positions. When surveying near towns, many signals will be found already prepared—such as church spires, cupolas of buildings, flag-staffs, factory chimneys, lighthouses, etc.; the last being specially useful, as they have a large range of visibility, and, being at prominent points of the coast, may be used in cutting in other signals; and in addition, they *must* be plotted on the charts. Fixed beacons in harbors may also be used as signals. Thus far all signals have been supposed to be on shore. At times in the survey of shoals at the entrances of harbors the signals on shore may not be placed to give good angles, either being on the same circle or having too little spread.

In this case water signals must be put up on the shoalest spots and cut in from the other signals. Where the bottom is of mud, a sharpened scantling may be driven down several feet in the mud and a flag or cage secured to the top, which will last some time in ordinary weather. Where the bottom is rocky, a pole may be secured with guys and anchors. (See description of securing tide-staff.)

32. When the bottom is of sand a good signal is made of $1\frac{1}{2}''$ iron pipe, which may be pumped into the ground by forcing water through it from the top. The mining effect at the bottom allows the pipe to sink deeper and deeper as long as the pumping is kept up, and additional lengths may be screwed on as necessary. When pumping stops, the sand settles about the foot of the pipe and holds it securely. This method was used in the survey of the shoals at Sandy Hook, N. Y.

In some places there are no natural objects which may be whitewashed, and it may be impracticable to transport lumber for signals. Large pieces of white sheeting wrapped around bushes or spread on the ground on the side of a hill, the edges being covered with earth to keep from flying away, or hung over a bluff and secured with small stakes, make good marks.

33. At all triangulation-points permanent marks should be left so they may be recovered by future surveyors. Underground marks accurately placed at the centre of the station should have a bottle about six inches above them so their presence may be announced and they may not be accidentally disturbed by digging. Surface marks of cairns, stakes, or brick or stone piers are also used. The location should be accurately described in the description of signals, referring to landmarks that may be permanent, by bearings and distances. Stone piers with copper bolts to mark the centres, and iron posts 4″ to 6″ diameter, are used on Coast Survey stations of primary triangulation.

34. To distinguish signals in the records they are given dif-

ferent names, which should contain as few letters as practicable. The names should be such as are suggested by the character of the signal, by the coast in the immediate vicinity, or by the position of the signal. If on a position which has a name, that name or an abbreviation of it should be given to the signal. Letters of the alphabet have been used as names for signals, but the practice is not recommended. Names which have similar sounds should be avoided, and the same name should not be repeated in any season's work.

CHAPTER III.

METHOD AND PLAN OF A SURVEY.

BASE-LINES.

35. THE plans of marine surveys vary greatly. The extent of the work, the character of the country to be surveyed, the time to be put on it, the amount of detail required, the number of assistants available—all must be considered in making the plan for any survey.

36. In one respect, however, they are similar: all are built up on a system of triangles, having for their vertices the most prominent points in the country to be surveyed, by means of which their relative bearings and distances are determined. The minor points are connected with these triangles by a secondary system of smaller triangles, which may or may not be continuous, but which depend on the main triangles for their correctness.

By observing at each of three points the horizontal angle between the other two, a triangle can be formed which is similar to the triangle formed by the imaginary lines on the earth joining the three points. If from two of these points the angles to a fourth point be observed, a second triangle may be formed which is in the same ratio to the triangle on the earth as the first one to its triangle. In this way a series of triangles may be formed, which will begin and end at any two points which may be selected as the limits of the survey. From these triangles are known the relative bearing and distance of all the points used. To find the actual distances it is necessary to know one of the sides of the triangulation, and this must be found by actual measurement. A side of the first triangle is generally selected for measurement, and becomes the *base* of the system of triangles, and from it all the other sides may be calculated or plotted. It is not necessary to measure the base before doing any other work, for a correct chart may be made by plotting the triangles with an arbitrary length for the first side. The measurement of the base will then determine the *scale* of the chart, which must be found before any distances can be measured on it.

37. At the commencement of a survey the first thing to be done is to make a reconnaissance of the field by steaming along close to shore, noting the different characteristics of the coast, prominent points, etc., and selecting those that seem best situated for the main triangulation. The next thing is the selection and measurement of the base, though the measurement may be deferred if desired.

BASES.

38. In the selection of a base for a survey three things must be considered: The *ground* must be as level as can be found; the *direction* of the line should be such as to make the first triangles well conditioned, and not too numerous; and the *length* will depend on the extent of the survey that is to be based on it.

The extremities of the base must be visible from each other, and should be so selected that as many as possible of the triangulation-points may be seen from them.

39. Before deciding on the base it must be walked over to see that there are no serious inequalities of the ground, and the line may be shifted to one side or the other, or swung on any point of it as an axis, so as to cover the best ground and avoid obstructions, taking care, however, not to change the angles of the first triangles too much.

40. The ends of the base having been decided on, erect skeleton tripods carrying flag-poles and flags over the positions, and, when the signals are built and secured, find the centres of the stations by means of plumb-lines from the heels of the flag-poles. This will be found more expeditious and accurate than marking the stations, and then trying to erect signals over the points. Each station may be marked by underground marks or by driving a stake in the ground with a tack in its upper end to mark the central point. A very good mark is made by driving a piece of $\frac{3}{4}''$ round iron $3'$ or $4'$ long into the ground vertically, until its top is almost flush with the ground. This is readily hidden, and when recovered by digging is not likely to be disturbed by a chance blow of a shovel. A cold chisel may be used to make a score in the end, across the direction of the base, as a fiducial mark.

41. The method used in measuring the base will depend on the time that can be given to it, the nature of the ground, and the accuracy required in the work. There are seven ways of measuring, of greater or less accuracy and rapidity:

1. First in point of accuracy is the method used by the Coast Survey for the transcontinental triangulation, in which a special base apparatus was used, described in the Coast Survey reports.

It is a very long, tedious operation, and would not be used in a nautical survey.

2. Measure with 100-ft. chain, 20-metre chain, length of wire.

3. Steel tape and battens.

4. Sounding wire.

5. Telemeter rod and telescope, or angle subtended by a known length.

6. Astronomical base.

7. Base by sound.

42. The simplest method of measuring a base is with a chain, but the country over which the line passes must be quite level to give accurate results. A stretch of sand beach is most desirable and satisfactory, and the line may be lengthened on a curved beach by crossing the bight below high-water mark, measuring of course when the tide is out.

Lengths of heavy wire, such as telegraph-wire, may be used, as well as the usual steel chains of 20 metres or 100 feet. In any case prepare two poles about 5′ long, 2″ in diameter, having iron pins in the lower ends ½″ in diameter, 4″ to 6″ long, and pointed. On the end of the pole secure a thin brass or iron plate about 3″ in diameter, or slip on a collar having a shoulder on the lower edge. The chain or wire should have handles fitted to slip over the poles and rest on the plates or collars. With the oblong handles usually fitted to chains, the poles must be cut to fit them, or the handle must be shipped on the bottom of the pole, and the plate or collar put on afterwards to keep it in place.

43. In preparing these poles great care must be taken that the initial points of the chain shall correspond with the axes of the pins, which is effected by forging the pins of the proper shape, and by means of the compensating screws on the chains. When the chain is on the poles it is tested on a standard length laid off on deck, and when the chain is taut and straight, and the poles vertical, the distance between the points of the pins should be the exact standard length of the chain.

44. With the chain are ten pins of heavy wire about 1′ long, having rings in the upper ends. Tie a small strip of white sheeting to nine of them, and a strip of red or blue bunting to the tenth. This will make them more readily seen and recovered when in grass, sea-weed, driftwood, etc.

45. Measuring the base: Ship the chain on the poles and stretch it at full length, noting carefully that there are no kinks in it, and straightening any bent links. One officer and an

assistant are sufficient for measuring a base. The latter first takes a pole of some kind—any small piece of driftwood will answer—and plants it on the line 300′ or 400′ from the first station, being aligned by the officer who holds a pole over the centre of the station, and signals the assistant to move to right or left until he is on range between the two base stations.

46. The officer now takes the pins, counts them, and goes to the forward end of the chain. The follower holds his pole vertical with the point in the groove on the mark at the station, or in the ground abreast it. The leader draws the chain taut with the pole, lifting it up if necessary to swing it clear of obstructions, and seeing that it is straight between the poles, and, holding the pole vertical, is signalled by the follower, by waving the hand, to move right or left until he is on range with the other signal. When aligned the chain is drawn taut, and when at a tension of about 15 lbs. the point on the pole is forced into the ground until the plate brings it up. The follower then raises his pole, which slacks the chain, and the front one is drawn out of the ground, leaving a clean round hole; a pin with white rag is stuck in the ground close to this, and the leader moves on along the line, dragging the chain. The follower must gauge his pace by the leader's, so the chain will draw straight along the ground. When the follower comes to the pin he stops, the tug on the chain informing the leader of the fact, and puts his pole into the hole left by the leader, holding it vertical, and picks up the pin. The leader, facing about, draws the chain taut, and puts his pole in the ground on line with the back pole, and the signal left. The poles are raised as before, a pin left to mark the spot, and the chain drawn farther along.

47. When the mark on the line is reached, the chain should pass close to it, and then the signal, this mark and the follower's pole are used by the leader in keeping his line, the alignment being checked frequently by the follower, who

notes if the front pole and the objective signal are on range with his pole. At the end of the 10th fleet the *blue or red* pin is left in the ground, and the chain stretched for the next one. The leader then has no pins; so he stops, makes a mark on his staff or in his note-book, or puts a stone or shell in his pocket as a tally. The follower, when he comes to the 10th pin, leaves his pole in the ground and carries the pins to the leader, and the pins are counted. A mark of some kind is then placed abreast the 10-pin point as a check.

48. The measuring then goes on as if the end of the 10th fleet were the original base, with the exception of putting ahead the range pole, which is omitted. If, when the leader draws his pole from the ground, he thinks the hole is likely to close before the follower reaches it, as it often does in very wet soil, as sand below H. W. mark, or in grass, he puts the pin *in* the hole, and the follower will know this from not seeing the mark within 3 or 4 inches of the pin, or by being told previously. Should there be any obstacle near either end of the chain, the handles can be slipped up the poles and the horizontal distance measured between the marks. Whenever the range-pole previously described becomes indistinct, the follower plants a stick of some kind at the point where his pole stood, and this one is used in connection with the base signal as previously described.

49. When the other end of the base is reached, the interval from the last pin to the base is measured by counting the links of the chain, and estimating or measuring the fraction of the last link. Then the length of the base will be ten times the marks the leader has on his staff, plus the number of *pins* the *follower* has in his possession into the length of the chain, plus the fraction of a fleet last measured. The accuracy of the line can now be tested by noting if all the range-poles are on range with the starting-point, and if proper care is taken they will be less than a foot from the line midway between the signals on a long base.

50. Should a pin be lost between two 10-pin marks, the length of that portion will be 9 fleets if it is lost by the leader, or 10 fleets if lost by the follower, and the proper length will be found by noting the distance between the marks on the second measurement. The base should be measured at least twice, and when one measurement is finished should be measured back again, care being taken that the 100-ft. marks going back are several feet distant from those made in the first measurement. The mean of the two measurements is taken as the length of the base. Two measurements will generally be sufficient for a harbor survey; but if the results are discordant, it should be measured once or twice more, and four times are none too few where the base is for an extended survey. The chain must be tested after each day's work to certify its correctness. Too much strain should not be put on the chain lest some of the links straighten out or open and break. This is less liable with steel than with iron chains, and for the same reason heavy wire is better than light for the construction of chains. $\frac{3}{16}''$ steel wire makes an excellent serviceable chain.

51. Measurements can be made very quickly by this method. By it a base 19,875′ long on a sand beach was measured twice in six hours, with a difference of but one foot in the two measures, by the Author, with a seaman as assistant. Should the line pass through water, the leader keeps his pole fast, and the follower makes a circle around him and becomes front man, and then leader makes circle, etc. Count must be very carefully kept in this case. In the Gulf of Dulce, Costa Rica, two measurements of a base 10,090′ long differed by but $2\frac{1}{2}'$ though for several hundred feet it passed through water 3′ deep and surf.

52. A more accurate method is the use of steel tape and battens, but a much larger force is needed. It is a very accurate method, as it measures the *horizontal* distance between the bases, and slight inequalities of the ground do not affect the result.

53. Prepare four triangular battens 25′ 6″ long, cross-section an equilateral triangle, 3″ edge. These must be of seasoned stuff, and perfectly straight. If carried any length of time on board ship they must be carefully secured to prevent warping. The blacksmith prepares about two dozen iron rods from 1½ to 4 feet long, of ½″ iron, forked at the top to fit the battens, pointed at the lower ends. A surveyor's steel tape, with brass marks at every 25 feet, or a flat steel tape marked to inches and tenths, 100 feet long, is used.

Prepare a number of sharp-pointed rough stakes about 1″ square and 8″ long, put a copper tack in the end of each one, and put a scratch across the head of each tack. Two sharp plumb bobs with linen thread for lines, a 24-lb. spring balance, a pocket-level, about 30 fathoms of cod-line, and two pike-staves with sheeting flags on them, complete the outfit.

54. Four men are detailed to carry the battens. An officer and assistant are needed for each end of the tape, another officer attends with a theodolite and signal-flag to preserve the line, and it is well to have two or three landsmen on hand to carry along the bundles of stakes, heavier stakes for 1000-foot marks, water, lunch-baskets, etc., and to clear away brush, etc., as necessary. Each batten man has a hatchet and a piece of wood to fit the forks so as to drive them down without breaking them.

55. The signals being erected and marked as before described, the theodolite is set up and levelled over the base station and one of the pike-staves is planted on the line about 120 feet from the base. A spare rod is put in the ground back of the base, a bowline in the end of the twine placed over it, and the twine hauled taut between the pin and the pike-staff and secured to the latter close down to the ground. The four battens are then laid along the line on the right-hand side, being placed

roughly end to end. This will show *about* where the 100 feet mark will come. A forked rod is put in the ground about 4 feet from the base and another about 5 feet from the 100 feet mark. These are placed touching the twine. The assistant in rear places the pocket-level in the fork of the after rod, and has the forward rod pushed in or drawn out until the two forks are in a horizontal line. The taut twine is then slipped into these forks. This gives at once a straight and level line. The batten men then place the rods for their battens, placing three for each one, driving them vertically under the twine until the forks are just level with it, care being taken not to push the twine out of line with any of the rods. The twine is then slipped off the back peg and hauled forward, where it is coiled down while the battens are being shipped. These are placed in succession, the after one first, so that it projects about a foot over the mark, and the others butting close to it. The top of these battens will be a straight horizontal line, and the steel tape is now laid along it, being kept from falling by the men along the line, who hold it loosely on top of the battens. The spring-balance being hooked and a slight pressure put on, the officer in rear holds his plumb-line on the 100 feet notch, and lowers the bob until it is just clear of the ground-mark, where it is steadied by the assistant. The leading officer then places his plumb-line on the zero notch, draws the tape taut, and lets the bob fall to the ground. The assistant drives a stake about two thirds home where the bob falls, with the scratch across the line. The officer replaces the plumb-line in the zero notch and lowers it almost to the stake, holding it with the right hand. He then calls out "Look out," that the other may not let the tape draw, and with the left hand he pulls on the spring-balance until it registers 10 lbs., noting that the tape is straight along the battens, and the assistant, by ramming the earth and working the stake, brings the mark exactly under the point of the plumb-bob when steadied. When this is attained he calls "all right," and both ends slack up. The tape is then lifted off the battens and placed on the ground on the left of the line. Both officers then score one fleet either on the battens or in note-books. The forward officer slips the loop of the twine over the last rod near the mark, and takes the pike-staff and twine out along the line as before, being aligned by the theodolite.

56. The men lift the battens out of the forks, and each man takes up two of the forks under his batten and the forward one of the man behind him. This is because the leading man leaves one fork each time, which is recovered by the last man after the next fleet. They then drag the battens along about 3 or 4 feet from the line, allowing the hinder man to move fastest. When the end of his batten is abreast the mark just made he drops it, and the others drop theirs when the after ends are about abreast the forward ends of the next batten to rear. The two assistants draw the tape along until the after end is abreast the mark, and drop it on the left of the line. The batten men always work on the right of the line, and until the twine is secured all keep off the line to give the theodolite a chance. As soon as the twine is taut the first and last forks are put in and levelled as before, and the same process gone through with again. The line between these two forks must be clear of the ground between them, and the long or short rods are used as may be necessary from the contour of the ground. In this way a lump 3 or 4 feet above the general level may be passed, the batten, if necessary, resting on the crest of the lump. It may be necessary to dig a short trench through the top of the lump, which would be done by the carriers, who would also clear away any brush that might interfere with the work, and whose number should be increased if necessary. A hollow 5 or 6 feet deep is easily passed by putting the rods in the slopes on either side and so keeping the battens level. In case of a long gentle slope, fleets of 25 feet can be

made by putting the forward or after end close down and raising the other end to the level with a long rod.

57. Every 1000 feet is marked by a long stake driven in a few feet from the line. Great care must be taken not to disturb the pegs in shifting the battens, each peg being left in its position so that if one is moved it is only necessary to go back one fleet, and then the number of fleets can be checked by walking over the line and counting the pegs, should there be a doubt as to the records. When the base is measured one way, go back again, using a new set of pegs. Twice over will generally be found sufficient for any base.

58. When working well, twelve fleets an hour is good speed over quite rough ground. This method is used by the officers of the "Ranger" in Lower California. One base of 9797.+ feet was measured twice within 3 inches, and of 9302.+ feet within 2 inches each in $2\frac{1}{2}$ days.

59. When the measuring party gets so far along the line that signals from the theodolite are hard to distinguish, the instrument is moved up along the line and set up over one of the positions of the pike-staff, this being preferable to setting up over one of the stakes, which are usually not exactly on the line, but to one side by about the width of the batten, as the plumb-line hangs over one side and is usually kept clear of the batten. Front and back observations will show if the line has been well kept.

60. A base-line may be quickly measured by using the sounding-wire, which is generally found on board surveying vessels. The base stations being selected and marked as before, a levelling instrument or theodolite with a vertical circle is adjusted over one base at such a height that a horizontal line to the other base will pass close to the ground. A party then proceeds along the line, and at intervals of 400 or 500 feet drives stakes on either side of the line about 4 feet apart and nails a cross-piece to them at the height directed by the theodolite, so

that the ends of the stakes will project above the cross-pieces. This being done, the sounding-reel and its bed-piece are placed on the extension of the line beyond the base signal, and secured by strong stakes driven in front of it. The wire leads from the bottom of the reel, the bed being placed so that the reel is on the end of the bed farthest from the line. A small boat anchor is carried to the other end of the line and securely planted about 10 fathoms beyond the other base station. The end of the stray line is then taken out along the line, the wire being allowed to pay out with a slight tension, and is led over all the frames along the line between the stakes. At the other end the stray line is secured to the ring of a large spring-scale, which is hooked to the ring of the anchor. When secured the reel is turned back by signal, until the scale shows a tension of 80 to 100 lbs. Men stationed at the different frames on the line lift the wire up so that it will be perfectly straight, and not be hindered by catching on rough wood. When taut and straight, a small mark is put on the wire, by means of a couple of turns of waxed thread securely tied, exactly where the wire passes over the marks at the extremities of the base. This being done the wire is slackened a little, and the stray line shortened up about 3 fathoms, secured and hauled taut as before, and two more marks put on. This is repeated a third time, and the length of the base is laid off three times on the wire, and the slip of any one mark checked.

61. The wire is then reeled up, one man holding the stray line to put the wire on the reel under the usual strain, and a second holding the wire between the marks so they may not be disturbed. When the first mark comes to the reel and is vertically under the axis, the register is set at zero, and the point where the mark comes is marked on the outside of the reel. The distances to the other marks are measured with a tape-line and recorded. The wire is reeled up until the first mark at the other end reaches the reel vertically under the axle, when the reading of the register will give the number of turns of wire between the marks, and by means of the mark on the outside of the reel the fractions of a turn can be noted. The distances between the three marks, being measured, should agree with those previously obtained, and then the turns reeled up, corrected for the number of turns of wire on the reel, will give the number of fathoms in the length of the base. The reel having twelve spokes, $\frac{1}{24}$ of a turn can be easily estimated, which will give the length within less than three inches.

62. If greater accuracy is desired the wire may be measured on board ship by reeling it up on a drum after passing it several times around a spare reel of standard size in the same way as when measuring the wire for constructing the correction curve for sounding. Or, a convenient length being laid off on deck by standard measures, the reel is placed at the after end of this measure and a spare reel at the other, and the wire led from one to the other. The wire being taut and the first mark at the forward mark on deck, a turn of waxed twine marks the first length, and this mark is drawn forward by reeling up the wire and a second mark put on aft, and so on until the whole length is measured.

63. It will be found that the light wire under the tension mentioned will be practically straight between the supports, and the error due to the sag between them will be inappreciable. Should the base be on an incline it can readily be reduced to horizontal measurement by observing the angle of elevation or depression of the line and multiplying the measured length by the cosine of this angle.

64. This method is useful in locating signals and running in coast-line which cannot be run by ordinary methods. It has been used in the survey of Alaska to measure across wide cañons and over breaks in the coast-line that could not be crossed by other methods, and has been found very satisfactory.

65. Bases may be computed by noting the number of divisions of a graduated telemeter rod held at one end of the base, included between two parallel horizontal threads of a telescope at the other, by measuring the angle subtended by a rod of known length, or by using the angle between the ship's masthead and water-line; but in these methods the error in length due to a very small error of observation is too large to make them of practical use, excepting for very short lines or limited surveys.

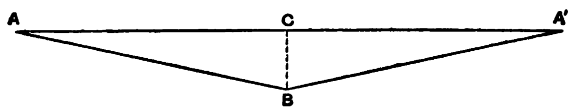
66. In a survey of large extent, beyond fifty or sixty miles in length, astronomical observation-spots are established at either end of the work, and the final scale of the chart made dependent on the distance between these two points. The triangulation is adjusted so that the observation-spot by triangulation may agree with the spot by observation. . If two points can be selected that are intervisible, nearly on the same meridian and about forty miles apart, the distance between them can be computed by observing carefully their latitudes, and their true bearing from each other, and reducing the difference of latitude to the great circle joining the two points.

67. The velocity of sound has been used in determining distances by observing the time necessary for a sound to travel over the intervening distance. But as sound travels about 1100 feet per second, it will be seen that measurements of this kind are of the roughest description, and would only be used in cases where all other means fail. The method is to fire a gun at one end of the line, and to have an observer at the other end to note the instant of the flash and also the instant when the report is heard. The distance in feet is approximately 1100 times the elapsed time in seconds. The observations are repeated several times, firing from each end of the base, and the mean of the results taken as correct. The velocity varies with the temperature, being about 1090 at 32° and 1120 at 59° F., etc.

The velocity of sound in feet per second at any given temperature *Fahrenheit* "$t°$" may be found by the formula

$$V = 1089.42 \sqrt{1 + \{t - 32\}\{.00208\}}.$$

68. In the selection of a base it frequently happens that the character of the ground will not allow of a straight line of suitable length being measured, but will permit of two or more lengths being measured such that the angles between the lengths are very obtuse and whose extreme ends are far enough apart to make well-conditioned triangles. This is called a "broken base." In this case the extremities of the different parts must be visible one from another, and each one must be treated as a separate base in measuring; that, is, signals and marks must be put over each extremity of the lines. The parts must be carefully measured, and the angles at each station must be observed with the utmost care. The base is then computed by the formulæ of Plane Trigonometry as follows:



Suppose AB and $A'B$ are two of the measured portions, and AA' the base to be used in the survey. BC is a perpendicular from B on AA'. By computing the excess of AB and $A'B$ over their projections on the line AA', and subtracting this excess from their sum, we obtain a very accurate result for AA'.

In the right triangle ACB we have

$$2 \sin^2 \tfrac{1}{2}A = 1 - \cos A = 1 - \frac{AC}{AB} = \frac{AB - AC}{AB},$$

or

$$AB - AC = 2\,AB\sin^2 \tfrac{1}{2}A.$$

A will always be a small angle, and when it is not greater than 6° we can substitute for sin $\frac{1}{2}A$, $\frac{1}{2}A$ sin 1′, without appreciable error, A being in minutes. The formulæ then become

$$AB - AC = \frac{AB}{2}A^2 \sin^2 1'$$

and

$$A'B - A'C = \frac{A'B}{2}A'^2 \sin^2 1',$$

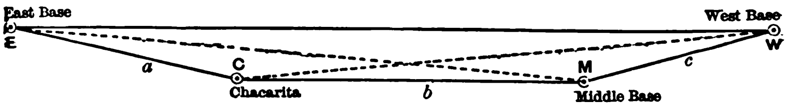
A and A' being in minutes, and

$$AB + A'B - (AB - AC) - (A'B - A'C) = AA'.$$

69. The following example is a base line measured at Punta Arenas, Costa Rica, in 1885, by officers from the U. S. S. "Ranger," the triangulation for 150 miles north and the same distance south depending upon it. The line was located in the only available place, and the parts WM and MC were measured. Then it was found that the largest angle subtended by the line WC at any available point was 23°. It being impossible to extend the original lines, the third part CE was measured, and the base WE subtended an angle of 32° at the nearest station. The lengths of the parts are the means of four measurements of each. The angles were observed from each station on four different days to insure the greatest accuracy.

There are two ways of computing WE, viz.: compute the length of EM and CW by the formulæ given above, and with EC and CW compute EW and check the result by means of EM and MW; or, compute the projections of MW, EC, and CM on EW. The projection of CM on EW is evidently the same as its projection on a line through C or M parallel to

EW, and the angle between these two lines is evidently $180° \sim (CMW + EWM)$.



a,	*EC* = 7878′,	*ECW* = 164° 26′,	*EWC* = 4° 40′,	*WEC* = 10° 54′
b,	*CM* = 11997′,	*ECM* = 169° 08′,	*MEC* = 6° 34′,	*EWM* = 13° 28′
c,	*MW* = 6440′,	*EMW* = 162° 12′,	*MEW* = 4° 20′,	*WCM* = 4° 42′
		CMW = 166° 30′,	*CWM* = 8° 48′,	*EMC* = 4° 18′

FIRST METHOD.

SIDE *a* AND ANGLE *CEM*	SIDE *b* AND ANGLE *EMC*	SIDE *b* AND ANGLE *WCM*	SIDE *c* AND ANGLE *CWM*
7878′ —— 6° 34′ = 394′	11997′ —— 4° 18′ = 258′	11997′ —— 4° 42′ = 282′	6440′ —— 8° 48′ ½ "*A*" 4° 24′
const. log 2.62642 — 10	const. log 2.62642 — 10	const. log 2.62642 — 10	log *c* 3.80889
log *a* 3.89642	log *b* 4.07907	log *b* 4.07907	log 2 0.30103
2 log 394′ 5.19100	2 log 258′ 4.82324	2 log 282′ 4.90050	2 log sin ½ "*A*" 7.76980
51.741, log 1.71384	33.785, log 1.52873	40.364, log 1.60599	75.808, log 1.87972
11997	51.741		40.364
7878	85.526 excess	11997	116.172 excess
19875 = *a* + *b*		6440	
85.526 excess		18437	
19789.474 = *EM*		116.172 excess	
		18320.828 = *CW*	

EM AND ANGLE *MEW*	*c* AND ANGLE *MWE*	*a* AND ANGLE *WEC*	*CW* AND ANGLE *EWC*
4° 20′ = 260′	13° 28′ ½ "*A*" = 6° 44′	10° 54′ ½ "*A*" = 5° 27′	4° 40′ = 280′
const. log 2.62642 — 10	log *c* 3.80889	log *a* 3.89642	const. log 2.62642
log *EM* 4.29641	log 2 0.30103	log 2 0.30103	log *CW* 4.26295
2 log 260′ 4.82994	3 log sin ½ "*A*" 8.13822	2 log sin ½ "*A*" 7.95524	2 log 280′ 4.89432
56.594, log 1.75277	177.068, log 2.24814	142.133, log 2.15269	60.770, log 1.78369
19789.474, *EM*	56.594	18320.828 *CW*	142.133
6440. *C*	233.662 excess	7878. *a*	202.903 excess
26229.474 *EM* + *C*		26198.828 *CW* + *a*	
233.662 excess		202.903 excess	
25995.812 = *EW*		25995.925 = *EW*	
		25995.812	
		2) 1.737	
		25995.868 = Mean length of *EW*	

SECOND METHOD.

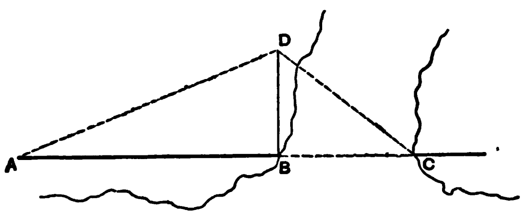
$ECM = 169^\circ\ 08'$	$EWM = 13^\circ\ 28'$
$WEC = 10^\circ\ 54'$	$CMW = 166^\circ\ 30'$
$180^\circ\ 02'$	$179^\circ\ 58'$

Angle between EW and $CM = 0^\circ\ 02'$

SIDE a AND ANGLE WEC	SIDE b AND ANGLE 02'	SIDE c AND ANGLE MWE
	log b 4.07907	Excess = 177.068
Excess = 142.133	const. log 2.62642 — 10	
177.068		
.002	2 log 2 0.60206	
319.203		
7878 a	.002030 log 7.30755 — 10	
11997 b		
6440 c		
26315 sum		
319.203 excess		
25995.797 EW		

The constant log used in the above computations is the log of $\frac{1}{2}\sin^2 1'$.

70. In a survey it may happen that the most suitable place for a base is intersected by a stream or a cañon too deep and wide to measure with a chain, and where it may not be desirable to measure with wire as previously described. In this case, having measured AB, send an assistant to put a small



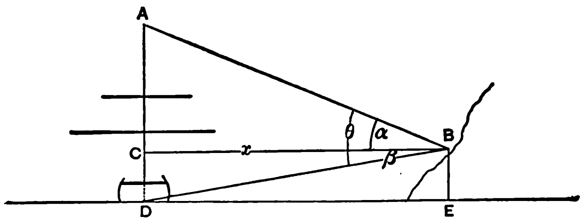
stake or other mark at C on the other side of the stream, placing it accurately in the extension of AB by sighting with the theodolite. Put up the theodolite at B, and measure in a direction at right angles to AB the line BD, so that BD shall be nearly equal to *BC*. Then observe the angles *CDB* and *ADB*, and compute *BC* from the right triangle *BDC*, checking the length of *DB* from the side *AB*, and angle *ADB* of the triangle *ADB*, and also by measuring the angle *BCD* after having crossed the stream. The base can then be extended as far beyond *C* as may be desired. The offset may be measured on either side of *AB*, or from *C* at right angles to *AC*, whichever may be most convenient and practicable. Should it be impossible to measure at right angles to *AB*, an oblique line may be measured and the side *BC* computed from *BD* and the observed angles at *B* and *D*.

71. No triangulation of any extent will be complete without the measurement of a verification base at the end of the chain of triangles which will be a side of one of the last triangles. A comparison of the computed and measured lengths of this line will expose any errors and test the accuracy of the work. In the triangulation of the west coast of Lower California by the officers of the U. S. S. "Ranger" a base of 6400 feet was the foundation used for a system of triangles extending over 175 miles, and at the end of this chain a base of 9797 feet was measured and differed but six feet from the computed length. It may be well to add that much of this triangulation was done with a "Bureau" theodolite, and mountain peaks marked by cairns were often used for triangulation points.

72. It may happen, in a reconnaissance of a harbor, that a base-line is desired, but time or other circumstances may not permit of its measurement. In this case the angle subtended by a mast of the ship may be used in determining the distance of the observer from the mast, and simultaneous angles observed at the foot of the mast and at the observer's position will serve to fix other points as may be required. The observer on shore, standing at the shore-line or in such a position that the height of his eye above the water level may be measured, observes the angle between the load water-line on the ship's side and the

main truck with a sextant or theodolite. If the former is used, and the angle is less than 5°, it is measured on and off the arc and the mean taken. If greater than the off graduation, the index error must be determined very exactly. If the theodolite (with vertical circle) is used, the angle is observed telescope direct and reversed. The height of the truck, measured from the plans of the ship, and the height of the eye being determined, the horizontal distance between the observer and the mast is found as follows:

Let DA represent the mast;
B, the position of eye of observer.



Let $AD = H =$ height of mast;
$CD = EB = h =$ height of eye above water-line;
$\theta =$ observed angle, $\alpha =$ angle ABC, $\beta =$ angle CBD;
$\theta = \alpha + \beta$, and $AC = H - h$.

Then $BC = DE = x =$ required distance.

By Plane Trigonometry we have

$$AC = H - h = x \tan \alpha; \quad \ldots \ldots \quad (1)$$

$$CD = h = x \tan \beta. \quad \ldots \ldots \quad (2)$$

Dividing (1) by (2),

$$\frac{H-h}{h} = \frac{\tan \alpha}{\tan \beta} = \frac{\sin \alpha \cos \beta}{\sin \beta \cos \alpha} = \frac{\sin(\alpha+\beta) + \sin(\alpha-\beta)}{\sin(\alpha+\beta) - \sin(\alpha-\beta)};$$

$$(H - h) \sin \theta - (H - h) \sin (\alpha - \beta) = h \sin \theta + h \sin (\alpha - \beta);$$

$$\sin (\alpha - \beta) = \frac{H - 2h}{H} \sin \theta; \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{\theta + (\alpha - \beta)}{2} = \alpha; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$x = (H - h) \cot \alpha. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

These formulæ, (3), (4), and (5), will give the correct value of x whatever may be the relation between H and x or between H and h. When h is greater than H, α must be considered as negative and due regard had for the signs.

By drawing a figure for this case and giving the same meaning to the letters, it will be seen that

$$\theta \text{ will be equal to } \beta - \alpha;$$

$\alpha - \beta$ will become $- \alpha - \beta$ or $- (\alpha + \beta)$, and is found from (3);

(4) becomes $$\frac{(\beta - \alpha) - (\alpha + \beta)}{2} = - \alpha;$$

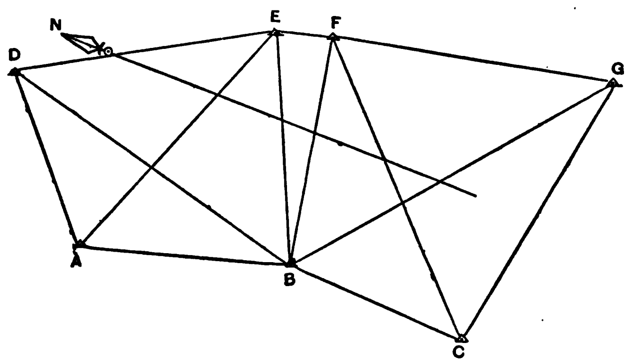
(5) becomes $$x = (H - h) \cot (- \alpha).$$

CHAPTER IV.

THE MAIN TRIANGULATION.

73. IN the selection of triangulation points much judgment must be exercised. The points should be as often as practicable the natural landmarks. Triangles should be made as few in number as can be used to cover the ground, and angles less than 30° should be avoided. Each point should be visible from at least three others, and more if possible. Each point should be marked in some way by a cairn, stake, or marks on adjacent landmarks which may be permanent and described in the records, and a record of the name of the station, date of occupation, and name of ship should be left in a bottle buried at the centre of the station.

There is one case in which a small angle may be admitted in triangulation, but it should then be observed with great care.



In the sketch, which is taken from the triangulation of the coast of Lower California, E and F are two high mountains with a very slight difference in heights, and so situated that *F* could not be seen from the *Nd*, nor *E* from the *Sd*. In this case, the side *BE* having been calculated, the sides *EF* and *BF* are found very accurately from the angles *FEB* and *EBF*, and *F* is well fixed by the nearly rectangular intersection of the two lines *EF* and *BF*. Thus it will be seen that though small angles are used, they may never be "receiving" angles; a receiving angle at a point being the divergence of the two lines to the two points from which it is located. When practicable, triangles should be formed as *ADE* and *AEB*, etc., and besides the angles at *A* and *E* observe the *two* angles at *B* and *D* and their sum. Then *EB* may be calculated from *ADE* and *AEB*, or *ADB* and *DBE*, which gives a convenient check on the accuracy of the work.

74. The greatest accuracy being important in the main triangulation, the best instruments must be used in observing the angles. A repeating theodolite should always be used when possible, one with 7″ circle being a good size. In a mountainous region where lightness is desirable, a 4½″ mountain transit does excellent service.

75. Observing the angles at any station between the other stations is called "occupying" that station, and is performed as follows. The theodolite is set up over the station so that the plumb-bob shall hang directly above the centre of the station, the legs being firmly planted and spread far enough apart to bring the telescope at a convenient height for observing.

Perfect the various adjustments of the theodolite as already described. Set one of the verniers to read zero and clamp the upper plate. Unclamp the lower plate and turn the telescope towards one of the signals, selecting the one that is most sharply defined, and bisect it with the vertical wire, just clear of the intersection of the two wires, perfecting the contact, after clamping the lower plate securely, by means of the tangent-screw of the lower plate. This first signal is then spoken of as the "origin" of angles. Note the reading of the vernier to be sure that it is still zero, and record in the angle-book the name of the signal observed and the readings of the two verniers. Now unclamp the upper plate and point the telescope at the first signal to the right of the one observed. Clamp the upper plate, bisect the signal as before, using the tangent-screw of the upper plate, and read both verniers, recording as before. Unclamp the upper plate, turn to the right until the next signal comes into the field, and bisect it as before; read both verniers, and record the angles. Proceed in this way until all the stations in sight have been observed, and then take a second observation on the "origin," being careful during the whole operation not to move the lower plate. If the reading is zero, the theodolite has not moved. If the reading is not zero, the angles should be remeasured and the first set rejected. If the first set is accepted, transit the telescope and repeat the round with the telescope reversed, recording all the angles anew. This will eliminate most of the instrumental errors and will discover any errors made in reading during the first round. An error of 5° or 10° is very easily made in reading an angle, the minutes and seconds being generally read with most care. Signals should always be observed as near their bases as possible to minimize errors. The levels must be looked at occasionally to see that the adjustment remains perfect.

76. In the case of angles of the triangles which appear in the main triangulation, greater care must be taken, and these angles are invariably "repeated," as follows: Observe the angle to be measured as described above for the origin and first station to the right. This done and recorded, unclamp the *lower* plate, leaving the upper and lower secured together, and turn the telescope back to the origin, clamp and bisect it, using the *lower* tangent-screw. Note the reading, and then unclamp the upper plate, turn the telescope to the right and bisect the second signal. The reading should be double the first, as the zero has moved as far to the left of the origin as the telescope to the right. Repeat the angle five or six times, or once around the circumference if the angle is less than 60°. The final reading, increased by 360° as many times as the zero has been passed, divided by the number of repetitions, will be the value of the angle to be measured. It should also be repeated with the telescope reversed, for greater accuracy. In observing an angle between two points, which can only be seen when occupied by heliotropes,—and only one is so occupied,—repeat several times the angle from the flash to some sharply defined point, preferably within the angle, and when the flash appears at the other station repeat the same number of times or oftener the angle between this same point and the second flash. When observing the origin, record the magnetic bearing of the line by means of the compass on the theodolite, noting both ends of the needle to avoid error of pivot or bent needle. An outline sketch of the view from the station is of great assistance to the draughtsman in putting in topography, and also in recognizing hills or other prominent points. Complete the record by remarks, including wind, weather, visibility of objects, instrument used, etc., so as to give weight to the observations in the calculations.

77. It is not always practicable to place the theodolite exactly over the centre of the station, in which case corrections may be calculated to reduce the angles to the centre of the station. In practice, however, the theodolite is placed as near as may be to the centre of the station, and if the distance is not more than a metre the correction is much less than the probable error of observation, and may be omitted. In case the distance to the centre of the station is considerable (five metres would be excessive), the angles may be observed from two points which are equally distant from the centre and on

opposite sides of it, and the mean of the two values of any angle taken as the correct one.

In a harbor survey, where the lines are short, the angles may be corrected in the observing by placing the vertical wire to the right or left of the observed signal, so that the line of sight may be parallel to the line joining the centres of the stations. The distance to observe to right or left can be seen at a glance by estimating the distance from the centre of the occupied station, and can easily be estimated on the observed signal from its known size and shape. The distance should be under- rather than over-estimated.

78. If two objects are not in the same horizontal plane and the angle between them is measured with a sextant held in the oblique plane, this angle must be reduced to a horizontal plane before it can be used. This is done by observing the altitudes of the two objects, and reducing the distance by the formulæ which will be given hereafter in treating of the astronomical bearing. If the altitudes are less than 3° and the angular distance greater than 30°, the correction may be disregarded. If one object is in the horizon and the distance is 90°, the correction is zero. In measuring the angle between two points which are close together but in an oblique plane, the value of the horizontal angle may be obtained very closely by observing the angles between them and some object in the horizon about 90° to right or left of them, the difference of these angles being the value sought. Or measure the angle between the lower object and a point at the same altitude directly under the higher one. Angles between elevated signals are particularly to be avoided in sounding when the boats are close in-shore.

79. The triangulation is kept plotted up roughly by means of the angles alone as they are observed, and points in advance of the triangulation are located approximately by angles and are of great assistance in selecting the triangulation-points. Before the final plotting, however, the triangulation must be calculated so that the lengths of the sides as well as the angles may be used in the plotting. The angles of the triangles will seldom be found to sum up exactly 180°, and must be adjusted so they will do so. Theoretically, the angles should always exceed 180°, as the triangles are spherical; but as the spherical excess (the amount the sum exceeds 180°) of the largest triangle ever observed is less than 45″, it can be disregarded in a nautical survey. The angles may be adjusted by means of least squares to the most probable values, and so that in a quadrilateral the sides and angles would stand the most rigorous tests. In practice, however, it is sufficiently accurate to divide the defect from 180° among the angles according to their respective weights as determined by the record, giving a small angle less than a large one for the reason that a change in a small angle alters the triangle more than a like change in a large one. The defect should seldom be more than 1′, never more than 2′, with a theodolite reading 30″.

Having adjusted all the angles, the triangles are solved as plane triangles, using the measured base and the angles at its extremities first, and each computed side in succession, checking as often as possible, by means of quadrilateral figures, as described above (Art. 73).

80. In order to locate the surveyed tract on the chart, we must know the latitude and longitude of one of the points and the true bearing of one of the lines of the triangulation. An observation-spot is usually placed near the base-line, and is connected with the triangulation by an auxiliary triangle. It should not be at either end of the base, nor at one of the main stations, as the signal must be removed while observing, and there must be no walking within 100 yards of the spot while observations are being made; and if it is isolated, the base can be measured, triangulation started, and shore-line put in during the observations. When completed, and a round of angles taken, a signal is put up, and angles from three or four stations fix it accurately.

81. The true bearing of a side of the triangulation is taken from the observation spot, and the most distant triangulation-point that is sharply defined is taken as the mark. The true bearing of this line is the angle which a vertical plane through it makes with the plane of the meridian of the observation-spot. The reverse bearing will not be the same *angle*, owing to the fact that the meridians are not parallel, but converge.

82. With this data, the latitude and longitude of any point of the triangulation and the true bearing of any side may be calculated by the formulæ of great-circle sailing, or by the more rigorous formulæ used in the Coast Survey, where the earth is treated as a spheroid and the differences of latitude and longitude are computed by the differential calculus. These last computations are made only on surveys of very large extent, and when made it is possible to plot any desired portion of the triangulation in its proper size and position without having to start from the original base and work through the entire system. It is only on surveys of considerable extent that the triangulation is calculated at all. If the extent of the survey is less than 25 miles there is no need of it.

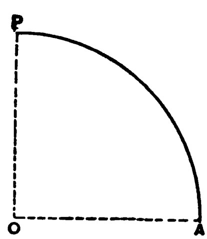
83. All the sides being calculated and the angles, sides, bearings, etc., tabulated, the work is ready for plotting. If possible, the length of the line from the observation-spot to the mark used for true bearing is computed, otherwise the longest line from the observation-spot to any point in sight is computed, its bearing found from its angle from the mark, and this line is used as the base for plotting inwards, being the first line drawn on the projection.

CHAPTER V.

THE PROJECTION.

84. In charts used for surveying purposes it is of prime importance that angles between lines on the earth's surface should be shown in their true size, and were this the only requisite, the Mercator's chart would be the most convenient for use and in construction. This chart, however, presents so many objectionable features that it cannot be employed in plotting work, the distortion of distances and the oval form of the geodesic line being insuperable objections. Considering the earth as a sphere or spheroid, it is readily seen that no chart can be constructed which will rigidly fulfil all the desired requirements. The one which seems to approach nearest to perfection is the one used in our Coast Survey, known as the ordinary polyconic projection. The principle of its construction is as follows:

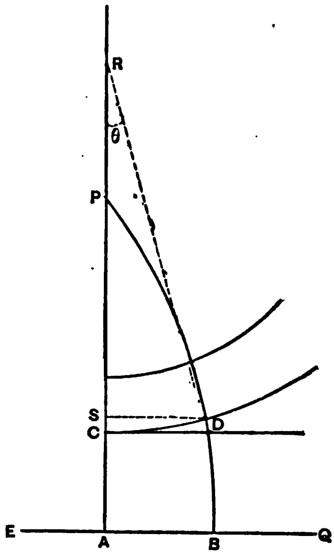
85. Let PA be a portion of any meridian on the earth's surface, P being the pole and A being at the equator. Conceive a series of cones tangent to the surface, whose vertices are in the produced axis (OP) of the earth. Imagine these cones, cut along elements, tangent to meridians $\lambda°$ on either side from PA. Now conceive a plane tangent to the earth at A, and capable of being tilted toward P without motion along AP, becoming tangent successively at each point of the arc AP. Now if, as the plane is tilted to contain the successive elements of the cones tangent to AP, the portion of the cone included be-



tween the slit elements be developed on it, the portions of the bases will appear on the plane as arcs of circles whose radii are the respective slant heights of the cones, which, considering the earth as a spheroid, will be represented by the formula $\frac{a}{(1 - e^2 \sin^2 L)^{\frac{1}{2}}} \cot L$. The plane will then contain a polyconic projection of that portion of the earth lying on one side of the equator, and included between the meridians $A + \lambda$ and $A - \lambda$. PA will appear as a straight line and in its true length, and will be the central meridian of the chart. Those portions of the chart lying near the central meridian will be little distorted, but the distortion will rapidly increase as we move far away from it. On a chart constructed to contain three or four degrees on either side of the central meridian the distortion will be inappreciable, and on it the geodesic line will appear as a straight line, the angles will be projected in their true size, and distances will have their true values.

86. The construction of the chart consists in drawing a right line of sufficient length to represent, according to the scale, the rectified arc of the middle meridian between the latitude limits of the desired chart, and in drawing in the parallels as circles having the above-mentioned radii, the meridians being fair curves drawn through the points of the parallels having the same longitude.

In practice, the chart is constructed from equations which may be derived as follows:



87. Let APB represent a portion of a polyconic chart, EQ

the equator, and PA the middle meridian, and let D be any point on the chart whose latitude is L and whose longitude liffers from that of the middle meridian by λ. Let RD be the radius of the meridian $CD = R$, or the slant height of the cone tangent to the earth on that meridian. The co-ordinates of D referred to the rectangular axes AQ and PA will be

$$x = SD,$$

and $$y = AS,$$

or $$x = R \sin \theta,$$

$$y = R(1 - \cos \theta) + AC$$
$$= R \text{ versin } \theta + AC;$$

and since the parallel CD is projected in its true length, the angle subtended at the centre from which it is struck will be, to the angle subtended by the arc of the true parallel, inversely as the respective radii, that is,

$$\frac{a}{(1 - e^2 \sin^2 L)^{\frac{1}{2}}} \cot L : \frac{a}{(1 - e^2 \sin^2 L)^{\frac{1}{2}}} \cos L :: \lambda : \theta;$$

$$\theta = \lambda \sin L.$$

$\frac{a}{(1 - e^2 \sin^2 L)^{\frac{1}{2}}}$ is the portion of the normal to a point on the elliptical meridian, at a point whose latitude is L, included between the meridian and the minor axis, a being the semi-major axis or the equatorial radius. Calling this value of the normal n and substituting, we have

$$x = n \cot L \sin (\lambda \sin L),$$

$$y = n \cot L \text{ versin } (\lambda \sin L) + m,$$

where m is the value of AC or the length of the rectified meridian between the equator and the parallel under consideration.

The origin of co-ordinates could be taken at any point on the middle meridian, and the chart constructed, the equations becoming

$$x = n \cot L \sin \theta,$$

$$y = n \cot L \operatorname{versin} \theta \pm m,$$

$$\theta = \lambda \sin L,$$

where $\pm m$ is the length of the rectified meridian above or below the origin to the latitude of the parallel under construction.

88. The "Projection Tables, U. S. Navy," give tabulated values for $n \cot L \sin \theta$ and $n \cot L \operatorname{versin} \theta$ for all values of L and λ, and using these tables the construction of a Polyconic Chart becomes a mere mechanical operation, which is explained at length in those tables.

CHAPTER VI.

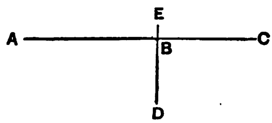
PLOTTING.

89. MUCH trouble will be saved in the plotting, and the result will be more accurate, if the paper is stretched on a board. If not, muslin-backed paper must be used, and care taken that when any line is drawn or distance laid off the paper is perfectly flat between the points. The size of the paper and scale of the chart will depend on the extent of the survey.

In the Hydrographic Office scales of $\frac{1}{2}''$, $1''$, $2''$, $4''$, and $8''$ to the mile are used in plotting, while smaller scales are used on published charts, measurements being in feet, yards, etc. A far better system obtains in the Coast Survey, where the metre is made the unit of measure and charts made on decimal scales $\frac{1}{5000}$, $\frac{1}{10000}$, $\frac{1}{20000}$, $\frac{1}{40000}$, $\frac{1}{80000}$. The first is used only on surveys of small extent where the soundings are very important, as in the survey of the bar at Sandy Hook, N. Y. These scales are very useful when distances are to be laid off, there being no call for reducing feet to decimals of miles, etc., as on a 10000^{th} scale 1 cm. = 100 metres, etc.

Having determined the scale to be used, the limits of the sheet are marked on the old chart of the place and the middle meridian and parallel determined, also the limiting meridians and parallels. The data for a polyconic projection within those limits is then calculated from the projection tables of the U. S. Coast Survey, the length of $1'$ of the meridian at the middle latitude being taken as the length of 1 mile. In marine surveys the nautical mile of 6080.27 feet is used exclusively, and is to be so understood whenever miles are spoken of in this work.

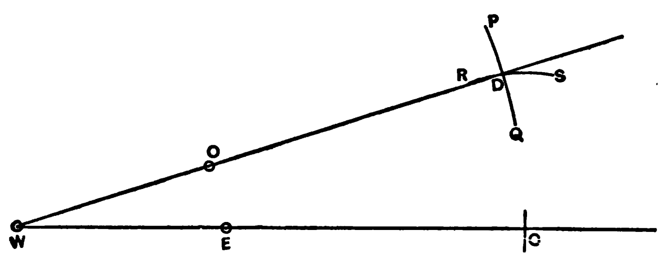
90. The paper being stretched on a suitable board and thoroughly dried the projection of the parallels and meridians is drawn on it with the utmost accuracy. The observation-spots are plotted in the same way as the intersections of parallels and meridians are, by computing the data from the tables. The ordinates of these intersections being very small are laid off most accurately as follows: Suppose it is desired to lay off BE equal to say .16″. This is not readily done with dividers, but if we lay off on the other side of AC a distance $BD = \frac{1}{2}$ inch or 1 inch, we may then lay off from D, $DE = .66''$ or $1.16''$ very accurately.



From the observation-spot a long line is drawn in the direction of the true bearing observed.

91. It will be found in practice that the extreme accuracy necessary in plotting triangulation cannot be attained by using a 3-arm protractor alone for laying off angles, as, besides the slight error of centring it over a station marked by a needle-point, there is the error in making the zero-arm coincide exactly with the line which is the origin of the angle, the practical difficulty of drawing the line for the other side of the angle to coincide exactly with the edge of the protractor-arm, the spring of the arm itself, and the necessity of making only short lines. The method of intersecting arcs, using only the lengths of the sides, is not sufficiently accurate for practical use. It will be readily seen that to draw a line six feet long through two points eighteen inches apart is almost an impossibility, and there will be an error at the end of the line no matter how accurately the points are laid off and the straight-edge laid against the points. It is much easier to erase a long line than extend a short one accurately. So all lines in the plotting of the main triangulation should be drawn as long as possible, and if it is necessary to extend a line the angle should be laid off anew instead of laying the straight-edge along the line. Angles are laid off most accurately by using chords, as will be now explained.

92. It is known that the chord subtended by any angle ϕ at the centre of a circle of any radius R is equal to $2R \sin \frac{1}{2}\phi$. So if we draw a circle, radius R, and from the extremity of any radius lay off a chord $= 2R \sin \frac{1}{2}\phi$, then the angle at the centre between these points will be ϕ. It will be seen that the longer the radius the less will be the error in the angle due to a small error in the chord, and also the long radius will make easier the drawing of the line through the centre and point found. On a large sheet a radius of 50″ will be found convenient, on smaller sheets 25″ or less may be used. In no case should the radius be less than the distance between the point *at* which the angle is observed and the point *to* which it is to be laid off. Using a radius of 50″ we would have chord $= 100'' \sin \frac{1}{2}\phi$, and this is taken directly from the table of natural sines by shifting



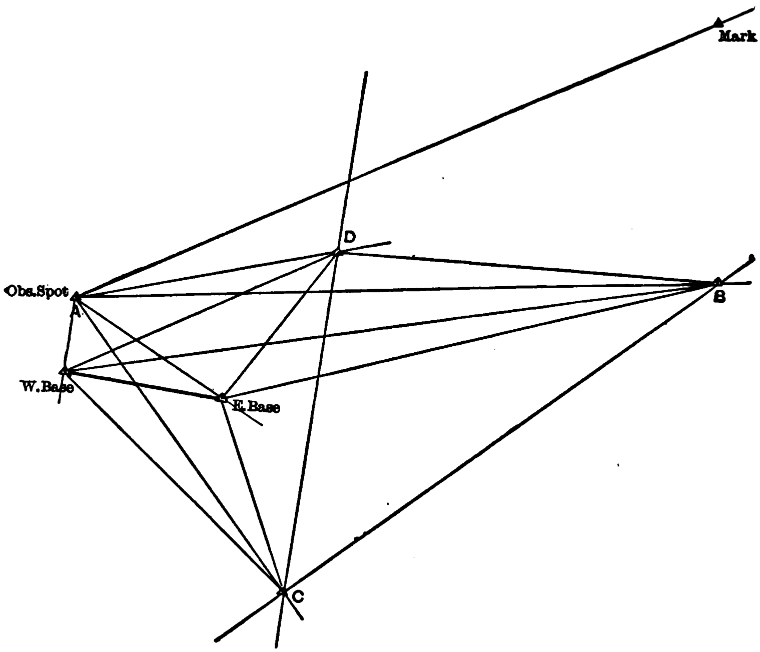
the decimal point two places to the right. An example may make the process clearer. Suppose at W the angle EWO is 28° 42′ 50″, WE being perhaps the measured base. We have the line WE already drawn as long as possible; so with beam compass with steel points, and from the standard scale, we lay off $WC = 50''$, making a faint prick at C, and drawing a short arc PQ at D, with W as a centre, the angle being laid off roughly with a protractor. From the table of natural sines we pick out $\sin 14° 21' 25'' = \frac{1}{2}\phi = .24796$, multiply by $100'' = 24''.796$.

Take this distance on the beam compass as before, and with one point at C describe a short arc RS cutting PQ in D. Lay the straight-edge accurately on D and W, securing it with weights and draw the line, and it will make the required angle with EW. The point O may be anywhere on WD, and its distance from W may be laid off, or an angle from E used intersecting WD. In any case we have the line WO truly laid off, and a long line to work on in case we wish to lay off an angle from it. In all cases the steel points should be used, as they are not liable to break in setting off the distances from the metal scale and there are fewer marks on the sheet; care must be taken, however, not to deface the scale with the hard points. The points should be held at a cant so as to impress the paper without scratching it, and the points C, D, etc., are marked by using a reading-glass and pricker—a needle-point mounted in a handle, usually found in the handles of right-line pens. Great care must be exercised in ruling the lines in order that they may be truly straight. The pencil should be the hardest made, and should have a "chisel" point, and be held at the same angle and close to the guide throughout the line.

93. It is not advisable to lay off a longer chord than 60° at one time, because it would be of inconvenient length, and the intersection of the two arcs would be acute and make the intersection difficult to determine accurately. For a larger angle than 60° lay off 60° by using the radius as a chord, and then lay off the remainder of the angle as described above, using the 60° mark instead of the zero. Equally accurate and expeditious is it to lay off the chord of half the angle twice, or for a very large angle that of one third the angle three times. Do not lay off half or one third of the chord of the required angle.

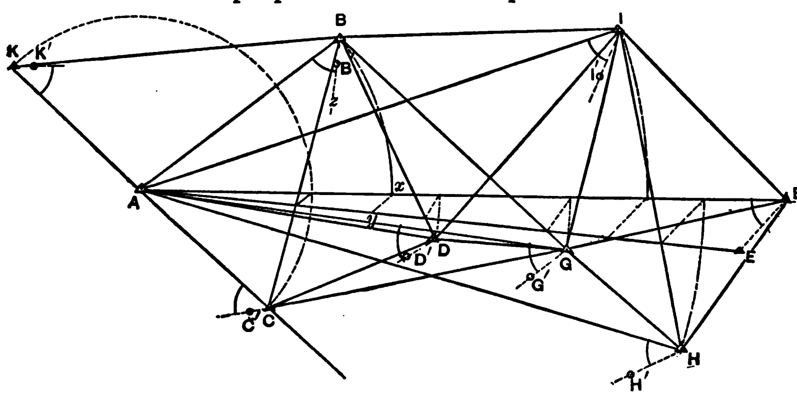
94. If the distance from the observation-spot to the mark observed for true bearing is computed, on the line we have drawn through the plotted observation-spot lay off this distance, making a fine prick at its position. If it is not known,

lay off from this line the angle to the distant signal (say *B*), whose distance is known, and plot its position on this line. From the observation-spot, which we will call *A*, lay off the angle to the station at which the angle between *A* and *B* is nearest 90°, and from *B* lay off the angle between *A* and this station, which call *C*, and prick it in lightly, checking its position by its computed distances from *A* and *B*. Then from these three points lay off the angles to a fourth station. If the



three lines intersect in exactly the same point the fourth station *D* is determined, and is checked by distances and by laying off the angle at *D* between *A* and *B* or *A* and *C*. If the three lines do not cut exactly in the same point there is some error, and the angles must be laid off anew. No point should be considered fixed unless three lines at least pass through it exactly when examined under a powerful reading-glass. Continue in this way until the base stations are plotted in, and then work on towards the other observation-spot until all the main triangulation-points are plotted. It will be found almost invariably that there will be two points for the second observation-spot. One located by latitude and longitude, call E, and the other plotted from the triangles, call E'; and before any of the secondary triangulation is plotted the main triangulation must be adjusted.

95. Draw lines from A to E and to E'. If these lines are of equal length, the error is entirely in azimuth; if they coincide, but are of unequal length, the error is in distance. Usually they will be distinct lines and of unequal length, showing error of azimuth and distance. The latter error may be predicted from the difference between the computed and measured lengths of the verification base, and may be eliminated before the plotting by increasing or diminishing each computed side in the same proportion as the computed base must be in-



creased or diminished to equal the measured base. There should then be no error in distance, and the whole system being swung about A until E' coincides with E, the triangulation would be adjusted. Practically the adjustments in azimuth and distance are made as follows: Suppose $ABCDGHIKE'$ is the plotted triangulation and E the true observation-spot. In order to preserve the relations between the sides and angles when E' is made to coincide with E, every point must be moved in a direction making the angle $EE'A$ to the left of the line joining it with A, and the distance any point as B moves is found from the proportion $AE' : AB :: EE'$: (distance). This distance is found thus: On AE' lay off $Ax = AB$, and draw xy parallel to $E'E$ until it cuts AE in y; then xy is the distance B must be moved to B' in the direction Bz such that $ABz = AE'E$. All the points are adjusted in the same way, the same rule holding for points beyond A, as K, noting that the angle $AE'E$ must be laid off to the *left* or *right* of the line *to* A, according as E' is to the left or right of E looking *from* A.

The accuracy of the adjustment is tested by laying off from E the true bearing observed there, and the line should pass exactly through the position of the station observed upon. $A'B'C'D'EG'H'I'K'$ are the adjusted positions.

96. Triangulation points are marked on the projection by small equilateral triangles about $\frac{3}{16}$ inch side. Secondary and minor signals are enclosed in circles about $\frac{1}{8}''$ diameter, and every point has its name written close to it, care being taken that points near the shore-line have their names in-shore so as not to obstruct the shore-line or interfere with the soundings. The main triangulation being finished, the next operation is to plot the secondary or minor triangulation, the shore-line, and, finally, the soundings. Topography within the shore-line is merely indicated on the projection and drawn carefully on the finished chart.

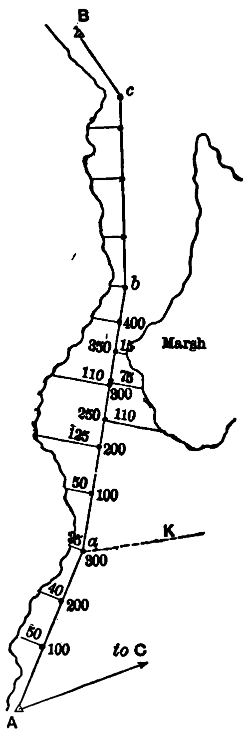
CHAPTER VII.

THE SECONDARY TRIANGULATION OR SHORE-LINE WORK.

97. WHILE not strictly triangulation, the shore-line work may be conveniently designated as such, and all the work of locating the minor signals and shore-line described under that head. It also includes the fixing of signals which are to be used by the boats in sounding. Signals will be very numerous, and of every variety. In erecting the signals several points should be borne in mind. They should be so spaced that from any point on the water where the boats may have occasion to go in sounding three signals at least may be visible, two or more signals must be visible from each individual signal, and auxiliary signals must be put up whenever it becomes necessary for the accurate location of the regular signals. This cannot always be strictly carried out, but will serve as a general rule. When there is plenty of time and considerable detail is desired the plane-table will be found most useful and efficient. In the abscence of that instrument and where the nature of the country will permit of it, the theodolite and chain may be used as follows:

98. Suppose we wish to run in shore-line from *A* to *B*. Set up and level theodolite at *A*, place the zeros together and bisect the signal *C* with the vertical wire; clamp the lower plate and point the theodolite along the shore-line towards *a*. A man previously sent out with a small flag goes as far along the coast as he can in a straight line, and plants his flag

at *a*. With the chain measure the distance from *A* to *a*, measuring offsets to the beach every 100 or 200 feet until *a* is reached. Clamp the plates securely together, remove the theodolite to *a* and adjust it there, after unclamping the lower plate. Transit the telescope, bisect *A* and clamp the lower plate, transit again, unclamp the upper plate and point at *b*, selected as before. The zero will be in the direction *aK* parallel to *AC*, and the line *ab* will be plotted in its true direction, even if we measure *Aa* incorrectly. The record will be kept as in the sketch, beginning at the bottom of the page and working up. Continue from *a* to *b* to *c* to *B* as described from *A* to *a*. This is called "running in the shore-line by the back angle," and is not much used in practice. The method may be used to fix the signals on a stretch of coast where signals back of the beach are impossible, as in some parts of the west coast of Florida.



99. There can be no rule given for the location of signals on a coast, as it is seldom that two parts are sufficiently similar to require the same treatment; but by remembering the directions already given and that a signal that cannot be accurately located is worse than none at all (as it misleads the boat officers and throws discredit on other signals), and that it is better to have too many than too few signals, the proper placing of signals is readily acquired. Locating a signal by observing angles to it from several different points is called "cutting it in;" an angle to any signal is called a "cut" on it. A signal accurately plotted is said to be *fixed*.

100. The following method of running in shore-line will serve as a guide, being altered to suit the country in which the survey is being made. We will suppose signals are erected along the shore-line which is to be run in, and that the main triangulation-signals are erected and cut in. It is understood that the triangulation and shore-line work are being done simultaneously, and that when the triangulation-points are occupied angles are observed to all the minor signals in sight. The signal at the end of the shore-line is occupied first. The angles to all the signals in sight, both main triangulation and minor, are observed as described in the occupation of the triangulation-point, no angles being repeated, but a check round being taken. The angle-book has one page for angles and a blank page for sketches and remarks at each opening. Record the angles on the left-hand page and make a sketch of the contour of the beach on the right, commencing at the bottom of the page.

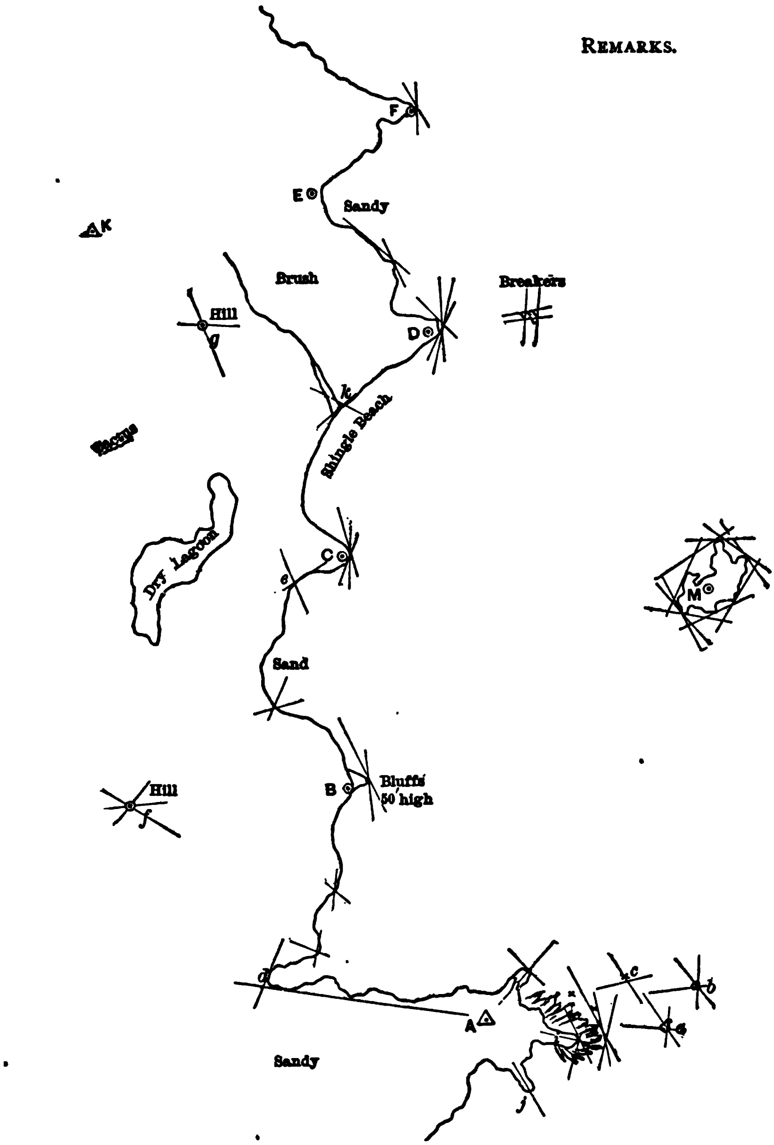
Having completed the round of angles at *A*, with the same zero direct the telescope so that the wire shall be tangent to the bottom of the bight at *d*, then cut on the hills *f* and *g*; observe tangent to the point off *B*, and if there is a rock, bush, or any object at *e* which can be seen, get a cut on it; observe also tangents off *C*, *D*, and *F*. (See diagram page 69.) Observe also the angles in the direction of the points *h*, *i* and *j*, and get cuts on the outlying rocks *a*, *b*, and *c*. Consider no detail too insignificant for cutting in, particularly breakers when not on the beach, or shoal water. Note at different points of the sketch the character of the beach—whether sand, shingle, boulders, rocky ledges, etc.,—and the estimated heights of bluffs, widths of streams or cañons, and any other data, offsets, etc., which may suggest themselves on the spot as of assistance in plotting the shore-line. These cuts are recorded by using small letters or numbers on the sketch and referring to them as in the following form of angle-book.

Place: BLANCO BAY, LOWER CAL. *Station occupied:* A.

Date: Jan. 10, 1889. *Observer:* A. B. C.

OBJECTS OBSERVED.	ANGLES.		
	°	′	″
⊙ *B*	90	10	
⊙ *C*	103	30	
⊙ *D*	116	5	
⊙ *M*	152	20	
Tangent to bight *d*	39	10	
Tangent off *B* ⊙	95	14	
Tangent off *C* ⊙	105	20	
Breakers { from	119	30	
Breakers { to	121	00	
End of shingle near *D*, *k*	108	20	
Direction of point *h*	161	30	
" " " *i*	226	27	
" " " *j*	269	50	
Rock *c* (awash)	198	30	
Rock *b* (10 ft. high)	203	27	
Rock *a* (25 ft.)	214	2	
Left tangent Island *M*	148	27	
Right tangent Island *M*	155	9	
Hill *f*	64	19	

REMARKS.

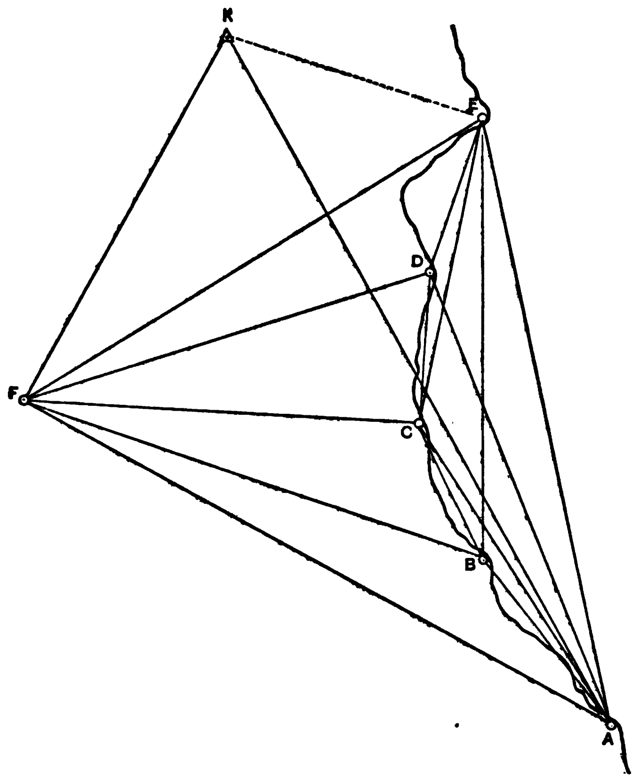

F
E
Sandy
K
Brush
Breakers
Hill
g
D
k
Shingle Beach
Dry Lagoon
C
e
M
Sand
B
Bluffs
50' high
Hill
f
d
A
c
b
a
Sandy
j

101. Having completed work at *A*, proceed to *B*, and observe in the same way. A man may be sent on from *A* to put up sticks at *d*, *e*, *k*, and like places that may be pointed out. Any small mark that can be seen from the adjacent signals will answer; a narrow strip of sheeting on a small wand is sufficient. As will be seen from the sketch, the tangents to points are of great use in determining their limits, and their shape can be drawn when the points are occupied or while going from one station to the next. All the details are noticed while walking between stations, and put on the sketch at the first halt. A small outlying island, as *M*, is limited by tangents, as shown in the sketch, and its true shape drawn by landing and looking at it from its highest point or by sketches from the shore. In the case of the sketch a signal should be placed on the island, as it would assist materially in fixing the other signals. Here it may be noted that the triangles formed in the shore-line work do not have to satisfy all the conditions of the main triangles. Small angles are of frequent occurrence, but "receiving" angles should always be larger than 30°; the nearer to 90° the better.

102. In plotting, a 3-arm protractor, carefully adjusted, is used in laying off the angles. We will suppose *A* and *K* fixed by the main triangulation, but that no angles have been observed at *K* on *B*, *C*, *D*, *E*, *F*, etc., and that there is a signal at *M* that has been occupied. First plot *D* by laying off the angle *KAD* and laying off at *K* an angle *AKD* equal to $180° - (KAD + KDA)$, two observed angles. Compute the angle at *K* between *C* and *D*, lay it off from *D*, and lay off the angle *KDC*. Plot *M* in the same way as *D*, then lay off at *M* the angle *AMC* and see if it cuts exactly the intersection of the lines from *D* and *K*, and check *D* in the same way. All these points are marked with a pricker and reading-glass. Now cut in *B* by lines from *C*, *M*, *A*, and a computed angle at *K*, and from *K*, *D*, and *C* cut in *E*, and from *E*, *D*, *M*, and *C* cut in *F*, and proceed in this way along the coast until all the signals are cut in and checked. A long cut from *A* on *E*, or *F*, or more distant signals, is a good check. Now lay off from *B* and *D* the cuts to *d*, from *A* and *C* the cuts on the rocks *a*, *b*, *c*, etc. Two cuts are enough to locate these minor points, as they are generally ill-defined. The shore-line is traced in from the sketches between the points thus plotted, and the character of the land in the different parts indicated by conventional signs.

103. The fact that the three angles of a triangle sum up 180° is of great use in this irregular plotting, as it enables one to use a distant point that may not be accessible or which is too far away to be occupied in the time at disposal.

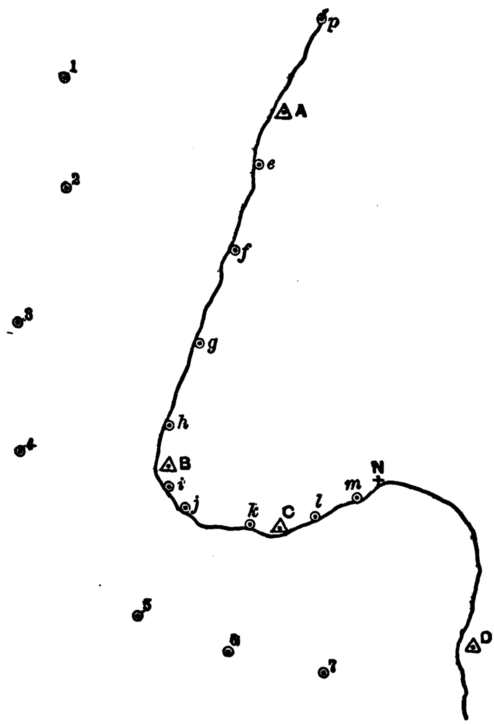
Suppose there is a stretch of coast, such as *A*, *B*, *C*, *D*, *E* (page 72), and it is desired to fix the various signals. Suppose *A* already fixed, and *K* a main triangulation-point. Though the angle *KAE* is small, *E* is well fixed from *A* and *K* by cuts nearly at right angles, but it is plain that *B*, *C*, and *D* could not be fixed by cuts from these points. At *A* it is noticed that the next few signals will be difficult to fix, so some mark is selected at *F*, a tree, rock, bush, cactus, or, if nothing is available, a man is sent to put up a stake well back from the beach. At each of the signals *A*, *B*, *C*, *D*, and *E* the angles to all the others are observed, and to *F*, and the shore-line sketched in as before. When it comes to plotting, first plot *E* from *A* and *K*, and then by using the angles *FEA* and *FAE* plot *F*. In the triangle *ABF* the angles *A* and *B* are known and *AFB* computed. Similarly *BFC*, *CFD*, *DFE*, checking these values by noticing if the sum of *EFD* and *DFC* satisfies the triangle *EFC*. Now from *E* lay off the angle between *F* and *B*, and from *F* an angle between *A* or *E* and *B*, and lay off an angle to *B* from *A*. *C* and *D* are plotted in like manner, computed angles at *K* being also used as checks. In this way, by selecting an auxiliary point whenever the signals appear to be drawing into line or becoming difficult to fix, much trouble is obviated. Signals are sometimes fixed by the three-point problem, but these should always be checked by cuts from other signals and the method should be used very carefully. The sextant may be used in observing angles, but care must be taken that the angles are observed in horizontal planes, and that



the sextant is held close to the centre of the signal, particularly when the lines between signals are short.

104. It sometimes happens that the shore-line is of such a character as will not admit of the fixing of signals by ordinary methods, as when there are high bluffs close to the shore or woods close down to it, and the beach is convex to seaward, or

in the case of steep sides of an island. In any of these cases the following method has been used successfully, the ship being used as the auxiliary station. The sketch represents a portion of the coast of Lower California, Cape Colnett, 30° 58′ N., 116° 20′ W. This remarkable promontory is 450 feet high, and its face to seaward is almost perpendicular. From *A* to *B* is practically a straight line, and from *B* to *N* a curve as shown,



the bluff ending at *N*, where the ordinary method is used. *A* and *B* are triangulation-points on top of the bluff. Boat signals could only be placed on top of the bluff or at the foot of it, and the former was impracticable because the boats had to sound close up to the beach, and angles on such signals would have been useless. Signals were made at *p*, *e*, *f*, *g*, *h*, *i*, etc., near the shore line by means of whitewash, and cut in as follows, the shore-line between being run in the usual way. Observers with theodolites were sent to *A* and *B*, where the angles between the ship and opposite station were observed on signal from the ship. The ship then steamed to position 1. Arriving there, several observers gathered at the taffrail in as small a group as possible, observed the angles from *e*, *f*, *g*, *h*, etc., including *B*, to a signal to the left, *p*, near the water-line; one also measured the angle between *A* and *B*. The ship being stopped, a large signal flag was hoisted at the peak as a signal for the theodolites to stand by. When all were ready the word "mark" was given, and the signal dipped quickly and lowered to half-mast. Each observer read his angle and quickly measured the angle between his signal and the right tangent to the bluff as a check angle. The observers on shore with the vertical wire bisecting the group on board followed the ship until the flag dipped, and then noted the time and read the angle. The flag being directly over the observing party on board was well within the field of the telescope, and its movements could be followed instantly. Altitudes of *A* and *B* are observed to reduce the angles between *A* and *B* and *p* and *B* to horizontal angles. The ship then moved to positions 2, 3 and 4, and the operation was repeated at each stop. The flag is not mast-headed until the ship is stopped, that being the signal to those on shore to "stand by," and they are ready to observe when the flag is dipped. This is necessary, as it is very trying on the eyes to follow the motions of the ship for a long space, and there is a chance of losing the angle from the observer being obliged to wipe his eyes at the critical moment. The observers on shore being picked up, the angles and times are compared to see that none were lost; and by adding the angle between *A* and *B* from the ship and the two theodolite angles at each stop, a check on the accuracy of the work is obtained. The plotting is simple. "1," "2," "3," and "4" are plotted by the angles from *A* and *B*, and then the angles from these points fix the positions of all the minor signals. The same process was gone through with to fix the signals *j*, *k*, *l*, *m*, etc., using *C* and *D* on shore.

105. In a survey (of any considerable extent) plotted on a small scale it is found convenient to plot the shore-line on a larger scale and reduce the plan to the scale of the general chart, the soundings being plotted on the larger scale and transferred to the smaller. As many of the triangulation-points as are needed are placed on the large scale chart by plotting each side by intersecting arcs 2, 3, 4, or more times the length on the small scale, and checking by the angles and then plotting the shore-line as already described.

The reduction is effected as follows: Draw a line between two corresponding triangulation-points on that chart, selecting those at the extremities of the large scale chart. Call this the base. Subdivide these bases into the same number of equal parts until those on the large scale are about half an inch in length. Through each of these points of division draw lines perpendicular to the base, and lay off on the extreme lines distances equal to those on the base on each chart, and through these points draw lines parallel to the base, forming a series of squares, until all the work to be transferred is included within them. Then the portion in each square is transferred to its corresponding square on the smaller chart by using proportional dividers or pantograph, or it may be done quite accurately by the eye. Both projections are sent in with the records.

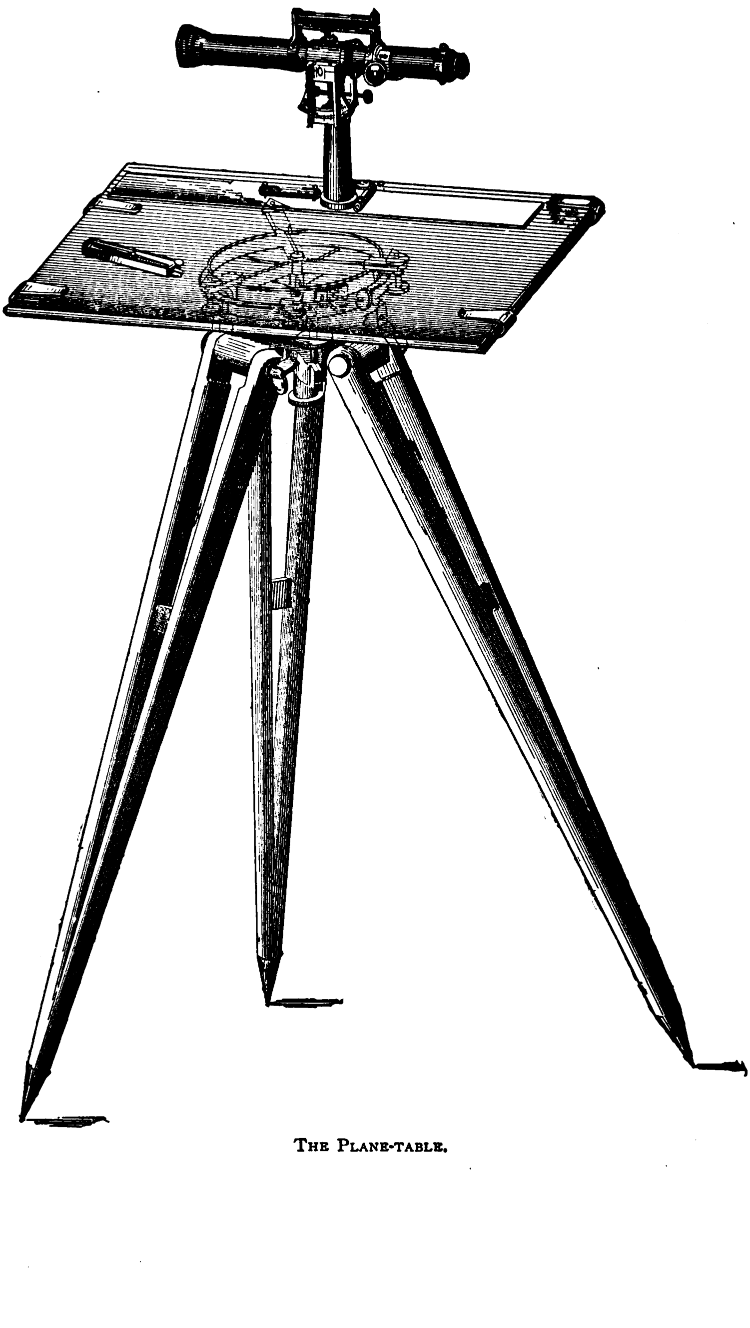
106. Angles from the ship are often very useful in fixing signals on a straight beach, where there are no available points inland. The ship being at anchor and not swinging, several angles are observed between the triangulation-points for fixing the ship, and then angles are taken from a fixed signal to each of those which it is desired to cut in. The fixing angles are then retaken, to be sure that the ship has been stationary. In plotting, since but two angles can be placed on the protractor at once, it is better to plot all the fixing angles by lines radiating from a point on tracing-paper. Then when laid on the chart and each line made to pass through the point observed the centre will be the required position, and will be quite accurate if three or more angles are observed. The cuts are plotted as if taken from a signal on shore.

CHAPTER VIII.

TOPOGRAPHY—THE PLANE-TABLE.

107. UNDER the head of secondary triangulation or coast lining were given instructions for putting in the topography near the coast. If it is desired to carry the topography farther inland, other methods must be used; though, for all purposes of navigation, only that portion of the country visible from a ship's deck is needed on the chart. When each peak is occupied, sketches or photographs of the surrounding country are taken; and from these views, from the computed heights of peaks, and from views taken from the ship's deck the contour-lines are put in by the draughtsman, and the character of the country indicated by conventional signs. Care must be taken in drawing contour-lines that they indicate properly the slopes, directions of arroyos, cañons, etc., and that rivers are not made to flow uphill No contour-line can have an end except by passing beyond the limits of the sheet, otherwise they must be closed curves.

108. In the topographical work of the Coast Survey the plane-table is used exclusively, and it may also be used in nautical surveys for running in shore-line, and with very accurate results, though at the expense of time. The plane-table comprises a drawing-board, tripod-head and tripod, and alidade. The board is made of well-seasoned wood, carefully constructed in panels to prevent warping, and with its upper surface perfectly plane, and has three brass sockets on its under side set at the vertices of an equilateral triangle, and equally distant from the centre of the board, by which it is secured by screws to the



The Plane-table.

tripod-head. The tripod-head is of brass, and consists of two plates similar to the azimuth plates of a theodolite, having clamp and tangent-screw, but no graduations, and having three grooved feet which rest on screws in the top of the tripod, which also serve for levelling it. The upper plate has three projections, through which pass the screws which secure the board; and a swivel-hook and screw at the centre secure it to the tripod. The tripod is made quite large at the top, and arranged to be very solid and rigid when set up.

109. There are various patterns of alidades, but all are the same in general principles. The alidade consists of a brass or steel rule about 20 inches long and 2½ wide, carrying at its centre a vertical column of brass about 3 inches high, and on either end of rule, close to the column, two levels—one in line with the axis of the rule, the other at right angles. On top of the column is a plate to which the Y's receiving the transverse axis of a telescope are attached. One end of this axis carries a graduated arc of about 60°, a vernier for reading it being attached to the standard. The telescope is fitted accurately near its centre of gravity within a short cylinder, to which the transverse axis is attached. The telescope revolves within this cylinder on its longitudinal axis through 180°, and stops are fitted to limit its revolution to this amount. This is for the purpose of adjusting the cross-wires for collimation, etc. On either side of this cylinder the telescope tube is slightly enlarged, forming narrow bands of equal diameter, on which a striding level may be placed. The diaphragm has one vertical wire and two or three equidistant horizontal wires. The distances between these wires being constant, it is plain that the number of graduations on a measured rod subtended by them will vary as the distance of the rod. A micrometer is sometimes attached to the eye-piece, having one fixed and one movable wire, and distances are measured by noting the distance between the wires when a fixed length on the rod is subtended by them. A magnetic needle in an oblong box accompanies the plane-table. The box has graduated arcs in either end, covering about 20° with 0 in centre, and the line of zeros is parallel to the sides of the box. This is used in placing the north and south line on the table parallel to the north and south line on the earth.

110. The adjustments of the plane-table refer mainly to the alidade. It must be assumed that the fiducial edge of the rule is truly straight, as this can only be remedied by the instrument-maker. It may be tested, however, by drawing a line along the edge of the rule, and then placing the same edge of the rule on the other side of the line and noting if they coincide throughout, which they should. The levels must first be adjusted. Set up the table, with its tripod firmly planted on the ground and its top nearly horizontal. Place the alidade on the table across the centre, with the edge of the rule parallel to the line joining two of the levelling-screws, and draw a short line near each end of it. By means of the foot-screws bring both bubbles to the centres of the levels. Turn the rule end for end, and replace it in the same position by the lines drawn on the paper. If the bubbles remain central, they are in adjustment; if not, half the error is corrected by the screws on the level and the other half by the levelling-screws. The fore and aft level is first adjusted, the rule being turned end for end several times until the adjustment is perfect. It is then placed at right angles with its former position, and the second level adjusted by its screws alone.

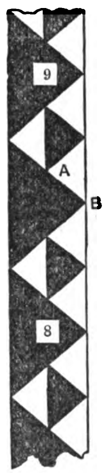
The next adjustment is for parallax. Move the eye-piece until the cross-wires are perfectly distinct, and then focus the telescope on some distant, well-defined object, and bisect it with the vertical wire. If, when the eye is moved from side to side across the eye-piece, the contact remains good, there is no parallax. If the wire moves off the object, however, the focus of the object-glass is changed until the contact cannot be disturbed by moving the eye about. If the object be not distinct, then the fault is partly in the eye-piece, and its focus on the wires should be examined and altered until the wires are in the common focus of the two glasses.

III. Collimation error. To make the line of collimation and line of sight coincide, sight at some distant object, and bisect it at the middle of the vertical wire, clamping the horizontal axis of the telescope. Revolve the telescope on its longer axis through 180°, and note how the object and vertical wire appear. If the contact is preserved, there is no collimation error. If they are separated, bring the wire half-way back to the object by means of the tangent-screw on the tripod-head, and then, by means of the screws on the diaphragm, perfect the contact. Revolve the telescope to first position and adjust again and repeat the operation until the adjustment is perfect.

The vertical wire is made to move in a plane at right angles to the axis of revolution, which must be parallel to the plane of the rule, by directing the telescope to a small clear object, and causing it to travel along the vertical wire by moving the telescope in altitude. If the object deviates from the wire, it is made to travel on it by turning the diaphragm on its axis until it does not deviate. It must be borne in mind that a collimation error will cause a deviation in the above case, but the object will move on the same side of the wire when the telescope is elevated or depressed, seeming to move in a curve, while in the first case it moves in a straight line, and is on opposite sides of the wire at the extreme ranges. Should the alidade not be fitted for revolution on its longer axis, the transverse axis must be reversed in the Y's in all cases where such revolution is called for. There is, moreover, a style of alidade in which the telescope may be turned on its transverse axis through 180°, or "transited." In this case the line of collimation is on one side of the centre of the standard instead of passing through it. In this instrument the *rule* is turned end for end by using a line drawn on the table, and the telescope transited in cases where it is necessary for the direction of the shorter axis to be reversed. Should the alidade not be fitted to revolve on its long axis, it must be lifted from its Y's, and its transverse axis reversed.

112. To adjust the vernier of the vertical arc. Place the striding-level on the telescope, and bring the bubble to the centre by means of the tangent-screw of the telescope; reverse the level, and bring the bubble half-way to the centre by means of the tangent-screw, and the remainder by the screws on the level. When this adjustment is complete, the axis of the telescope is horizontal, and the vernier may be set to read zero of the vertical arc. Look through the telescope, and note what object is bisected by the middle horizontal wire. Revolve the telescope through 180°, and if the same object is still bisected, the adjustment is perfect. If not, by means of screws on the diaphragm move the horizontal wires up or down until the middle one has been moved over half the space it was separated from the selected object. Select a point bisected by the wire in its new position, and revolve the telescope; adjust half the error, and so on, until none remains. The table must be accurately levelled during this adjustment, particularly that of setting the vernier.

113. A telemeter should accompany each plane-table, for the measurement of distances. It consists of a light board about 14 feet long, 4 inches wide, 1 inch thick, graduated on one side according to the distance between the horizontal wires of the instrument with which it is to be used. Usually they are made in two parts, hinged in the middle, with a sliding bolt on the back to keep the parts in line when opened, and a short rod or tube attached to one edge of the board (at right angles to it), by which it may be held perpendicular to the line of sight from the telescope. In the absence of such a rod one may be readily constructed as follows: Provide a suitable board and paint it white. Set up and level the plane-table and place the alidade upon it, with the telescope level. Measure very accurately 100 feet from the object-glass of the telescope in a horizontal line, and place the board vertical with its face at the exact distance and secure it in that position. Look through the telescope and have an assistant mark with a sharp pencil where the lines of sight from the middle and upper wires cut the board. From these lines up and down divide the board into spaces equal to the distance between them, marking each space by a line across the board, and then divide each space into parts as shown in the figure, numbering the even divisions from 0 to the highest number, painting the numbers wrong side up if the telescope inverts them. It is evident that at 200 feet distance two spaces will be included between the wires, and by directing the middle wire to an even division the number of spaces and parts of space included between the wires will be the distance in hundreds of feet and fractional parts. Each angle, as *AB*, on the rod represents $12\frac{1}{2}'$, and fractions may be estimated by noting where the wire cuts the line from *A* to *B*. The telemeter may be used up to about 1200 to 1500 feet, beyond which distance the rod has to be too long for convenience of transportation, and the divisions become too indistinct to be read with accuracy.



114. In using the telemeter a man takes it to the point whose distance from the plane-table is to be measured, and holds it in a vertical plane through the instrument, and sighting along the rod on the side holds it at right angles to the line of sight from the instrument. If the two points are on the same level it is of course held vertical. The space included between the wires of the telescope is observed by bisecting the rod with the vertical wire and reading off the spaces between horizontal wires and the angular depression or elevation, read on the graduated arc. If this exceeds 30′ either way the distance is reduced to a horizontal distance by applying the cosine of the observed angle, correcting for refraction. In practice, a table of reductions for all angles and distances is made out beforehand, and carried in the pocket. When engaged in plane-table work, the observer should wear a light coat, with wide side pockets to carry pencils, rubber, metal scale, protractor dividers, tables of reduction for angles, note-book, etc., so as to have them handy and not have to keep them always on the table, where they interfere with the alidade and obstruct the work.

115. While it is possible to start with a clean sheet of paper, measure a base by telemeter, and cut in all the signals the same as if angles were observed by theodolite, it is not recommended. In practice, the topographical work follows the triangulation, and it will be assumed that all the principal stations have been determined from a measured base and that they are accurately plotted on the sheet that is to be used. The paper should not be "stretched" on the board, as it soon loses its shape when removed, and is liable to damage from rain-squalls. As it is the only record of the work done, it should be kept in as perfect condition as possible. A tin case to contain the sheet should always be carried, and in warm weather a large umbrella to keep the sun from the table and alidade and save the glare from the white paper on the observer's eyes. Muslin-backed paper is used, and it is cut to the *width* of the *long* side of the table, and will generally be longer than the width of the table; so the excess is rolled up inward, and fastened with a metal spring-clamp biting from the top of the sheet on the table to the inside of the roll beneath. One clamp at each corner of the table holds the ends of the sheet, and it is secured along the edges between these corners by shorter clamps, though metal strips along the sides of the table secured by clamps afford more security from winds.

The sheet should never be rolled to a less diameter than three inches on account of the damage to the surface fibres caused by compression when rolled smaller. Having secured the sheet, placed the table and the alidade in adjustment, and erected signals at the triangulation-points, one of the last may now be occupied.

116. Set the table up over the point and level it. In setting up the table over a station, it is placed in its approximate position and the N. and S. line placed in the meridian by means of the "declinatoire." A small object is then placed over the point on the sheet representing the position occupied and the observer, standing a few feet away, notes whether it is vertically over the surface mark of the station, and if not, the assistant moves the table without *turning* it until it is. This is repeated by the observer, looking in a direction at right angles to the first, and the adjustment made as before. This done, the table is "oriented" and the work proceeds. If greater accuracy is desired, a point on the under side of the table, corresponding to the point on top, may be found by measuring its distance from an end and a side, and a pin stuck at the point with a light plumb-bob attached, which may be made to hang exactly over the centre of the station by moving the table. In practice, the first adjustment is sufficiently accurate. Place the rule with its edge on the line joining the station occupied with any other point on the sheet and revolve the *table* until the telescope points in the direction of this object. Look through the telescope and revolve the table until the object is nearly on the vertical wire, when clamp the table securely and perfect the contact with the tangent-screw. Take hold of two corners and press the table slightly in the direction of revolution to see that it is secure, and then observe that the vertical wire still bisects the object, correcting any error by means of the tangent-screw. The principal condition required in plane-table work, and without which no accurate work can be done, is that the table shall be in position or, as it called, "oriented." The table is in position when all the lines joining points on the sheet are parallel to the corresponding lines on the earth. The rule of the alidade is placed against the lines joining the station occupied with all the other points on the sheet in succession, and each corresponding signal should be bisected by the vertical wire of the telescope. If some are not, it is because the plotting is faulty or the paper has changed its dimensions, and the defect must be corrected before proceeding farther. If, however, each signal stands the test, the projection is good and the table in position. By means of the magnetic needle or "declinatoire," draw near the middle of the sheet a line to represent the magnetic meridian to facilitate putting the table in position when a new point is occupied.

117. Place the alidade on the table across the centre with the rule parallel to the line joining two of the foot-screws of the tripod-head, and by means of those screws bring both bubbles of the levels to the central positions, and then set up securely the central screw under the tripod-head. Unclamp the revolving plates and turn the table until it is in position and clamp it firmly, verifying the position as already described. In handling the alidade, it is always grasped by the column supporting the telescope, and it may be carried from place to place, resting in the hollow of the elbow, the rule horizontal and resting against the hip. It is desirable that the work at each station be completed on the first occupation, so that a reoccupation may not be necessary, but for convenience of description the different portions of the work will be explained separately.

118. Call the station occupied *P*. Place the edge of the rule on the position of *P* on the sheet and revolve it about that point until any object which is to be cut in is bisected by the vertical wire. Draw a short line along the edge of the rule which will cross the point on the sheet which this object occupies relative to known positions, and repeat this operation until the line to every object to be cut in is drawn, marking each one with its name or some distinguishing mark, or numbering them and noting in a book what each number means. Rocks near shore, breakers, rocks awash, etc., are all to be observed in this way. Remove the alidade from the table, and all the pencils, rubber, etc., and move to the next position. The assistant lifts the table by grasping two of the legs and lifting them from the ground, the table resting on the other leg, closing all three together, and then carrying it over the shoulder. Arrived at the second station, it is lowered carefully, and the same legs held firmly while the third is pushed out with the knee to its proper position on the ground and landed, and then the two near feet are landed so that the top of the table may be nearly level and the proper point plumbed over the centre of the station. Call the station now occupied *A*. In speaking of a line on the sheet, the point at the eye end of the telescope or near end of rule is named first, and the point at the objective end or far end of rule last. Level the table and place the rule along the line *ap*, and revolve the table until *P* comes in the field of the telescope. Clamp the table and bisect *P* by means of the tangent-screw. The table is again in position. Verify the direction of each of the plotted stations from *A* in the same manner as they were verified from *P*. Place the edge of the rule on the point *a* on the sheet, and, revolving it about this position, point the telescope successively at each of the points cut in at the preceding station, and draw short lines crossing the ones already drawn to the corresponding points. The intersections of these lines will be the positions of the objects observed upon; but each one should be verified by similar observations from a third position, and no point considered definitely fixed without having at least three cuts on it through the same point, and intersecting at angles not less than 30°.

119. When a line is drawn from the position occupied to any point not plotted on the sheet the latter may be occupied and cut in by *resection*. Suppose *D* (page 89) is such a point. While at *P* the line of direction *pdn* was drawn on the sheet. Set up and level the table at *D*, and place it approximately in position by means of the "declinatoire." Place the alidade with the edge of the rule along the line *ndp* and, by means of the tangent-screw, bisect the signal at *P*, and the table will be in position. Place the edge of the rule on some point which bears about 90° from *P*, as *B*, the plotted point in this case being at the far end of the rule and, keeping it on the edge of the rule, move the alidade until the object is bisected by the vertical wire. Draw a short line crossing the line *ndp*, and the intersection of the two will be the point *d*. Repeat this operation on some other signal bearing not less than 30° from each of the two already used, and draw a second line across *ndp*. If these lines all meet in a point when examined with a reading-glass the position of the point is assured, and may be pricked in with a fine pricker and used as though it was one of the original stations. Signals should always be observed near their bases. All lines must be drawn lightly and carefully with a hard pencil having a chisel-point, and it must be kept close to the edge of the rule, and at the same inclination throughout. Should the rule and paper not be in perfect contact the pencil must not be allowed to run under the edge of the rule, and thus deviate from a straight line.

120. The accompanying diagrams will serve to illustrate the foregoing operations, $TT'T''T'''$ representing the table, and the arrow the direction in which the alidade points. The capital letters indicate the position of the objects on the ground, and the corresponding small letters their plotted positions on the sheet. The positions of a cupola, spire, and windmill are shown as cut in from three stations, and Fig. 3 will illustrate the location of *d* by *resection* on *B* and *A*.

121. The scale of the chart is known from the measured or

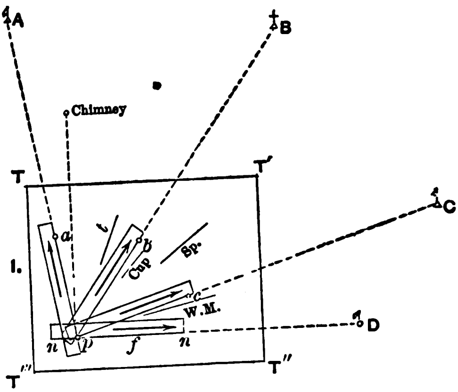


Fig. 1.

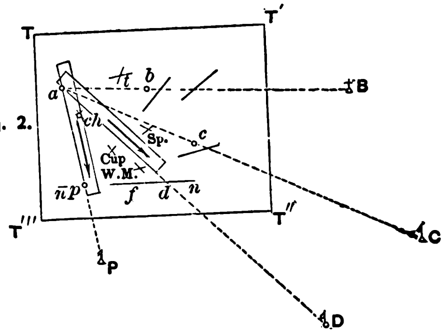


Fig. 2.

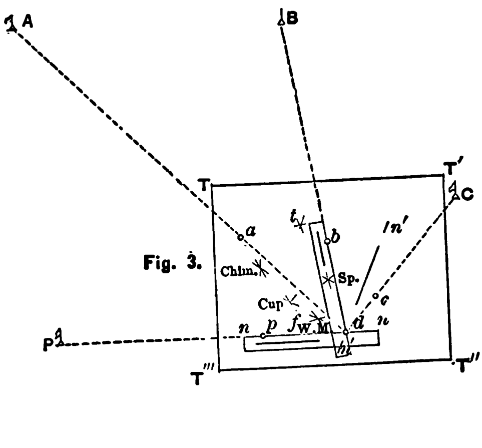


Fig. 3.

computed distance between two of the signals plotted upon it. If it is a decimal scale the telemeter should be graduated to read metres instead of feet, and the facility which this system gives in reducing distances is again apparent as, if the chart is on the scale of $\frac{1}{10000}$, and an object is 647 metres distant, it is merely necessary to lay off from a scale 6.47 centimetres in the direction of the object to have its position, and the latter distance may be taken at once from the scales usually supplied. If, on the other hand, miles, yards, and feet are used, the sheet should be on a scale of 6″ or 3″ to the mile, as then in the first case 1 inch will represent 1013 feet and hundreds of feet may be taken from a scale as tenths of inches without appreciable error.

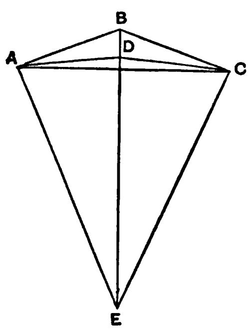
122. In connection with the plane-table the telemeter is in constant use. Suppose the table set up and oriented at a station A near the coast, where the shore-line is to be run in. An assistant is instructed as to the method of holding the rod, and to go along the coast and rest it on every prominent point he passes. Every bight, rock, river mouth, cañon point, and any irregularity in the shore-line must be put in. He moves along the shore, and at the first point faces the table and holds the rod vertical, resting on the ground, and sights along the side rod as explained. The observer places the edge of the rule against the point A on the sheet, bisects the rod with the vertical wire, and reads the number of spaces and parts of spaces of the rod included between the horizontal wires, one of the wires being at the zero of the rod. With dividers he takes from the scale the number of inches corresponding to this distance, and lays it off along the edge of the rule from the point occupied, and makes a small dot at the proper distance. As soon as the reading is obtained the observer raises his hand or waves a handkerchief as signal to the rod-man, who moves on to the next position, which is plotted in the same way by direction and distance. Buildings, fences, streets, wharves, etc., are quickly plotted in this way, the topography being drawn in between the points thus plotted by observing it while moving to the next position, or if possible from the position occupied. If the table is above or below the rod-man, the distances must be reduced to horizontal distances before being plotted. When the rod-man has reached the limit of distance which may be measured by the rod, he on receiving a preconcerted signal marks the point occupied by the rod and waits until the table is brought to his position, where it is set up over the point he last occupied, and he goes on along the shore. The bearing of the new position is of course accurately plotted, but the distance may be slightly in error. The position is verified or determined anew by resection on two or more signals which will give good angles and the survey proceeds. Instead of a diaphragm having two fixed wires, a micrometer is sometimes attached to the eye-piece, and the two wires of the micrometer, one fixed, one movable, are made to cover two targets on the rod which are at a fixed distance apart, and by means of a table of distances the micrometer readings are reduced to metres or feet. The targets may be placed at different distances apart, being widest separated for long distances, so that the subtended angle may change sufficiently for accurate measurements.

123. Contour-lines may be run in with the plane-table in two ways. In the first it is necessary that the position of one point of each equidistant level plane be determined with a levelling instrument, and the table set up and oriented at these positions. The telescope is clamped in a horizontal position, and a target fixed on the telemeter rod at the height of the optical axis of the telescope. The rod-man then moves up or down the slopes by signals until his target is bisected by the middle wire, and then his direction and distance are plotted. In this way successive points of the curve are plotted, and the line through these points is the contour, allowing of course for intermediate features. Curvature and refraction must be taken into account when the distances become great enough to require it.

124. In the second method the positions and heights of a number of characteristic points are determined, and the curves drawn in accordance with these results. The difference of level of any point from that of the point occupied by the table is found from its angular altitude or depression and observed distance by applying the sine of the angle to the distance. Tables are prepared for this purpose.

125. One of the most valuable features in the use of the plane table is the practicability of setting it up at any place where three points may be seen and then determining its position by resection on these three points, because of the facility it affords for the prosecution of a survey. To get the best results from the table and to know how to select positions to advantage requires a knowledge of the three-point problem, and the same conditions are required and the same principles involved as will be explained in the chapter on Sounding, to which the student is referred.

126. The table may be put in "position" at any point whose position is undetermined and from which three known points may be seen, excepting on the circumference passing through the points, as follows: Suppose *A*, *B*, and *C* are three points on the sheet, and the corresponding objects are visible from the point occupied, which call *D*. Set up and level the table and unclamp the plates. Place the rule along the line *CA* and point the telescope at *A*. Clamp the table, and with the edge of the rule on *C* point the telescope at *B* and draw the line *CE*. Unclamp the table, set the rule on *AC* and point at *C*, and clamp the table. With the



edge of the rule on *A* point again at *B*, and draw the line *AE* intersecting the line already drawn from *C* at *E*. Place the rule on the line *EB* and revolve the table until *B* is bisected by the vertical wire, and the table will be in position, as the point *D* will be somewhere on the line *EB*. Clamp the table securely, and with the edge of the rule on *A* point the telescope at *A* and draw the line *AD*, and *D* will be the point sought, which may be verified by resection on *C* and any other signals in sight.

127. The triangle formed by the lines joining the three points is called the *great triangle*, and the circumference passing them the *great circle*. When the table is not in position, the lines drawn by resection on the three points from any point not on the great circle will not intersect in a point, but will form a triangle called the *triangle of error*, or two of the lines will be parallel, intersected by the third. Since the lines drawn from any two objects include at their intersection the actual angle between the two objects at the occupied position, the true position of the point sought must be on the circle passing through the plotted positions of these objects and the intersection of the two lines, and, as there are three such intersections, the true point lies at the intersection of three circles passing through each two points and the intersection of the lines drawn from them. The construction of these circles is not convenient in the field, but the approximate position of the true point may be easily determined by imagining two of the circles drawn and estimating the true point of intersection from the directions of the circles. There are, moreover, simple rules by which the position of the true point may be estimated from the triangle of error:

1. When the point occupied is within the great triangle, the true point is within the triangle of error.

2. When the point occupied is within the great circle, but without the great triangle, when it is without the great circle

and the centre object is the nearest of the three, and when the three points are in range, the true point is outside the triangle of error and on the opposite side of the line from the middle point to the intersection of the lines from the other two points.

3. When the centre object is the most distant of the three, the true point lies on the same side of the line from the middle point as the intersection of the lines from the other two points, and in every case the point lies in the angle between the lines from the extreme points, which is part of the triangle of error, or in its vertical angle; that is, the line from the true point to the intersection of these two lines will always *cross* the enclosed area of the triangle if produced. The approximate position of the true point can always be determined at a glance by these rules, and the direction in which the table must be turned is plain. Facing the table and signals, if the true point is to the right of the line from any of the three signals, turn the table to the right, or with the sun; if the point is to the left, turn the table to the left. Resect again on the three objects, forming a new triangle of error. This triangle will generally be very small, and a slight additional movement of the table will place it in position, when the work may be proceeded with.

128. There being no other record of plane-table work than the sheet itself, great care must be taken to preserve it in its original shape and dimensions. In a small piece of work, it is sometimes convenient to stretch paper on the table and so dispense with all the clamps. Should this be done, the work must be transferred to the smooth sheet or a sheet of backed paper before being removed from the table, on account of the distortion which always follows the removal of a "stretched" sheet of paper. Conventional signs are used in the field work excepting where a large area has the same covering, when it may be indicated by a word and filled in at any convenient time.

129. Photography has been used in topographical work with considerable success. The entire landscape to be surveyed is included in photographs taken from several points of view, and the angles, both horizontal and vertical, are measured from the plates by means of a scale of equal parts. Rectilinear lenses must be used, the focal length must be accurately determined, and the corresponding angular view included on the plate known. The field work is done in a very short time, but the office work becomes a long and tedious job and requires great care and nicety, and then the results are but fairly accurate. Where time in a place is limited, the method might be of value, as the records are permanent and may be plotted at any subsequent time and no detail is omitted.

130. In ordinary surveying work, photographs are taken to assist the draughtsman, and furnish views which appear on the charts. Every four or five miles along the coast, when within two or three miles of the shore, a series of connected views including the whole coast is taken, also views of harbor entrances and of headlands and prominent features of the coast as they appear from different bearings. In unfrequented harbors a round of views on which landing-places, watering-places, etc., are marked is of great assistance in preparing sailing directions; and a view of each observation-spot, to include enough of the surrounding country to make it readily identified and recovered at any future time, should not be omitted.

131. During the whole course of an extended survey of coast, notes should be kept of the prevailing winds, currents, swell, character of surf at different parts of the coast, facilities for landings, dangers to be avoided, etc., and included in the sailing directions, and for each harbor or anchorage the sailing directions should include all information as to courses, ranges, set of currents, tidal or steady; tides, positions for anchoring, etc., as will enable any navigator to make the best use of the charts prepared, and the surveying-vessel should enter and leave the harbors, following closely the directions given before leaving the working-ground.

132. The accompanying diagrams show the conventional signs used in topography and also the symbols used on the finished chart to represent various objects. Buoys are generally colored on the charts. In U. S. ports black buoys with odd numbers are found on the right side of the channel, going out; red buoys with even numbers on the left. Red and black horizontal-striped buoys are found over obstructions and must be avoided. Black and white vertical stripes are found in mid-channel, and may be passed close to. Green spar-buoys are sometimes placed over wrecks. Some buoys also have bells, whistles, cages, or lights as special distinguishing marks, and their use is known from the chart of the harbor.

CHAPTER IX.

SOUNDINGS.

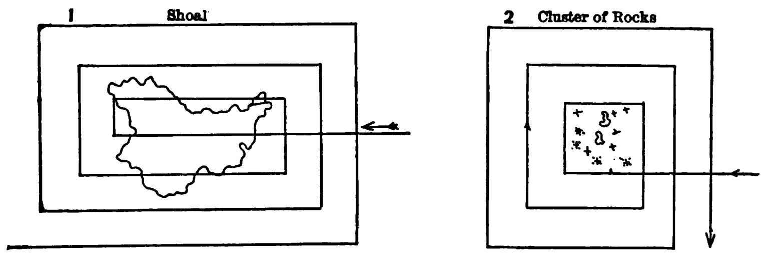
133. THE soundings form one of the most important features of a hydrographic survey and should be made with the utmost care and exactness, as a depth wrongly measured or improperly placed on a chart is worse than none at all. As shore signals are liable to be destroyed by storms or other causes, it is best to have the sounding work and secondary triangulation go on together, the soundings being put in as soon as a sufficient number of signals is erected and cut in. A plan should be decided on before a single sounding is taken, as it will not only add to the value of the work but tend to accuracy and neatness, and there will be no holidays to be filled when the soundings are plotted.

134. Soundings are made at regular intervals on imaginary lines, over which the ship or boat is made to pass, and, the position of the vessel being fixed by angles at various points of the line, the positions of the soundings are known.

Soundings are made on parallel lines at intervals which depend on the scale and nature of the survey. They are usually run normal to general trend of the coast, and extend, on the open coast, to a fixed distance or to a certain depth. In a harbor the lines are more numerous, and if the place is of considerable importance a second system of lines is run at right angles to the first, and the accuracy of the work is checked by the agreement of the soundings where the lines cross. Unless a harbor is of the greatest importance, lines are not run closer than 100^m unless the survey precedes making improvements. In *any* harbor the lines should be not more than 200^m

or $\frac{1}{10}$ of a mile apart, and in open roadsteads $\frac{2}{10}$ or $\frac{1}{4}$ mile. On the open coast, lines should be $\frac{1}{2}$ mile apart to a line 3 miles from shore, and beyond that 1 mile apart to 8 miles from shore, or to the 100-fm. curve on a much-frequented coast, being farther apart beyond the 8-mile line if the 100-fm. curve is farther out and the coast not much frequented. The lines from the shore to the 3-mile line should be done by launches, and beyond that by the ship. Lines in harbors should be parallel to those on the adjacent coast. The distance between soundings depends on the depth, but should never be greater than the space between the lines. A good general rule for ordinary surveying is $\frac{1}{20}$ of a mile up to 5 fathoms, $\frac{1}{10}$ of a mile up to 15 fathoms, $\frac{1}{4}$ of a mile up to 25 fathoms, $\frac{1}{2}$ of a mile up to 50 fathoms, and 1 mile apart beyond that depth.

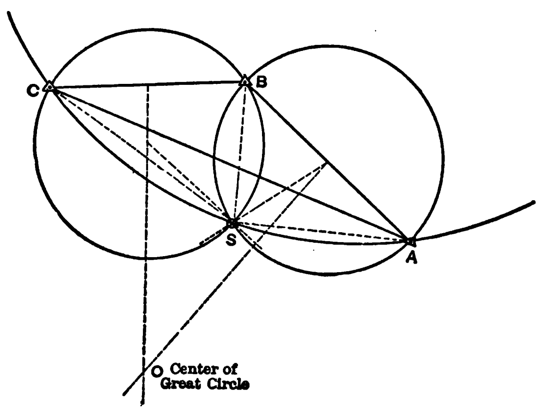
135. Shoals, banks, rocks, etc., must be developed by running additional lines across and around them so as to deter-



mine accurately their extent and limits; and no spot where soundings are irregular, as where soundings decrease, going off shore, should be left without an examination, more or less thorough, depending on its locality. It is not a good plan to develop a shoal by running a number of lines across some one point of it on different courses, forming a series of radials, as this makes a large number of soundings on the bank where they are of least value. Lines run as in the sketch (1) will thoroughly determine any shoal for all purposes of navigation, and a cluster of rocks enclosed by lines as in (2) will be thoroughly and quickly developed.

136. The positions of the soundings are usually plotted by means of the "three-point problem," which is, "to find a point such that three lines drawn from this point to three given points shall make given angles with each other." The three points are three signals on shore, and the required point is the position of the boat. The angles are observed with sextants. In the practical use of this problem a knowledge of the principles involved is essential to proper selection of objects. The objects are called, as looked at from the boat, the right, centre, and left objects; and as the right-hand one of two objects is the reflected object and is brought to the left-hand one, it is customary to record the right object first. The proper selection of objects is soon acquired by a study of the geometric principles involved.

137. All angles of a given size whose sides pass through two given points have their vertices on the segment of a cir-

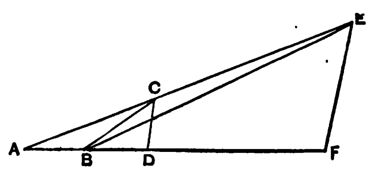


cumference passing through the two points and any one position of the vertex. Thus, if the angle *ASB* be measured, *S* must be somewhere on the segment *BSA*. Now if at *S* the angle *BSC* be measured, *S* must also be on the segment *BSC*; consequently it is fixed by their intersection, and the fix is good or poor according as the circles intersect nearer or farther from 90°. The following rules should be always borne in mind: Each angle should be not less than 30°. The centre object should be on the same side of the line joining the extreme objects as the observer, whenever possible. The closer the centre object is to the observer the better the fix (with good angles of course), other conditions being equal. Always use the nearest practicable objects.

138. Since *ASB* and *BSC* have been measured the angle *ASC* is known, and of course the segment *CSA* may be used in fixing the position, so that *S* is always fixed by the intersections of three circles. Now, so long as any two of these circles intersect at an angle greater than 30°, we have *S* well fixed. The angle between the circles at *S* is the same as the angle between their tangents, which is equal to the angle between the radii to that point. Now the angles between the circles at their two intersections are equal; hence it follows that the nearer the centres of the three circles are to each other the poorer will be the fix, until at the limit where the centres coincide *CSB*, *BSA*, and *CSA* are the same circle, and the problem is indeterminate, as *S* may be at any point on the circle passing through *A*, *B*, and *C*. This circle has been called the "great" circle, and the triangle *ABC* the "great" triangle. In this position the angle *ASC* is the supplement of *ABC*, and as this last angle is generally obtuse the sum of *ASB* and *BSC* will be less than 90°. If we occupy a position outside of the great circle the position is not indeterminate, but the fix will be poor because the angles will be small, since their sum will be smaller than the supplement of *ABC*. Thus it will be seen that the nearer *S* approaches to the great circle, either from within or without, the poorer becomes the fix. A set of angles taken from a position on the great circle is called a "revolver" or swinging angle.

139. So in the use of the three-point problem we have two things to avoid—small angles and the great circle. At times small angles are unavoidable, and experience alone can give the judgment necessary in using them. They should never be used unless the other conditions are of the best. If A, B, and C are on a straight line, the great circle will be of infinite radius; and if B is on the same side of AC as S, the great circle will be on the other side of AC and the fix will be good. If the angle $ASB + BSC > 180°$, S is within the great triangle and is perfectly determinate. So it follows that so long as SB is shorter than SA and SC, S cannot be near the great circle. In practice these conditions cannot always be satisfied, but any doubt can be dispelled by drawing the great circle on the working sheet, and if the position of the observer is near it one of the objects may be rejected, or, what amounts to the same thing, a third angle may be taken to a fourth object; being careful to note, however, that the fourth object is not on the same circle as the first three.

140. Within the power of the telescope of the sextant the probable error of an observed angle does not depend on the distances of the objects. With two given objects the change in the angle due to a given change in the position of the observer varies inversely as a function of their distance; consequently the probable error of an angle will make a greater error in the position of the observer when the objects are distant than when they are close. Suppose at A the equal angles CAD and EAF are observed between objects CD and EF. If the observer moves to B, the angle between C and D will change CBE more than the angle between E and F. Hence



close objects must always be used when angling for position. When close *practicable* objects is said, it refers to other conditions, such as visibility, proximity to great circle, size of angles, etc. Another rule to remember is this: Use near objects for position, distant objects for direction, which follows from what has been said here, and previously in regard to drawing a straight line between two points, an angle being more correctly laid off from a long than from a short line.

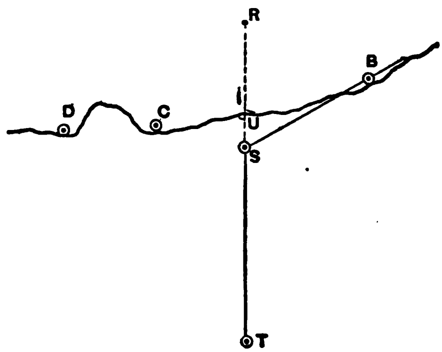
141. Soundings are taken at regular intervals, by time or by distance as shown by patent log. Where it is not necessary to stop for each cast the former gives good results, but when the water is too deep for good casts while moving ahead, the latter must be used.

The practical work of running a line of soundings is as follows: Having decided on the plan, etc., the lines to be run are drawn on the boat sheet and the boat goes to the beginning of the first line. The signals to be used are selected from the boat sheet, and when near the position two angles are observed and the position plotted. If it is not on the line or not at the end of it, the boat is moved in the proper direction until by trial angles she is found to be in the right place, and she is stopped there, headed in the direction the line is to take, and a sounding taken. The patent log, turned until it reads an even tenth, say six, is then put over and the boat started ahead on the compass course taken from the sheet. The time, angles, sounding, bottom, compass course, reading of patent log are recorded in the proper columns, and the bearing and approximate distance of the nearest prominent signal are noted in the remarks, also the estimated distance of the shore in the direction of the line. When the log has registered one tenth of a mile (or the distance selected) the log-reader calls out "*Seven-tenths*" loud enough for the leadsman forward to hear, and he takes a sounding. The recorder records the log-reading and the depth of water, and the boat keeps on her course. At the end of about three tenths from the start a position is taken and plotted. The log-reader gives warning when about one half a tenth from the sounding and the observers get the angles on their sextants, keep them on with the tangent screws until the even tenth, then mark together, at the sounding, and read the angles, which are recorded, the right angle always first. The time is also recorded. The position is plotted as quickly as possible, and if on the line the boat continues on the same course. If it is off the line the course is changed slightly so as to bring the boat to the line at the next position, the new course being recorded abreast the position and a note made in the remarks of the change of course. Observing angles for position is called "taking an angle" or "angling," for brevity. If the boat keeps the line well, it is not necessary to angle oftener than at each half mile, unless there are currents or other disturbing causes. Having proceeded half a mile from the last position another position is taken, recorded and plotted as before, the course being kept or changed as the occasion requires. If at any time between positions it is suspected that the boat is getting off the line, a trial angle is taken.and plotted without being recorded. If it shows that the boat is getting off the line, a position is taken at the next sounding and the course changed as required. The course should never be changed *between* positions, and the speed should be kept as uniform as possible. Much trouble will be saved in plotting by taking a position whenever the interval between soundings is changed, or by not changing the intervals between positions. In sounding by time the recorder calls out "*Sound*" at each half minute (or other interval), and in both cases he gives notice of the time for angling by saying, at one sounding, "*Angle next.*" When it is necessary to stop for soundings, the machinist can be instructed to stop and back at the order to sound without further orders, and he goes ahead as soon as he sees that the leadsman has the cast. When about to angle he is told to "stop her dead," and then he waits until told to go ahead, which should not be done until the position is plotted.

In a pulling boat the stroke oarsman can have the same instructions and the other oarsmen follow his motions.

142. The log-reader should be specially instructed to keep the log-line clear of the screw when backing. When the boat is stopped for angles she may be kept in the same position by having the leadsman leave the lead on the bottom and draw the line taut. By manœuvring the boat to keep the line up and down she will remain in one position as long as may be required. The officer who plots the position should observe the right angle, as that is the angle always recorded first. At the word "mark" he reads his sextant, calls out his angle, which is repeated by the recorder, puts his sextant down and sets his angle on the protractor. By this time the left angle has been read, and he is ready to set it on the protractor as soon as it is repeated by the recorder. When the position is plotted and the necessary arrangements are made about the course, the objects angled upon are told to the recorder. Having reached the end of one line on the sheet, the boat's head is turned towards the nearest end of the next line, which being reached, the line is run as already described.

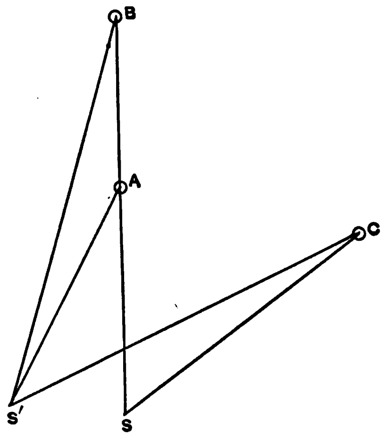
143. The keeping of the boat on the lines is much facilitated by the use of ranges. In very close harbor work artificial ranges are sometimes put up, but in general natural ranges must be used. A natural range may be readily picked up (if there is one to be had) as follows: Supposing the plotted position of the boat to be at *S*, and that *ST* is the line to be run. Place the centre of the protractor on *S*, one arm on *ST* and the other on *SB*; i.e., measure the angle *TSB* and subtract it from 180°, or measure directly the angle *BSR* on the continuation of *TS*. Set a sextant to this angle and observe what point on shore the reflected image of *B* covers. This will be *U* or some point on the line *UR*, and by noticing what object is in range with this point from the boat and running from *S* to *T* on this range the line will be truly kept. If the boat is at *T*, keep her steady as shown by the lead-line, and see what object is at the angle *BTS* to the left of *B*, and get the range as before. In a river we can get ranges on the opposite shore by this means, and can tell exactly where the end of the line should strike the shore. In all cases where ranges are used the objects should be as far apart as practicable, as a slight deviation from the



line will cause a large separation of such objects, where with objects close together a considerable deviation is barely noticeable. The object *B* should be at considerable distance, so that a slight movement of the boat will least affect the angle, which should be less than 45° rather than greater. This is one application of "distant objects for direction."

144. When two signals are in range the position of the boat may be fixed by one angle between one of these signals and another signal, as at *S*, page 106, as it is evident that but one point can satisfy the two conditions imposed; in fact, one angle in this case is zero. *S′* is a case where a small angle may be used, the centre object *A* being quite close and *B* comparatively distant. Ranges are recorded thus: *A* & *B* -0-0-0, the nearer object being recorded first and the three zeros meaning that the boat and two signals are on one line.

145. Detached rocks, wash rocks, breakers, etc., are cut in from the boat by observing the angle between them and some signal at two or three positions and plotting the different cuts. Signals whose positions are doubtful may be checked in the same way, and additional natural signals cut in if necessary. A note is made in the record whenever sunken rocks, kelp, or shoals are passed close aboard, noting the time or reading of the log and the estimated distance abeam. Each day's work is indicated in the record by the letters of the alphabet in succession, accents being used when the letters have all been used once. This is called the "day-mark," and is useful in



referring to any position. The positions of each day's work are numbered consecutively, the first one of each day being number 1. The symbol "$\overset{3}{\vee}h$" is the abbreviation for "position '3' of '*h*' day."

146. Sometimes it is impossible to get angles when close under the land at the beginning or end of a line. In this case the line is started as before, but without angles, and as soon as possible a position is taken, and after three or four more casts a second position, being careful to preserve the same course and speed up to the second angle. The line is then plotted in the continuation of the line between the positions, and the soundings are spaced the same as those between the positions. In ending a line this process is reversed. If only one angle can be taken, it is very useful in checking the last position, as it is then plotted by course and distance and one angle. Sextants should always have their index errors made zero before starting the day's work, and examined from time to time to detect any changes. In any case angles should be corrected for index error, so as to be recorded correctly at once. It is a good plan for the observer who is not plotting to observe a third angle as quickly as possible after reading his first observation, so as to detect a possible error in the first angles or objects. The same objects should be used as long as the angles between them remain good and they can be seen well enough to angle on, as a mistake in reading an angle would be at once detected from its irregularity, as generally the angle between two objects changes regularly as we approach or recede from them by equal stages. It also serves to show when we are approaching the great circle. If one angle changes very slowly, we are running nearly parallel to its circle. If both change very slowly, their circles are nearly parallel and the fix bad, as has been shown above; other objects should then be selected at once.

147. Notes should be made, in the remarks, of the state of the weather and sea, as a rough sea will frequently account for the failure of soundings to cross within the required limits and save the credit of work which might otherwise be considered doubtful. Everything in the record should be completed in the boat while on the working-ground, and nothing left to memory, as no work is acceptable unless the records are so kept that the work may be plotted by any intelligent surveyor without special knowledge of the actual locality. Lead-lines should be measured before and after each day's work, and the corrections, if any, noted in the records. When sounding with wire, the readings of the register of the sounding-machine should be corrected for turns of wire in use on the reel before being recorded as soundings. Note should be made when rope or wire is used, and whenever a change is made.

148. The sounding work of the ship may be classed under two heads, the off-shore or deep-sea sounding work, and in-shore work. In the former class, the soundings are taken out of sight of land, and positions obtained by astronomical observations, it being simply very accurate navigation. The first sounding of the line or the point from which the departure is taken may be fixed by angles from objects on shore, and each succeeding sounding is fixed by solar or star observations, the latter being preferable, as a very accurate position may be obtained by Sumner's method, using several stars. On making the land, the last position is plotted by angles, and the whole line adjusted for the difference between the actual position and the position as worked up from the last observations in the same way as described in adjusting the triangulation. The soundings, of course, would be taken with wire.

149. In the in-shore work, the lines are drawn on the working-sheet, and are run and recorded in the same way and in the same kind of books as the boat work. The deviation being known, however, the course can be laid very accurately and the magnetic course is recorded, changes being noted as in the boats. Soundings are taken with rope up to about thirty-five fathoms, when it becomes necessary to stop the ship for up-and-down casts; so above that depth wire is used, giving increased accuracy and causing no loss of time. Where soundings are taken at greater intervals than half a mile, angles should be observed at each sounding. Several observers should be on deck to get simultaneous angles at each position, as much assistance may be rendered the boats by cutting in natural objects on the shore-line for their use as signals, and in fixing signals that may be doubtful.

150. The angular altitude above the horizon, of peaks, hills, bluffs, promontories, islands, and all prominent points within the limits of the survey should be observed at different positions, when the ship stops for soundings, to furnish data for calculating their heights above the sea-level. These should be measured from the same level, so that one dip-table will suffice for all; and a number of observations should be made on each object from different positions, so as to get the mean height. In the computation of the height of a given peak, the largest angular altitudes are selected, ten being usually a sufficient number to work up for any one peak.

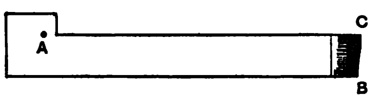
151. When sounding from the ship with rope, the deep-sea lead is always used, and various plans are adopted to decrease the labor and increase the speed of sounding. The plan in general use in surveying-ships is to have a wire jackstay rigged alongside the ship, with a sort of carriage to which the lead is hung while being transported forward preparatory to letting go. A reeling-engine is indispensable. The arrangement is as follows: An outrigger is secured on the ship's quarter, in a convenient place, generally in the extension of one of the quarter-boat davits. It has an open eye or score in its outer end, in which the wire jackstay ships, and a block seized to it for the lead line. A short boom is secured in the fore-chains or on the forecastle just forward of the fore-rigging, which has a similar score in its outboard end. This must be secured above and below by a topping lift and jumper, and also by guys. The jackstay is of wire $\frac{3}{4}''$ diameter, with an eye in either end. The after-end is set up abaft the sounding-davit, and the forward end is secured by a tackle, by which it is hauled taut when shipped in the two scores. A block of wood is secured to the jackstay, so as to bear on the after-side of the forward boom. On the jackstay a traveller is suspended on two rollers. This is a block about $18'' \times 10'' \times 3''$, having a hook pivoted in it so that the bill of the hook crosses a slot cut in the under edge of the block. Through the forward end of the block projects a bolt which, when pushed in, turns the hook back and leaves the slot clear. The bolt is held away from the hook by a spring. On either end of this block are hauling-lines, by which it is drawn forward and aft between the two outriggers. The lead is fitted with a double becket—one short, in which the lead-line is secured as usual, and one about two feet long, having a hammock-ring spliced in its end, by which it is hung to the traveller by pushing back the bolt, putting the ring in the score, and allowing the hook to engage it. The lead-line, after reeving through the block at the davit-head, is taken to the reeling-engine by suitable leads and coiled down beyond the barrel of the reel. A platform is rigged for the leadsman convenient to the davit-head. In sounding, the lead is hauled forward and at the proper time is dropped by forcing the bolt against the block already mentioned and disengaging the hook. The leadsman gets the cast in the usual way and the line being taken to the barrel of the reeling-engine is reeled up. The traveller meanwhile is hauled aft. As soon as the lead is up it is hooked on as before, the specimen-cup examined and cleaned, and is ready for another cast. In this way, soundings up to thirty fathoms may be taken without slowing below six knots. Beyond that depth it becomes necessary to slow and stop, in which case the wire-sounding apparatus is equally rapid and far more accurate.

152. Sunken rocks sometimes exist which may not be discovered by ordinary methods, and which may be of such a character as not to be indicated by any irregularity in soundings. When such are suspected, they are searched for by sweeping. Two boats, towing between them a length of small chain or lead-line weighted at intervals, move slowly over the suspected locality and endeavor to locate the obstruction by fouling it with the bight. In smooth water, isolated rocks may be discovered at moderate depths by their color, differing from that due to the greater surrounding depth, and in rough water their presence is indicated by breakers.

153. Before being placed on the finished sheet the soundings are reduced to the same plane of reference by applying the tide-correction, as will be explained later on. In plotting soundings, the positions are first plotted and connected by light pencil-lines. The plotting with three-arm protractor involves no special difficulty but must be carefully done. When the observed signals are very close to the position, the protractor may not be used, because the hub covers the points and they cannot be seen. Tracing-paper is used in this contingency. (Set the angles on the protractor as usual and lay the instrument on the tracing-paper with the centre near one corner. Mark the centre with a pricker, and with a sharp, hard pencil draw lines along the three arms. Remove the instrument and continue the three lines to the point marked at the centre, and then move the paper until each line passes over its proper signal when the centre will be the point sought. Several angles may be plotted at once by this method, and it is specially valuable in laying off cuts from an anchorage. Several angles being used, the position is fixed with great accuracy.)

154. Graduated circles printed on tracing-paper are sometimes supplied, and may be used for plotting. They are about 12″ diameter, and marked to 15 minutes. The line from centre to 0° is taken as the middle line and the observed angles laid off on either side, using a straight-edge. While these are very convenient, they have the disadvantage of soon becoming useless from the multiplication of lines at the centre, causing great liability to mistakes, and from the centre becoming unduly enlarged. In practice it will be found much more convenient and accurate to use plain paper, taking a new centre for each set of angles. As the lines may be very short, many more positions may be plotted with a square foot of plain paper than with one paper protractor. Again, the small pieces may be used in a boat where the use of the large paper protractors would be quite impracticable.

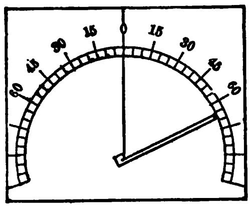
155. When there is much wind and sea, the use of paper presents an additional difficulty, constantly getting wet, torn, or blown away. To remedy this defect, a glass protractor was constructed on board the "Ranger," by Ensign J. B. Blish, for use in the boats, and, though not sufficiently accurate for final plotting, it was of great use in wet and windy weather, and needed but more careful construction to be accurate. A sheet of plain glass about 8″×10″ had a small hole drilled near the middle of a longer edge, and then, by using a small flat piece of copper and some powdered glass was ground until the surface was rough enough to retain pencil-marks without having its transparency too much reduced. A circle about $4\frac{1}{2}''$ radius was drawn with the small hole as centre, and this circle was divided into degrees by an ordinary protractor, taking the line across the centre of the glass as zero and marking up to 90° on either side. These marks were cut in the glass with a diamond, the 5th and 10th marks being longer than the others for distinction. A small straight-edge was made shaped like the figure,



having a fine pivot at *A* in the line of the working edge *AC*, and having on its end *CB*, which was bevelled to a fine edge, six divisions, commencing from the edge *C*, equal to 5° of the graduated circle. When the pin *A* was in the centre hole of the plate the edge *CB* just reached to the divisions on the scale, and by means of the vernier it formed, angles could be laid off to five minutes. To prevent breakage the plate rests in a very shallow box lined with black cloth, the sides of the box being no higher than the thickness of the glass, and the black being used to make the graduations plainer.

156. When it is desired to plot a position the rule is placed

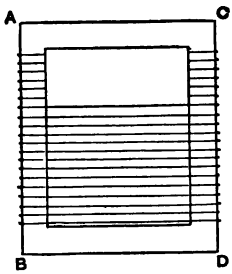
on the plate at the required angle and a fine line drawn along its edge, the right angle being laid off to the left of the centre line and *vice versa.* The rule is then removed and the glass placed face down on the projection, and moved until the three lines cover the required signals, when the observer's position is pricked through the centre hole. The black lines on the glass show very plainly against the sheet, and there is no parallax on account of thickness of glass, etc. When one position is plotted the lines may be washed off the glass, and it is ready at any time for use and not affected by water.



157. As each position is plotted it is marked with a needle point, a circle drawn around it, the number of the position placed abreast, and a line drawn from the preceding position. These lines should terminate just outside the circles of the positions, not at the points themselves. When all the positions are plotted, or before stopping for the day, the positions are inked in by making a circle about $\frac{1}{10}$ inch diameter around each one, and writing the number and day mark abreast every fifth position, also the first and last of the day. Different colors are used to distinguish between the boats and ship, as each one has the same series of day marks; red being generally used for the ship's work, green and blue for the boats; with a further distinction of capitals and small letters should there be more than three *vessels.* These auxiliary marks are never placed on the sheet in black, as they are not transferred to the finished chart.

158. The next step is to plot the soundings. If the same number of casts were taken between every two positions, the spaces might be laid off with proportional dividers, but as this is never the case for many intervals another device is used.

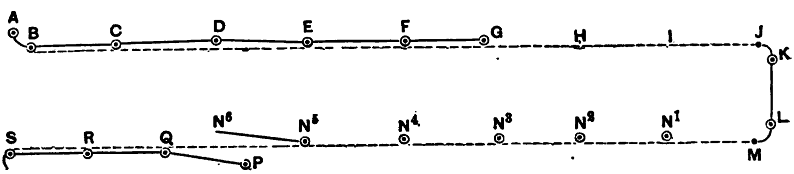
A frame about 6″ square inside is made of strips $\frac{1}{4}'' \times 1\frac{1}{4}''$ as in the sketch. On the edges *AB*, *CD* draw a series of parallel lines about $\frac{1}{8}''$ apart and make a shallow cut along each mark with a penknife, and drive a fine tack or pin in the outer edges abreast each mark. String this up as a harp, using fine silk thread and drawing it taut across the frame in each cut. Turn the frame over and number each thread consecutively, calling the first one o. If the o thread is placed over any point on the chart and any other thread over a second point, the intermediate threads will divide the line joining the two points into a number of equal parts equal to the *number* abreast the thread which crosses the second point. The soundings are then written in black ink over each point of division and at each position, and the character of the bottom is put in at intervals.



159. Hitherto in discussing in-shore work it has been considered that every position was fixed by angles and the soundings plotted on the lines connecting them. The distance from shore to which soundings can be carried and fixed by angles varies from 8 to 10 miles for a low coast, such as the Atlantic seaboard, to 40 miles or more when the coast is mountainous. On the west coast of Lower California soundings have been fixed by good angles when the nearest point of coast line was 35 miles and the mountains forming the right and left objects were 80 miles apart. These were from 3000 to 6000 feet high. It frequently happens in in-shore work that the lines of soundings must be carried beyond the limits of visibility of the signals and not far enough for the methods of deep-sea work to be employed. Observers aloft will be able to get good angles for a mile or two after those on deck are "out of sight of land," but this may not be sufficient. Then the lines must be run by course and distance, the error of the patent log being determined and the steering carefully attended. The line is fixed at the beginning and ending by angles, and when completed the whole line is adjusted.

160. The following examples from the work of C. S. Str. "Bache," "Approaches New York Harbor, 1883," will explain the method. By numerous observations it was determined that with the helm put hard over the advance and transfer in turning through eight points were each .1 mile, and the distance passed over about .16 mile. Two patent taffrail logs were towed, one on either quarter, which were read simultaneously and served to check each other. Over the first dial, on each log, a small circle on paper divided into 100 parts was pasted, and a fine-pointed index-finger substituted for the blunt ones usually supplied, care being taken to have the axis of rotation of the index and circle concentric. These divisions were plainly visible, and with a small reading-glass half divisions could be accurately estimated. The lines were run E. and W. true and one mile apart along the Jersey coast, and N. and S. normal to the Long Island shore, and extended about 25 miles from the beach, the greatest depth being about 30 fathoms. The speed of the ship being about six knots, soundings were taken by time every five minutes, and angles were taken every ten minutes while in sight of signals. One pair of lines, out and in, constituted a day's work and took about ten hours, the start being made at 7 A.M. The line began about 2 miles from the beach; soundings to 10 fathoms were taken with hand lead, after that with deep-sea lead.

161. The triangulation being plotted on the projection, scale $\frac{1}{40000}$, the E. and W. lines were run on parallels of latitude which were already drawn. After getting under way the ship steams towards the point selected as starting-point, with logs over and observers ready. Trial positions being plotted, the distance to be run is known, and when the log shows that the line is .1 mile distant, position *A*, the helm is put over and the ship swings into line as at *B*, and then, heading on her true course and at an even minute, angles and soundings are taken and the log read simultaneously. The soundings are then taken regularly and need no further consideration. The engineer has instructions to make a given number of revolutions and maintain them regularly. As each ten minutes passes, the recorder gives warning and calls out sharply "*Mark*" at the last second, and angles are taken and the log read. This is continued until signals can be no longer seen, the ship being kept on the line as in ordinary work, and the compass course determined on, which she makes true E. By measuring *BC, CD, DE*, etc.,

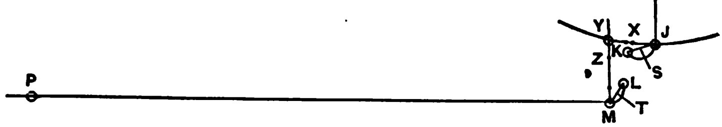


and comparing each one with the distance as shown by the log, we get the mean correction for the patent log, the whole distance *BE* being also used. Losing signals at *E*, the ship is kept on her course, and as the log is read each ten minutes the correction is applied and the position plotted lightly as at *F, G, H, I*, etc. If the wind increases, the course may be changed slightly and the positions plotted on the new course. Having reached the end of the line *J* at an even ten minutes, the log is read and helm put hard over and the ship brought to head true S. at *K*, a run of .8 mile made to *L*, when hard over again and head W. at *M*. From *J* to *M* is considered as true N. and S., and exactly one mile. The line is continued as from *E* to *J*, the compass course being accurately steered and the true course as near W. as possible, changing it slightly as may be made necessary by wind and sea. When the ship approaches the distance from shore at which the last angles were observed a sharp lookout for signals is kept, and as soon as possible an angle is taken (at a 10 minutes, of course) and plotted. This position will generally be inshore of position *E*, as signals may be carried out farther than they can be recognized on approaching the shore, and will differ from N^6 (which is plotted by course and distance) both in latitude and longitude, seldom, however, more than .3 mile in latitude. Suppose the position of N^6 by angles to be *P*. The line is completed the same as *BE* was run, and a second log correction obtained as in the morning. The line must now be adjusted so that N^6 and *P* shall coincide and the positions between *E* and *P* have their most probable positions.

162. On the smooth sheet all the positions that have angles are plotted. The entire distances on each course between *E* and *J* are then plotted, using the true courses from the deviation table and applying the log correction obtained as before, but from the more careful plotting. Then the line N^6—*M* is plotted *backwards*, starting from *P*, using the log correction obtained between *P* and *S*, and plotting the traverses as on the first half. When *J* and *M* are thus plotted they are marked "1st approximation." By careful measurements the departure between *J* and *M* is obtained and divided into two parts proportional to the corrected distances *EJ* and *PM*. These portions are applied to the corrected distances, subtracting from the line which extends farthest off-shore, and adding to the other. This gives the final distances *EJ* and *PM*, and comparing these with the *log* distances gives the final log correction for each part. The traverses between *E* and *J*, *P* and *M* being changed as required by the new correction, *J* and *M* are in a N. and S. line. This is the "2nd approximation." Measure the distance *JM*. Divide its defect from one mile into two parts proportional to *EJ* and *MP*, and lay off these distances from the points *J* and *M* respectively to *J'* and *M'*, so that *J'M'* shall be exactly one mile. These are the final positions of *J* and *M*, and the lines *EJ* and *PM* are swung to these points in the same way as described for adjusting the triangulation-points. The positions are laid off between the ends of the traverses by the corrected distances and the soundings plotted as usual.

163. In the case of a line run off shore and on shore on courses at right angles to each other the two parts of the line are plotted as in the first approximation, and each part ends in a quadrant of a circumference having a radius of .1 mile and concave towards the other part. Then (the letters having the same meaning as in the other figure) with *E* and *P* as centres and radii equal to the distances *PM* and *EJ* describe arcs intersecting in *Y*, and lay off on these arcs *YX* and *YZ* = .1 mile, and take *X* and *Z* as the true positions of *J* and *M* and plot the lines as above.

164. Soundings up to 3 fathoms are sometimes taken with a pole 1½″ diameter marked



to feet and tenths, having a disk of wood 4″ diameter on the end to keep it from sinking in the bottom. This disk is covered with thick lead to facilitate its sinking through the water.

165. Boat-sheets should be made on manilla-paper, to keep the eyes from being strained by the glare from white paper in boat work. If no such paper is to be had, white paper stained by sponging the surface with strong coffee makes an excellent substitute.

Two battens across the gunwales of a boat make a good support for the boat-board while surveying.

166. Launches for surveying work on open coasts should be

fitted with whale-backs in the bows to keep out the seas, and a platform for the leadsman greatly facilitates the work. This may be secured to the whale-back and braced from the gunwale below, should be about 1′ wide, 2′ long, and have stanchions at each corner to secure the breast-band and hold an apron to keep the spray from wetting the leadsman. In cold weather rubber gloves add greatly to the comfort of the leadsman.

167. Launches for surveying purposes should have double engines, and should have a condenser pipe along the keel for the exhaust to prevent the noise caused by exhausting into the smoke-pipe. The use of double engines will be apparent to any one who has to do sounding work near a coast on which surf is breaking or near sunken rocks where the sea breaks, as it is often of the greatest importance to be able to back or go ahead without the chance of having the engine on a centre.

CHAPTER X.

SOUNDING WITH WIRE.

168. In surveying work, all soundings beyond forty fathoms should be taken with wire. In less depths soundings may be taken with rope, but always with diminished accuracy. When it becomes necessary to stop the vessel to get the cast, the wire is equally expeditious and much more accurate than rope, and the gain in time by using wire instead of rope increases very rapidly as the depths increase, not to mention the diminished force required. In boat work, fifteen fathoms may be taken as the limit of sounding with rope when wire is provided. Soundings up to 135 fathoms have been taken from boats with rope, but it is a very tedious operation. Sigsbee's deep-sea sounding machine is used on board a few of the steamers of the Coast Survey, and on board the Fish Commission steamer "Albatross." It is fully described in a book by Comdr. Sigsbee entitled "Deep-sea Sounding and Dredging," which may be found in any ship's library, and is a superior machine of its kind.

169. Most naval vessels have on board one of the original machines of Sir William Thompson, which consist of a reel one fathom in circumference for holding the wire, having on its face two scores—one a wide flat groove for the wire, and the other a V-groove for a rope-band which passes around the reel and, with a round turn, around a smaller fixed grooved wheel. The friction of the smaller wheel checks the momentum of the larger one, and is used in controlling the wire in paying out. The wire is reeled in by cranks shipped on the ends of the axle, the friction-band being removed while reeling in.

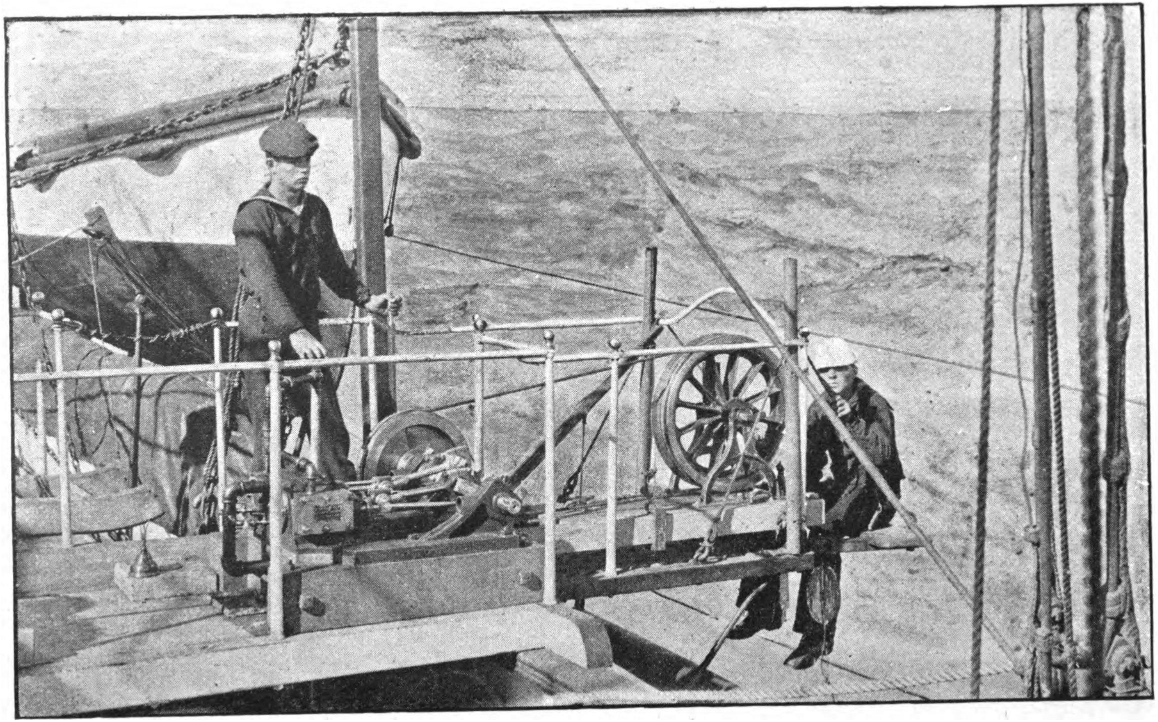
170. A modification of this machine by the author of this work has been used on board the "Ranger," the only vessel of the navy exclusively engaged in surveying work, for the past four years, with great success.

171. The sounding-machine of the "Ranger" is not a new invention, but merely the original machine of Sir William Thompson modified by the addition of a few improvements, so as to produce a serviceable and reliable machine that is cheap, and not liable to get out of order.

172. The description will be made clearer by first giving a few of the details of the "Ranger's" deck and bridge where the machine is mounted. Among other alterations which the "Ranger" has undergone during eight years of surveying work, her battery has been removed to give greater coal capacity. In the place usually occupied by the forward pivot-gun, a chart-house or draughting-room, about eight feet wide, twelve feet long, and seven feet high, has been erected. Across the rails at the after ends of the pivot-ports is the bridge, about three feet wide, resting on the rails and chart-house. Projecting from the ship's side, at either end of the bridge, are gratings about four and one half feet square, that hook into the rail and are supported by braces from the ship's side beneath. Over the port gangway the bridge has been doubled in width; the ends of the extra portion, which is forward of the main bridge and built into it securely, resting on the chart-house and rail. On the outboard end of this extension the engine of the sounding-machine is placed, and the remainder of the machine is on the grating that projects beyond the port end of the bridge.

173. A sounding-machine consists essentially of a reel for holding the wire, with a register for showing the amount paid out, arrangements for controlling the motions of the reel while paying out, and an engine for reeling in.

174. The reel used is the navy steel reel, having twelve spokes, with a capacity of about ten thousand fathoms of wire,

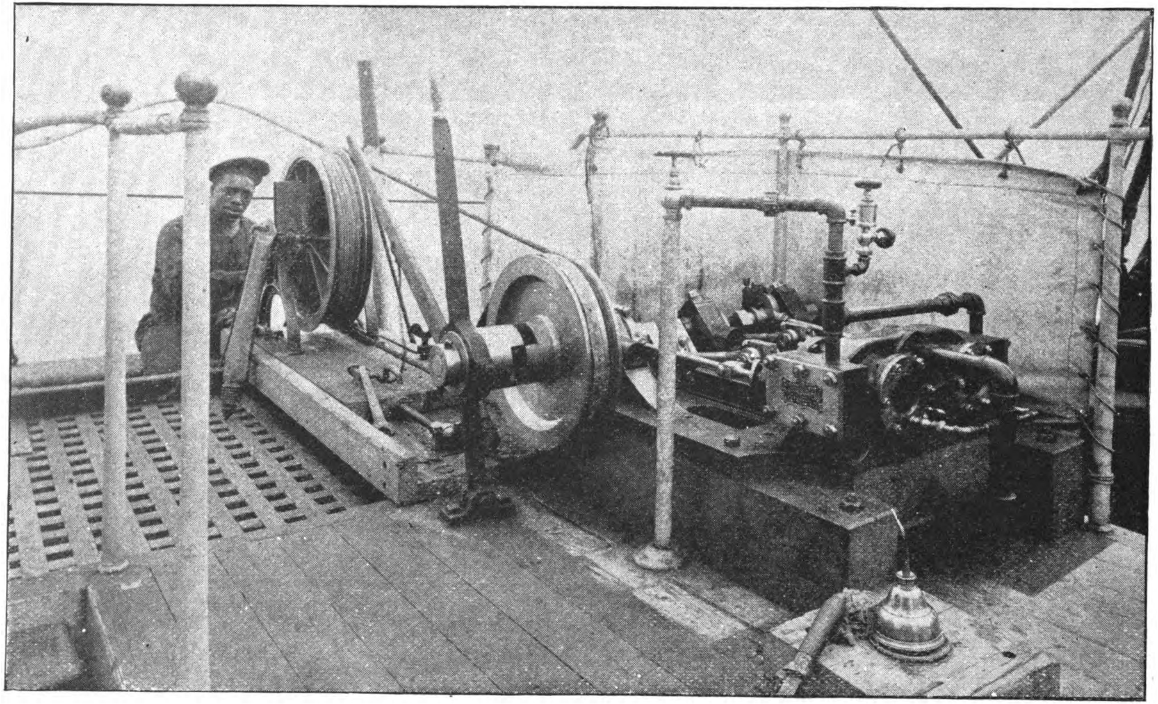


SOUNDING-MACHINE OF U. S S. "RANGER."

and having on one side a V-groove for the controlling band. Its diameter is such that it is one fathom in circumference, less a slight correction for the diameter of the wire used. On the axle of the reel is a worm which engages one of the cog-wheels of the register, to show the number of turns the wheel makes, and a ratchet wheel, in which a pawl fits, to hold the wheel in any desired position. The reel is mounted on brass standards, on a bed about three feet long and fifteen inches wide. The bed moves in a trough-shaped slide, having its sides even with the top of the bed, and wide enough to allow the bed to travel freely along it. The slide is about five feet long, and rests on the ship's rail and a narrow ledge on the outboard side of the grating, being secured by screw-bolts through either end. These bolts have square heads, and are set in flush with the upper surface of the slide. The slide has on its outer end two iron straps that project over the bed when it is run out, and keep it from rising. The bed is run in and out by means of a brass screw about twelve inches long, that works in a nut screwed to the after end of the bed, a hole being bored in the bed to receive it. At the other end of this screw, where the threads stop, it is enlarged slightly and made hexagonal to take a wrench, and it ends in a ball having a slot turned in it for a collar. A small pillow-block fits this collar and is screwed to the bottom of the slide. A few turns of this screw will move the bed in or out as may be desired, and, as will be seen, it is very powerful. On the after end of the bed is a small cleat for securing the stray-line, which will be referred to later on.

175. The engine is a double horizontal engine, having cylinders $3\frac{1}{2}$ inches by 6 inches, and occupies a space about three feet square and about eighteen inches high, being blocked up in order to give room for the fly-wheel. As it needs to run but one way, the links and backing eccentrics are removed. Steam is led to the engine by a two-inch iron pipe which is connected to a joint formerly occupied by a steam-heater pipe, led forward under the spar deck, up abaft the chart-house, and under the eaves of the house to the bridge, where it turns outboard. Covered with canvas and painted white, this pipe is not in the way and does not detract from the appearance of the ship's deck. The drain-cocks of the cylinder open into the exhaust-pipe, which bends under the machine and discharges over the side through a long canvas pipe. The fly-wheel of the engine is 18 inches in diameter, and is fitted with a clutch coupling for detaching from the engine while paying out. Its face is 2½ inches wide and has two grooves on it, a flat groove 1 inch by ½ inch deep, and a V groove ¾ inch wide and 1 inch deep. In the V groove is a band made of 1¾-inch hemp well stretched and spliced with a long splice, so that when it is around the reel and fly-wheel and taut the reel lacks about six inches of being chock out. This band is kept taut by means of the screw in the bed-board, and besides transmitting power to the reel, serves to keep it under control at all times. The slack is to allow for stretch that is sure to occur as the band wears.

176. The brake is in the flat groove, and consists of a strap of galvanized hoop-iron about four and a half feet long, having on its under side a number of pieces of oak wood half an inch thick, three inches long, and just wide enough to fit the groove. These blocks are cut to fit the curve of the wheel, are secured by two small screws to the strap, and have the grain running across the groove so as not to jam in case of splitting. They are separated by about a quarter of an inch, and there are holes in the strap abreast these openings for oiling. There is riveted to either end of the strap a rectangular link, 1 inch by 3 inches inside measure, of $\frac{3}{16}$-inch iron. Through the bottom of the slide there is a U-shaped piece of iron with one arm longer than the other. The long arm passes through the slide, and has a nut underneath; the short arm resting in a socket about ½ inch deep. The link on one end of the brake-strap hooks to this staple, that also carries a third link to hold the



Sounding-machine of U. S. S. "Ranger."

heel of the brake-handle. The strap passes from this staple under the fly-wheel up and outboard over the top, and the brake-handle ships through the link on the end. The handle is of ash, flat, about 1 inch thick, tapering towards the handle, being 2½ inches wide at the lower end, where it is held by the spare link mentioned above. The upper link is kept about one foot from the lower end, and both are kept from slipping by notches cut on the edges of the handle. It will be seen that when the wire is paying out the brake is set up automatically, and slackened when the wire is being reeled in. The weight of the handle is sufficient to keep the reel from paying out the wire faster than forty pounds of lead can sink. A small lanyard is fitted to the handle to keep it from being drawn up too far when reeling in. In using the machine the brake is kept well oiled, because it grips too hard when dry, besides wearing more rapidly and causing an unpleasant noise. The wood used on the iron gives better results than an iron strap would, and when worn out can be replaced without risking the chance of a break in the simple strap.

177. The steam-pipe for the engine comes through the bridge near the rail, rises as high as the hand-rail, and has the throttle at the top of this portion. The clutch is worked by a vertical lever three feet long, that is just above the ship's side, and the clutch-lever and throttle are so placed that the operator can keep a hand on each of them, and keep the register and wire astern in view at all times by a slight movement of the head. This engine was not designed for this use, but bought in open market and adapted. A vertical engine would work equally well and occupy less space. Any engine for reeling in wire should be double, however, on account of the steadiness of the motion.

With a pressure of fifty pounds at the boilers, this engine easily makes three hundred revolutions per minute while reeling in a forty-pound lead, with several hundred turns of wire out and the ship steaming about seven knots. With this engine it is not necessary to reel in a single turn by hand. It can be started as gently as the reel could be by hand, and when the lead is up it can be raised as little as six inches at a time, if desired.

178. The sinkers used are forty-pound leads cast on board ship, with "Sand's" cups. The leads are made in an open-ended iron mould, made in halves and held together by a clamp. The lead is two feet long, two inches in diameter at the top and three at the base. The upper half is conical and the lower half hexagonal, with a uniform taper. The cups are cast in the lead by placing the plug in the end of the casting before the material sets, and they are held in place by the lead, which runs in the hole left for the forelock. The sinkers are fitted with beckets to which the stray-line is bent. The stray-line is a piece of small rope which connects the wire with the sinker to keep the wire from coiling on the bottom, and to make the handling of the sinker easier and simpler when it is near the surface of the water. Braided, signal-halyard stuff was used for this purpose, between seven and ten fathoms of it being used. It makes a very neat splice, and does not twist when being hauled through the water.

179. The splice is made as follows: With a file sharpen the end of the wire and then unlay about two inches of the end of the rope. Force the wire into the centre of the rope about one or two inches, and then let the point come through the side of the rope. Draw through about three feet of wire, and then clamp the frayed end of the rope and the wire in a vise, and haul the rope taut. Take eight or ten round turns with the wire just above where it appears through the rope, and then stick the end through the rope and haul it taut, stick again and take another set of turns, and then stick the end through two or three times and break the wire off close to the rope. Put a short seizing on to keep the end from sticking out and cutting the hand that will guide the wire. Scrape the frayed end of the rope down to a point, and serve it with twine for about two inches, securing the ends of the twine by sticking through the rope with a sail needle. This makes a neat, strong splice, and it offers the least possible resistance to being drawn through the water. With one of these splices, as many as three hundred casts have been taken without an accident.

180. For joining the lengths of wire, the "Belknap" splice was found to be most serviceable and convenient. It is made as follows: Point the ends of the wires to be joined, and lap them about eighteen inches. Stop one end to the other wire, and with the loose end take half a dozen turns about the other wire and stop the end to it. This will make a long-jawed twist. Now put a very small drop of solder about every two inches of the doubled portion, not enough to surround the wires, but sufficient to hold them together. Take the stops off the ends and solder the points to the other wires. This will need a trifle more solder than the intermediate points, but should not increase the size of the splice perceptibly. The whole is then served over with waxed twine. This splice being long, slender, and flexible, stows very neatly on the reel without making lumps, and will adapt itself to any block it is paid out over without danger of breaking, and the very small quantity of solder necessary prevents the temper being taken out of the wire by continued heating. The splice is very quickly made, and requires no special experience to make a good one. The twine takes up any chafe that would otherwise come on the wire, and can easily be renewed should it become much worn.

181. The wire must be coiled on the reel in regular layers, for if ridges are formed the outer turns are apt to spring off and the wire become bent and so rendered liable to fracture. This guiding of the wire presents no difficulty, and in a very short time any enlisted man can be taught to lay the wire on smoothly. For the man who does the guiding there is a small

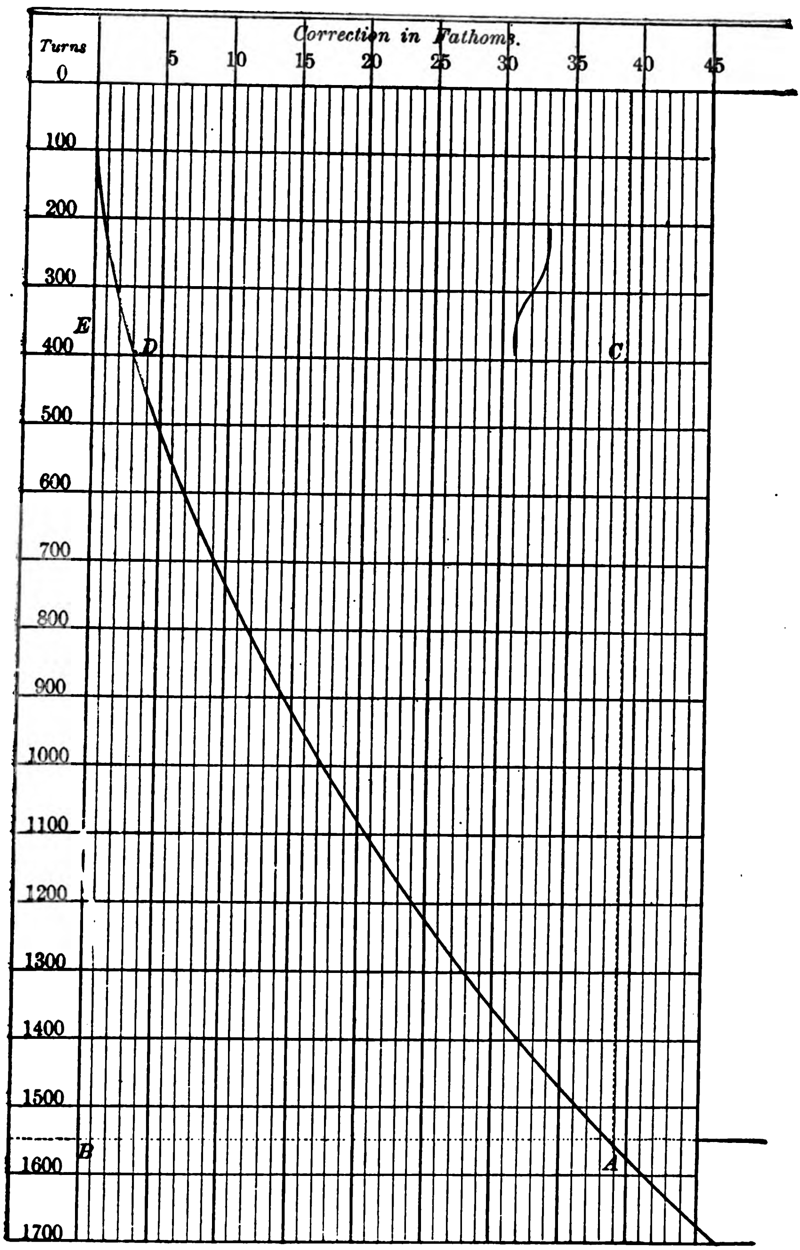
stage rigged beyond the end of the projecting grating; it is supported on two outriggers whose ends hook into bolts on the side of the grating, and by guys which go over the rail and hook to the grating inside. One of these guys is used to hold a bucket, that stands on the stage and holds water, in which the specimen cups are washed after the specimens have been removed. The other is useful for the man to hold on by when the ship has much motion.

182. For reeling in when under way, a brass snatch-block having a 5-inch sheave, about $\frac{1}{2}$ inch wide, is hooked to an eye-bolt on the forward outrigger, so that when horizontal the score is exactly under the centre of the score on the reel that holds the wire. This sheave is countersunk $\frac{1}{8}$ inch in each cheek of the shell, to prevent the wire from getting between the sheave and shell and running on the pin. This block hangs down while the wire is paying out, and is lifted up and the wire put in while the register is being read, the lead being on the bottom. When the sinker is up, the man outside takes off the specimen-cup and cleans it, after removing the specimen.

183. The register consists of three small axes in a brass frame, carrying cog-wheels that gear into each other, and having on their extremities index fingers which move over graduated circles. The lower wheel has 100 teeth, and gears into the worm on the axle of the reel. Each of the graduated circles is divided into one hundred parts, and it will be seen that each division on the lower circle represents one turn of the reel, or one turn of wire paid out. The second pointer makes one revolution for each ten revolutions of the lower one, and the upper one makes one revolution for each ten of the second; so that each division of the middle scale represents ten turns, and of the upper scale one hundred turns, the highest record being ten thousand turns. The width of the score is such that about one hundred turns of the wire used can be put on without riding turns, and then, since the diameter of the reel has been increased by twice the thickness of the wire, it is evident that each turn is no longer an exact fathom, also that the deviation becomes greater as the amount on the reel increases.

184. Since the register merely gives the number of turns paid out, a correction must be applied to each reading to obtain the correct sounding, and this correction is obtained from a curve, devised by Comdr. C. D. Sigsbee, U. S. N., in which the turns of the reel are ordinates and the corrections corresponding to each number of turns abscissæ. This curve must be obtained by actual measurement of the wire when it is put on the working reel, and will always be the same for the same reel and wire, so need be obtained but once. To measure the wire, it is led from the coils in which the wire is supplied, five or six times around a spare reel and thence to the working reel. The spare reel must be exactly like the working reel, and the turns must not be allowed to ride. The registers on the two reels give the number of turns each makes, and it is evident that a simultaneous reading of the registers will give the number of *turns* on one reel and the number of *fathoms* that have passed the spare reel, and the difference will be the correction which is always additive to the reading of the register. The curve must be constructed for the longest length of wire put on the reel, and then it will serve for any smaller amount of wire. A portion of the curve is shown on page 131, and explains itself. The use of the curve is as follows: At the point in the column of *turns* corresponding to the number of turns on the reel, say 1550, B, draw a horizontal line to meet the curve in A, and draw a dotted vertical line through A. Evidently the length of wire on the reel is $1550 + BA$ or 1589 fathoms. Suppose in making a cast we pay out 1150 turns. Run the eye up the line AC a distance corresponding to 1150 turns, which is to C; then count the spaces from C to D, the point where a horizontal line through C cuts the curve, and we find it to be 36 divisions. Then the sounding is 1186 fathoms. Because the whole length of wire on the reel is 1550 turns + *BA* fathoms, and if we pay out 1150 turns there are left 400 + *ED*, and the sounding is 1150 + *BA* − *ED*, and *BA* − *ED* is evidently *CD*. Should wire be lost, it is only necessary to move the point *A* and draw a new dotted line from which to count. If the curve is drawn on profile paper, the operation of counting spaces is much simplified by the more minute subdivision of the spaces representing turns. The register is set at zero when the sounding-cup is just in the water, and when the sinker is on the bottom the reading of the register will be the actual depth in turns of wire. In this method the turns of stray-line are given the same value as turns of wire, which of course is not true. No appreciable error is caused by this proceeding, as there are so few turns of stray-line.

185. The method of taking a sounding is as follows: With the engine uncoupled, it is turned over several times to expel condensed water from the steam-pipe and cylinders, so as to be ready for reeling in. The lead being suspended as in the view, with the cup in place, the register properly set, and the band between reel and engine taut, the pawl is released, and the wheel allowed to revolve and pay out the wire. The operator, with one hand on the brake-handle, watches the wire to note any evidence of slacking, and has complete control of it. The man outside with a fold of canvas draws the wire slightly towards him, so that it will have a slight pressure on his hand as it pays out over it. If the wire slackens from running too fast it is felt at once in the decreasing pressure and warning given to the operator, and on striking bottom he involuntarily draws his hand back and so takes up all the slack wire that is not taken by the sinker falling over on the bottom. The instant the lead strikes bottom the brake is pressed firmly, and the reel stops within less than one turn. The pawl being put up, a slight pull on the band takes up the slack wire and the register is read. The clutch of the engine is then en-


Correction in Fathoms.
Turns
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B
A

gaged and, the wire being in the block, the reeling in commences, the man outside guiding the wire by holding it in a fold of canvas, and the ship may steam ahead on her course, care being taking not to put the helm over so as to get the screw foul of the wire. The engine is started very gently, but as soon as a start is made speed may be increased very rapidly. The operator, with one hand on the throttle and one on the clutch-lever (to keep it from uncoupling accidentally), watches the register, and when the lead is about twenty-five fathoms away, slows down and warns the man outside to watch for the stray-line splice, so as not to get his hand caught between the wire and reel. Great care must be exercised in lifting the lead from the water when the ship is under way, to keep it from swinging violently forward and slipping the stray-line over the flange of the wheel, which is almost certain to cause the loss of the lead. The lead being up to the reel, the cup is unscrewed and the specimen removed. The cup being washed and returned to its place, the machine is ready for the next cast. The reading of the register being corrected as explained above, the sounding and character of the bottom are written on a small blackboard attached to the rail, to be read and recorded by the recorder on the poop, where the working-sheet is kept and the observations plotted. If at any time during the operation the band shows signs of slipping, a turn or two of the screw on the slide will stop it at once.

186. The machine is secured by slipping the band out of the scores, taking off the register (for safety), and unshipping the brake-handle. The end of the brake must be hooked to the spare link to keep it in its place, and then the stray-line is unwound from the reel to keep it from rusting the wire. The splice being clear of the reel, the line is belayed to the cleat on the bed mentioned above, and the wire set taut and secured with the ratchet. Canvas covers are placed over the reel and engine when they have been cleaned, and a wooden cover is placed over the screw in the bed to keep it from being bent or injured. The machine is very easily prepared for work. All that is necessary, after removing the covers, is to ship the band, brake-handle and register, and turn on the steam, of course getting the lead over the side.

187. This machine is ready for use at a moment's notice, has no delicate parts to get out of order, requires but two persons to run it, has a moderate first cost, and needs practically no repairs of any consequence. It is efficient and economical, and rapid in its working. It takes but half a minute from the time the lead takes the ground to read the register, couple up, and start reeling in the wire. With the same sinker, without changing a splice, 329 recorded casts were taken in from 50 to 600 fathoms, in all weathers, without an accident or casualty. The bridge being near the centre of gravity of the ship is not affected by pitching, and when rolling it is only necessary to slow down slightly on the lee roll when paying out. Soundings have been taken with perfect safety when rolling 15° each way. The average speed, paying out, is 100 turns in 50^{s} to 55^{s}, which is as fast as the lead would sink. The same amount is reeled in in from 35^{s} to 40^{s}, though when the ship is under way, and there is no need for such speed, it is more comfortable to reel in slowly, which keeps the water from flying from the wheel in the face of the man guiding the wire.

188. The method generally recommended for the preservation of the wire is, when not using the reel, to keep it in a suitably formed tank filled with sperm or linseed oil, so that the wire and reel are completely covered. This certainly preserves the wire, but, unless the reel is not to be used for several months, is not at all necessary, and causes much dirt and trouble in cleaning the wheel every time it is taken from the oil. By treating the wire as will be described, the reel may be kept mounted ready for use, and the wire in good condition for an indefinite length of time.

189. Towards the end of each day's work, or after each deep cast, while reeling in the wire, let a man hold a rag well oiled against the wire in the score. Holding the hand against the inboard side of the reel, fingers down, is perfectly safe. Keep plenty of oil on the rag, so the wire may be well oiled all through. The water is stripped from the wire by the man laying it on the reel. When the reel is to be secured, the stray-line is unwound and secured to the bed, being careful always to keep a slight strain on the wire. Now with a swab and hot fresh water wash the wire thoroughly, and dry it with the same or another swab. Pour a small quantity of oil on the wire, and rub it around the reel with rags, using enough oil to coat the wheel all around. Rub the rags over the bright parts of the reel, put a small flat pan underneath for the drippings, and put a canvas hood over the reel. If the wire is used next day it will be found bright and clean. If it is not to be used, have a quartermaster examine it every morning when bright work is cleaned. Should the wire or reel begin to rust on top, as they are apt to do from sweating under the canvas and the oil running down, a rub with an oiled rag and a few drops of oil will stop the rusting. Twice a week in dry weather is often enough to look at the wire. In this way wire has been kept on the reel without dismounting it for eighteen months, during five of which the wire was not used once, the ship being at a navy-yard, and at the end of that time, the wire being taken off for inspection, was found to be in as good condition as when first laid on, though there were five hundred fathoms that had never left the reel during that time.

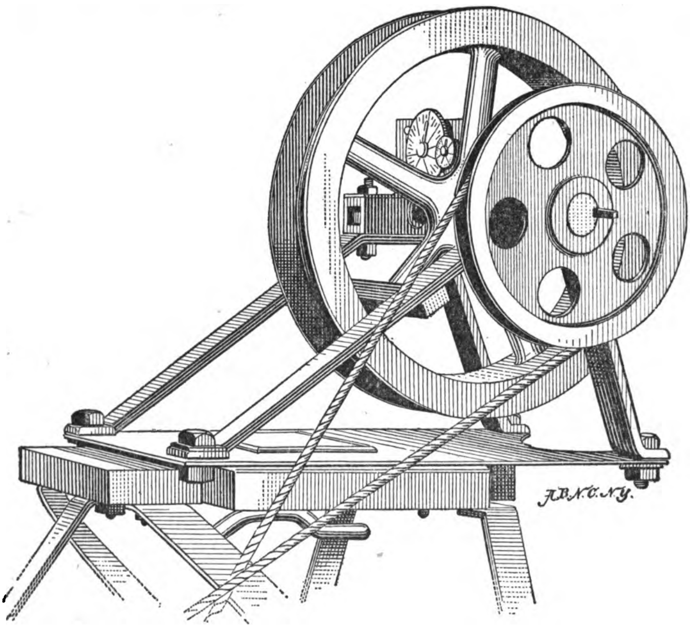
190. In all surveying work, next to accuracy, time is of the greatest importance, and any device that will shorten the time for a sounding is valuable. It is customary to steam ahead as soon as bottom has been reached by the sinker, and the wire can be reeled in quite as safely while towing as when vertical. Of course at great depths the speed of reeling up should be decreased, but in no case need it be slower than sixty turns per minute, and when not more than a thousand fathoms are out, double that speed is safe with a vessel steaming eight knots, should such speed be necessary. After a cast of 650 fathoms with a forty-pound sinker, the ship started ahead full speed as soon as bottom was reached, and the sinker was brought to the reel at an average speed of one hundred turns in forty seconds, and an examination of the stray-line splice failed to show that it had been unduly strained. It was found that with this machine the wire would stand any strain the engine could put on it if the submerged end was free and the strain was gradual, not a jerk: and it may be added in conclusion, that the life of the wire is in keeping it taut, avoiding kinks.

191. Wire has been used in the launches of the "Ranger" with success and profit, both in time and accuracy. One turn of wire on the reels used is just four feet long, so there are 150 turns in 100 fathoms. The reel is of brass, having a flat score on its face 2½ inches broad and 1½ inch deep. There is no groove for a friction-band, and the reel is keyed to an axle about 18 inches long which rests in bearings on proper standards. The register is a circular brass plate ¼ inch thick, having 150 teeth on its circumference and 100 equal divisions on its face. It is secured to a vertical plate on one of the cap squares, and is turned by a worm on the axle. A smaller plate, about 1½ inch in diameter, is also secured to this plate, and a button on the larger one engaging grooves on the smaller one causes it to register each complete revolution of the larger dial or each 100 fathoms. The correction curve already described must be used for correcting the readings of the dial, which are not turns, but approximate fathoms. Handles may be shipped on the ends of the axle for reeling in, but it is simpler to use steam for that purpose.

192. A light brass wheel 12 inches in diameter is keyed to the axle. On its edge it has a groove ¾ inch wide and 1 inch deep, and there is a similar wheel on the shaft of the engine, bolted to the balance-wheel on that shaft. A rope band passes around these two, and is kept taut by having one part run through a tail-block which can be moved to any desired position. As this contemplates going ahead while reeling in, a snatch-block just like the one described above for the ship's reel is hooked to the rail just under the machine. In sounding, the band is used as a friction-band to check the reel, and it is also stopped by grasping the rim with the hands. Nine- or fourteen-pound leads are used with this machine, with about five fathoms of stray-line. Soundings as high as 283 fathoms have been taken with great ease, celerity, and accuracy.

193. As shipped in the "Ranger's" launches, the machine rests on a platform about a foot higher than the rail (high enough to clear the spray-cloths). This platform is about 15 inches square, 2 inches thick, and is secured over the thwart separating the stern-sheets and engine compartment. It has five braces of $\frac{5}{16}$-inch iron $1\frac{1}{2}$ inch wide. Two lead from the outboard corners forward and aft and rest on the rail, where they are secured, rising at an angle of about sixty degrees. From the inboard corners two braces lead to the rail and secure to it *inside* just abreast the other braces. A heavier brace leads from the middle of the inboard side and steps on the thwart underneath, being placed at sufficient inclination to give lateral as well as vertical support.

194. Two frames were used for supporting the reels, one of wood and the other of iron. The latter was so far superior to the wooden one in strength and convenience that the slight additional weight, if there was any, was more than made up for. This frame was devised by Ensign W. R. Rush, and was made under his supervision on board ship. The bed-plate is of $\frac{1}{4}$-inch boiler-iron, 15 inches by 24 inches, with a hollow cut in the front end to keep clear of the wire. The standards (of $\frac{1}{2}$-inch iron, 2 inches wide) are bolted to the corners of this plate, and are shaped as shown in the figure; the Babbitt-metal bearings for the axle being bolted to the tops by the same bolts that hold the cap squares. A long slot is cut in the bed-plate to allow the machine to be run in and out, and to



BOAT-SOUNDING MACHINE AND PLATFORM.

admit the holding-down bolt. The machine is readily unshipped from its platform, and the latter makes a very convenient step to use when entering or leaving the launch. Two men are required to run the sounding-machine in the launch, one to attend the friction-band and one to guide the wire.

195. The record of one cast with this machine is annexed, to show the form used in recording deep casts. Usually the times of each 100 turns are taken as shown by the lower part of the form, but being a short cast, each fifty turns was timed.

196. U. S. SURVEY STEAMER "RANGER,"

SEBASTIAN VISCAINO BAY, LOWER CALIFORNIA, MARCH 16, 1888.

Turns of Reel as per Register.	Reeling Out.					Reeling In.					Remarks. To be made by the Officer of the Deck.
	Times.			Intervals.		Times.			Intervals.		
	H.	M.	S.	50 f. S.	100 f. S.	H.	M.	S.	50 f. S.	100 f. S.	
0	3	9	..	..	..	3	18	08	34	51	Sinker used, *lead.* Weight, *40 lbs.*
50	3	9	26	26	..	3	17	34	17	33	Was sinker detached or recovered? *Recovered.*
100	3	9	49	23	49	3	17	17	16	33	No. of fathoms of stray-line used, *about 10.*
150	3	10	11	22	45	3	17	01	17	37	No. of turns of wire in use on reel, *1600.*
200	3	10	36	25	47	3	16	44	20	38	Kind of reel used, *Navy steel.*
250	3	11	02	26	51	3	16	24	18	34	Reeled in by *steam.*
300	3	11	26	24	50	3	16	06	16	37	Reeled in first *0* turns by hand.
350	3	11	53	27	51	3	15	50	21	39	Reeled in last *0* turns by hand.
400	3	12	21	28	55	3	15	29	18	41	Wind, *on bow.* Force, 2.
450	3	12	49	28	56	3	15	11	23	..	State of the sea, *long swell.*
490	3	13	11	22	50	3	14	48	..	..	Vessel rolling, *10° each way.*
1100											Vessel pitching, *none.*
1200											
1300											*Ship started ahead four bells as soon as reeling in commenced. Speed, 7 knots.*
1400											
1500											
1600											
1700											
1800											LOSSES OR CASUALTIES. *None.*
1900											
2000											
2100											
2200											Register-reading, . *490*
2300											Corr. stray-line, ... *00*
2400											Corr. turns of wire, *22*
2500											Correct depth, ... *512* fms.
2600											
2700											
2800											
2900											
3000											
Totals.											

Signature of Officer Sounding, HARRY PHELPS, *Ensign, U. S. N.*

197. The sinker here described may be used in casts up to about 1500 fathoms and recovered. Beyond that depth a detachable sinker is used to lessen the strain of reeling up. When these detachable sinkers are used, a sounding-rod (or cylinder) and detacher are attached to the stray-line in place of the lead. The rod is of brass, about $2\frac{1}{4}''$ in diameter and $12''$ long, hollow, and contains a series of valves so arranged as to allow the water to run through it while descending, but which are closed when the weight is detached, and retain a specimen of the bottom, which enters the lower end. Next to the ring by which this rod is attached to the stray-line is a hook with a spring attached, so fitted that when the rod is suspended by the line the hook will support a weight, but when the rod is supported by its lower end, the hook is upset by the spring in such a way as to have its only opening downward. The weights used are cast-iron spheres, about 60 lbs. weight, cast with a hole through the centre large enough to admit the sounding-rod, and having lugs to which a wire sling may be made fast. In use the rod is run through the shot so as to project several inches beyond it, and the sling is hooked over the detacher already mentioned, the whole being suspended by the ring. On reaching the bottom the rod enters the bottom soil and engages a specimen. The wire being slackened, the spring throws the hook out of action and the weight slips off the rod, which is then drawn back to the ship more easily than the heavy weight could be. The heavier weight descends more rapidly than the light one, and the rod may be reeled back more rapidly, so time is saved on both parts of the sounding.

198. Temperatures are taken at different depths by attaching specially constructed thermometers to the line, near the sinker, lowering to the desired depth, and then reeling in—a new cast being taken for each temperature. These thermometers are arranged to register the lowest temperature reached.

199. In taking a deep cast the first necessity is the placing of the ship in such a position as to be most easily controlled

and manœuvred to keep the wire up and down. In most ships this position is with the stern to the wind and sea, and if there is much wind or sea the engines slowly backing will generally keep the ship perfectly stationary, and by the proper use of the helm she may be made to move across the wind as may be necessary.

200. In paying out the wire the reel must be kept from paying out faster than the weight can sink, because the spring in the wire will cause the turns to fly from the reel and so get caught around the axle and break, and it might cause a premature detachment of the sounding-shot. When the weight reaches bottom the reel must be stopped at once, as if the wire is allowed to slacken it will spring into round turns, and when drawn out these form kinks, which always break on the application of a slight strain.

201. In reeling in the wire care must be taken not to put too great a strain on it by reeling in too rapidly, and the wire must be coiled smoothly on the reel. The ship may be steaming ahead while the wire is being reeled in, but must be stopped before letting go for a cast.

202. In sounding with wire from boats the speed of the reel must be carefully regulated, as with the light lead used it is very apt to pay out too fast. So long as the wire between the reel and water is straight, there is a strain on it; but when the reel runs too fast the strain is relieved and it will form a spiral between the reel and water, and then the reel must be checked very gently, or the lead will bring up with a jerk and part the wire or a splice. For boat work, instead of carrying the curve for correcting the soundings for turns of wire it is more convenient to make a table of the corrections for every ten turns, including the deepest water that is expected to be found. Three hundred fathoms of wire is sufficient for an ordinary season's work with a boat reel; and a table made out once may be readily altered, should wire be lost, by subtracting from each number in the turns column the amount lost, and from the corrections corresponding to these numbers the correction for the amount lost. Thus if the first table represents a portion of the original table, and 50 turns of wire be lost, by subtracting 50 from 60, 70, 80, etc., and 2.0 fms., the correction for 50 turns, from 2.3, 2.7, 3.1, etc., the second table is obtained, and must be used until another loss of wire occurs, when it must be again altered in the same way.

300 TURNS.

Turns.	Corr. Fms.	Turns.	Corr. Fms.	Turns.	Corr. Fms.
10	0.4	50	2.0	90	3.5
20	0.8	60	2.3	100	3.8
30	1.2	70	2.7	110	4.2
40	1.6	80	3.1	120	4.6

250 TURNS.

Turns.	Corr. Fms.	Turns.	Corr. Fms.	Turns.	Corr. Fms.
				40	1.5
		10	0.3	50	1.8
		20	0.7	60	2.2
		30	1.1	70	2.6

203. Soundings which are taken without reaching bottom are recorded, and entered on the charts thus, $\frac{0}{400}$, meaning "No bottom at 400 fathoms."

In places where there is a large range of tide, soundings are often taken in places which are dry at low-water. In these cases the reduction for tide is greater than the depth, and the reduced soundings are negative. They are placed on the chart thus, $\underline{7}$, which means the spot is 7 feet above water at low tide.

CHAPTER XI.

RECORDS

204. It is of great importance that there should be uniformity in all records of surveying work, and no record can be considered complete which is not capable of being plotted by any person having a proper knowledge of surveying. Every detail must be included in the records, nothing left to memory. The record of all in-shore sounding work, whether by ship or boats, is kept in books ruled after the annexed form and in the manner shown in the specimen pages (pp. 144 and 145).

The time column contains the time by a clock or watch which shows the same time as that of the tide-gaugers, and is recorded at every position, unless the soundings are spaced by time, when the time of each cast is recorded. If the soundings are spaced by the patent log the reading is recorded at every cast. The "distance interval" at each cast is the distance from the preceding cast on the line being run. Each day's work when continuous is regarded as one line, and the positions are numbered consecutively each day, the first position each day being No. 1.

205. In the "Bottom" column the character of the bottom as shown by the specimen brought up by the lead is recorded, using the abbreviations in the annexed table.

ABBREVIATIONS FOR BOTTOMS.

MATERIALS.

C..........	clay.	K........	kelp.	P..........	pebbles.
Co..........	coral.	M........	mud.	S..........	sand.
G..........	gravel.	Mrl.......	marl.	Sh..........	shells.
Gl..........	globigerina.	O........	ooze.	Sp..........	specks.
Grs..........	grass.	Oys......	oysters.	St..........	stone
		Wd....................	weed.		

COLORS.

bk	black.	dk	dark.	lt	light.
br	brown.	gn	green.	rd	red.
bu	blue.	gy	gray.	wh	white.
		yl	yellow.		

OTHER QUALITIES.

brk	broken.	hrd	hard.	sft	soft.
crs	coarse.	lrg	large.	sml	small.
fne	fine	rky	rocky.	spk	speckled.
grd	ground.	str	streaked.	stf	stiff.
		stk	sticky.		

206. In the course column at each position the course *from* that position is recorded. In boat work the compass course, and in ship work where the deviation is known the magnetic course, is recorded, one of the words "compass," magnetic" at the head of the column being crossed out as required. In the remarks there are noted the bearing and distance of the nearest prominent signal to the beginning and end of the line, the state of sea, wind, weather, etc., at intervals, and the kind of line used in sounding—whether wire or rope, all changes of course, and changes in distance interval, and any other details that may assist in the plotting or assist in making the work complete. The check and number abreast the first angle of a position shows by reference to the column of soundings which one was taken at that position, and they may or may not be on the same line, according as the space in the angle column may require. All angles, altitudes, etc., recorded after a check mark are understood as having been taken at that position until another check mark appears. The angles by which the position is plotted, which are the first taken, are recorded first, the right angle before the left, and check angles and "cuts" afterwards. Soundings with wire should be corrected for the turns of wire on the reel before being recorded. Altitudes are recorded in the angle column, and the word "altitudes" is used to distinguish them and to show that a left object has not been omitted.

207. *Place:* IN VICINITY OF LAGOON HEAD ANCHORAGE, LOWER CALIFORNIA.

Date: ——, 188—. *Vessel:* U. S. S. ——.

Time.	Reading of Patent Log.	Distance Interval.	No. of Pos.	Soundings. Original. Fathoms.	Ft.	Red. for Tide.	Soundings. Reduced. Fathoms.	Ft.	Bottom.	~~Compass~~ Magnetic Course.
A.M.										
7.45	78.7		1 √	9		¾	8¼		gy., S., P.	N.⅜W.
	.8	.1		10		¾	9¼		" "	"
	.9	.1		11½		¾	10¾		" "	"
	79.0	.1		13		¾	12¼		" "	"
	.1	.1		13		¾	12¼		gy., S., brk. Sh.	"
7.50	.2	.1	2 √	15		¾	14¼		" "	N.⅝W.
	79.4	.2		16		¾	15¼		gn., M., brk. Sh.	"
	.6	.2		17		¾	16¼		" "	"
	.8	.2		18½		¾	18		" "	"
8.00	80.0	.2	3 √	20		1	19		rky., Co.	N.N.E.
	80.5	.5		27		1	26		gn., M.	"
8.12	81.0	.5	4 √	35*		1	34		"	"
	81.5	.5		48		1	47		"	"
8.25	82.0	.5	5 √	72		1	71		"	N.E. by N.
8.36	83.0	1.		147		1	146		"	"
8.48	84.0	1.		238		1	237		"	"
9.00	85.0	1.	6 √	320		1	319		"	N.E. by E.

Observers: A. B., C. D., E. F. *Recorder:* J. K.

Leadsman: L. M. *Daymark:* A.

Angles.					Remarks.
By Whom.		° ′ ″	Right Object.	Left Object.	
A. B.	1✓	41.17	Spine.	Last.	Line begins about 4⅛ miles W.N.W. of Lagoon △.
C. D.		36.58	Last.	High.	
E. F.		73.22	Last.	Way.	Sounding with rope.
		1°02′20″	High.	(Altitude.)	
					Clear weather. Light breeze from N.E. Smooth sea.
A. B.	2✓	38.41	Spine.	Chief.	
C. D.		75.10	Chief.	Nail.	
E. F.		20.15	Nail.	Tooth.	C.C. to N.⅝W. Changed interval.
		2°27′10″	Nail.	(Altitude.)	
A. B.	3✓	62.20	Good.	~~000~~	
			Rosa and	Last. ~~000~~	Changed interval.
C. D.		37.12	Good.	Bluff.	C.C. to N.N.E.
A. B.	4✓	35.20	Saddle.	Last.	*Commenced using wire at this cast.
C. D.		30.38	Last.	Chief.	
A. B.	5✓	34.27	Saddle.	Dan.	
C. D.		39.30	Dan.	Back.	Changed interval.
E. F.		24.20	Dan.	High.	C.C. to N.E. by N.
A. B.	6✓	25.29	Saddle.	Dan.	
C. D.		30.47	Dan.	Back.	C.C. to N.E. by E.

208. In a running survey the same record is used for the sounding work, all astronomical observations for latitude, longitude, and true bearing being recorded in a separate sight-book, in which a more suitable form is ruled. A note is entered in the remarks abreast each position at which such observations are made, and the corresponding number in the sight-book may be referred to.

In off-shore or deep-sea sounding work special forms for recording observations are used, and the sounding record contains in columns the number of position, depth of water, latitude and longitude of cast, character of bottom, serial temperatures, and notes of wind and weather, etc.

CHAPTER XII.

HEIGHTS.

DIFFERENCE OF LEVEL.

209. THE height above the sea-level of all the prominent points within the limits of a survey must be computed and noted on the charts. In these computations the earth is regarded as a sphere, and the height of any object is the difference between the distance from the centre of the earth to its summit, and the mean radius of the earth. All points at the same distance from the earth's centre are said to be at the same true level, while points in a tangent plane have the same apparent level.

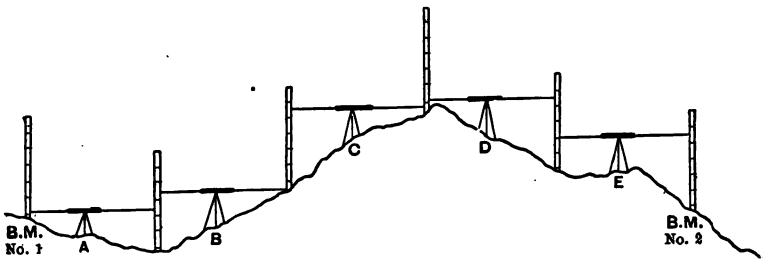
210. The most accurate method of measuring the difference of level between two objects is by using a levelling instrument and graduated staff. When the objects are widely separated, however, either in distance or altitude, this method becomes very laborious, and others are used instead. The only use the level would be put to in an ordinary marine survey would be to find the difference of level between the plane of reference of the soundings and the bench-mark, though in a topographical survey it might be used in connection with the plane-table for contouring. In practice the level is set up and adjusted, equally distant from two positions of the staff, to eliminate errors due to curvature and refraction ; and the difference of the readings of the staff in the two positions gives the difference of level of the points upon which the heel of the staff rests at the two positions. The level is then moved, and the staff in the second position sighted on and then moved to a third position, and so on until the staff rests on the mark whose elevation above the point at which the staff was *first* placed is desired. In going up hill the level is placed so as to read as near the top of the staff as possible, and then the staff is moved up so that the reading shall be as near the heel as possible. The first reading after the level is set up is called the *back* observation and the next is the *fore* observation, and the difference of the two gives the *rise* or *fall* according as the *fore* observation is the less or greater reading, the zero of the staff being at the bottom. The difference between the sums of all the rises and falls gives the difference of level which is rise or fall according to which sum is greater. The two objects whose difference of level is required may not be visible from each other, and the line of levels may be in any direction, straight or zigzag, as the nature of the country demands. The level of a bench-mark is checked by reversing the operation, using different stations for the level and staff.

A theodolite with a vertical circle may be used in place of a levelling instrument by reading the staff each time telescope direct and reversed, the tube being levelled by the level on the telescope, and taking the mean as the true reading or by sighting at a fixed mark, telescope direct and reversed, and setting the vertical arc so that the line of sight may be horizontal by using the index correction thus found.

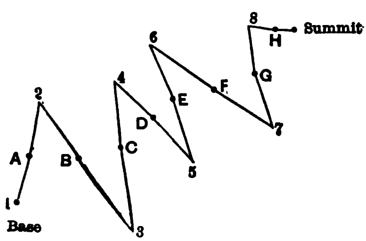
211. The level record is kept as shown on page 149. The positions occupied are midway between the positions of the rod, and the rise and fall refer to the positions of the rod, and are entirely independent of the positions of the instrument. The fore sight at one station and back sight at the succeeding one are taken with the rod at the same point, and the level and rod are moved on alternately.

The sketch shows the profile of the line levelled as shown by the record as it would appear if projected on a vertical plane through the two extreme points. It is not necessary that the line of levels should be straight, nor that the instrument should be on the line joining two consecutive positions of the rod; only that it should be accurately adjusted and nearly equidistant from the two positions of the rod in order

Position.	Back sight.	Fore sight.	Rise.	Fall.	Height above Bench Mark.
	BM. No. 1.				
A	1.40	3.70		2 30	− 2.30
B	5.00	0.10	4.90		+ 2.60
C	6.30	0.20	6.10		+ 8.70
D	0.70	5.80		5.10	+ 3.60
		BM. No. 2.			
E	3.20	6.20		3.00	+ 0.60
	16.60	16.00	11.00	10.40	+ 0.60



that the effects of refraction and curvature may be equal on both sights and so be neutralized. In crossing a steep hill the instrument should be placed so that the back sight shall strike near the top of the rod and the fore sight near the base, and the rod must be far enough away to be read by the telescope. The *plan* of a line of levels over a hill would be as in



the sketch; *A, B, C, D,* etc., representing positions of the level, and 1, 2, 3, 4, etc., positions of the rod. The number of traverses and the angles between them will depend on the height and steepness of the hill.

212. Heights of peaks and other distant objects are computed from their observed angular altitudes and distance, sea miles being used, measured from the chart. In the course of the sounding work angular altitudes of all prominent points within the limits of the survey are observed from different positions fixed by angles. These positions being plotted, their distances from the objects are measured from the chart, and the distance to the shore-line in the direction of the peak is also measured. This being done for all the observed altitudes, those which are to be computed are selected and arranged in groups. The height of the eye in all the observations being known, the distance of the sea horizon and dip for that distance are worked out, and the dip of the shore horizon for all distances in the table less than that of the sea horizon is computed by the formulæ from Walker's Navigation:

Dip of sea horizon $= 58''.77 \sqrt{x}$;

Dip of shore horizon $= 25''.454s + 33''.923\frac{x}{s}$;

Distance of sea horizon in nautical miles $= 1.156 \sqrt{x}$;

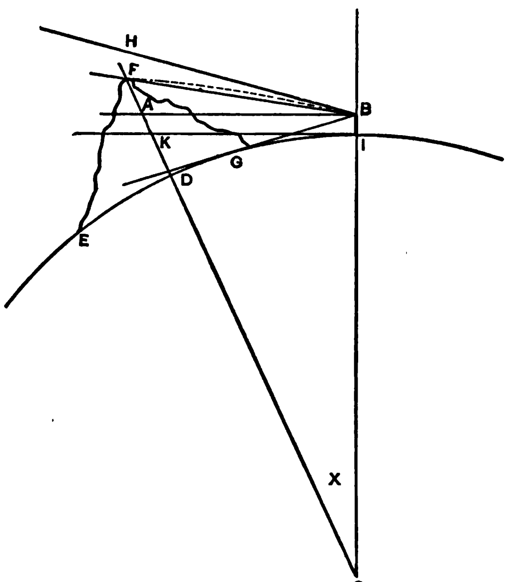
x being the height of the eye above the sea-level in feet and s the distance of the shore-line in nautical miles.

These formulæ all depend on the nautical mile being 6080.27 ft., which is the mile used in the Coast Survey and Hydrographic offices. This value for the sea mile is the length of one minute of arc of a great circle on a *sphere* whose area is equal to the area of the earth.

213. Rays of light passing from one object on the earth to another are subject to terrestrial refraction, and while the amount of it is variable under different atmospheric conditions it is always a function of the distance. Its mean value is $\frac{1}{13}$ of the distance in sea miles, in minutes. So each distance at which objects have been observed is divided by 13, and the result tabulated as minutes. Both dip and refraction increase the observed altitudes, so they are subtracted from the observed altitude to get the true altitude. The apparent height of the object in feet, its elevation above the plane of apparent level, is now found by the formula

$$h = 6080.27d \tan alt.$$

214. The true height differs from this, owing to the spherical form of the earth, and to obtain the true height a correction must be added to the apparent height, which is called the *correction for curvature.* This is the line *KD* in the figure, which is of course much distorted.



Let *EFG* represent an object whose height is required, *B* the position of the eye of the observer, and *C* the centre of the earth. The observed angular altitude is *HBG.* The correction for dip is *GBA*, and for refraction *FBH*, giving the true angular altitude *ABF.*

The apparent height is *AF*, and correction for curvature *KD*, which it is required to find. *IK* and *ID* are practically equal, being the distance of the object in sea miles, and also the *minutes* of the angle x at the centre of the earth. $KIC = 90°$, $CI = R =$ radius of earth.

In the triangle KIC we have

$$KC = CI \sec x = R \sec x;$$

$$KC - CD = KD = R(\sec x - 1) = R\left\{\frac{1 - \cos x}{\cos x}\right\}$$

$$= R\left\{\frac{(1 - \cos x)\sin x}{\sin x \cos x}\right\};$$

$$\therefore KD = R \tan x \tan \tfrac{1}{2}x.$$

Since x is always a small angle, we may put $x \tan 1'$ for $\tan x$, or what is the same thing, $x \sin 1'$. Whence

$$KD = \frac{Rx^2}{2}\sin^2 1' = x^2 \left\{\frac{R \sin^2 1'}{2}\right\};$$

$$KD \text{ (in feet)} = x^2 \left\{\frac{R\text{(in feet)} \sin^2 1'}{2}\right\}, \ x \text{ being in sea miles,}$$

$$\log 2R = 7.6209147;$$

$$\log KD = 2 \log x - 0.05369.$$

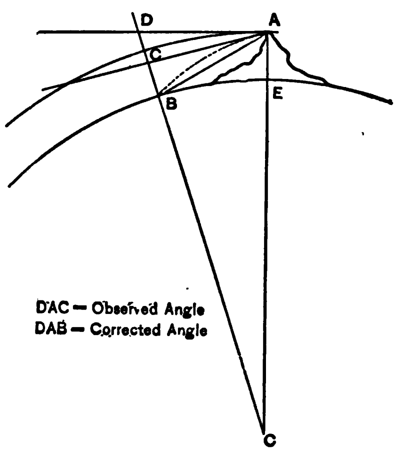
The altitude of the observing instrument BI must also be added, as the apparent height is the elevation above the plane of apparent level BA, and the correction for curvature is the height which is below the *tangent* plane of apparent level IK. The distance BI is practically equal to KA. This gives the true height, and the mean of several observations on one object gives the mean height.

215. A convenient arrangement for computation is the following:

Day.	Object.	Obsd. Altitude.	Dip.	Ref.	True Alt.	Distance.	Apparent Ht.	Curvature.	Ht. of Eye.	True Ht.	Mean Ht.
7/A	Dome	1°.02′.40″	4′.09″.34	1′.06″	0°.56′.24″.66	14.30	1426.77	180.72	18′	1625.49	
10/D	"										

216. In this computation the angle BAF has been considered as a right angle, which is not strictly true. However, as the excess above $90°$ is equal to the angle x, which is always less than one degree, generally less than $20'$, the error introduced by so regarding it is much smaller than the probable error of observation, and may be disregarded.

217. Thus far sextant angles alone have been considered. Heights are readily obtained from theodolite angles, and with more accuracy than by sextant angles above sea or shore horizon, as the variable element of dip is eliminated from the observations. The angles may be taken from any station which is occupied. A theodolite having a vertical circle is, of course, a necessity. After taking the round of angles the angular altitudes of the prominent points in sight are observed by bisecting each one with the horizontal wire with the telescope direct and reversed. This eliminates index error and vertical collimation error, and gives the apparent altitude above the plane of apparent level of the instrument, and when corrected for refraction gives the true altitude. The remainder of the computation is the same as in the cases of sextant angles.



218. The height of the instrument above the sea-level must be known and added to the computed apparent height of every object, as that is only the height above the plane of the instrument. If the point of observation is at the sea-shore the correction may be estimated; but if its elevation is considerable, it must be determined either by levelling or by observing the angle of depression of some point on the shore whose distance may be found from the chart. The height of the instrument is then found by the formula

$$h = 6080.27d \tan \textit{depression}.$$

The refraction, however, is *added* to the observed angle and the correction for curvature subtracted, as will be evident from the figure. ADB is the right angle of the right triangle, $AD = BE$ the distance, BD the apparent height, and from D to the outer circle the correction for curvature. The refraction is added to the angle because the effect of refraction is always to *decrease* the *zenith* distance of any object.

219. If a sextant is used in measuring depressions, the angle between the object at the shore-line and the distant sea-horizon is observed. The refraction is added to this, and also the dip, which is computed for the estimated height of the eye above the shore-line. If the computed height differs much from the estimated height, the dip is computed for the approximate height as found and the height computed again, and the second approximation will be the correct height unless it differs considerably from the first approximation, in which case the height should be computed a third time.

220. It is possible to compute the distance of a peak from its known height and observed altitude. First, estimate the distance, correct the observed altitude for dip and refraction, and subtract the correction for curvature, computed for the estimated distance, from the known height. Multiply the remainder by the cotangent of the altitude, and it will be the distance. If it differs much from the estimated distance, perform the operation again, using the computed distance as the first approximation, and the result will be close enough for all practical purposes.

221. The barometer may be used in determining difference of level. Owing to the variable conditions of the atmosphere at the sea-shore, two barometers must be used and simultaneous readings taken at the summit of the elevation and at the sea-level. The difference in hundredths between the two readings, when reduced to the standard temperature 32° F., multiplied by the vertical distance corresponding to a change of .01, about 9.3 feet, will be the height of the object desired. The barometers must be compared at the same level before the observations. Aneroid barometers may be used in these observations, and will give approximate results up to a considerable elevation. The mountain barometer (mercurial) is quite heavy, and needs careful carriage; and at best the barometrical heights are only approximate, so that the method is seldom used in a nautical survey. A pocket aneroid may be carried at all times to determine heights approximately.

CHAPTER XIII.

TIDAL OBSERVATIONS.

222. SOUNDINGS being taken at all stages of the tide, it becomes necessary to reduce them to what they would have been had the surface of the water maintained a constant level, which is called the plane of reference. This plane is usually that of mean low water, and is determined by a series of observations on the rise and fall of the surface.

For a complete determination of the plane of reference, tidal observations at low-water should be continued during a whole lunar month.

Tidal observations should be made whenever the boats are engaged in sounding work. They consist simply in noting on a vertical graduated staff set up in the water the height of the surface above the zero of the staff. Then, when the staff reading corresponding to the plane of reference has been determined, the correction for any sounding is obtained very easily, being the height of the surface at the time of the sounding above the plane of reference.

223. The instrument used in measuring the tides is called a "tide-gauge," and there are several varieties in use. The simplest one is a board about 4 inches wide, having divisions to feet and tenths painted on one side. In a harbor where there are wharves, or where a pile could be driven, the gauge is secured to a pile or other upright in a vertical position, so that the zero, which is at the lower end, will be below low-water level, and the upper end of the gauge will not be covered at high-water. For ordinary sounding purposes, readings of the gauge every half-hour are sufficient, halving the interval, however, near high and low water. Where there is considerable swell or sea on, the staff is enclosed in a long box having a number of small holes near the bottom, so that the water within the box is not affected by local disturbances, but maintains the same general level as the water outside. The staff is attached to a float and is movable, the reading being taken at the point where the staff emerges from the box at the top. In using this staff the graduations are reversed, the zero being at the upper end, and so high as never to fall below the top of the enclosing box.

224. In harbors where a continuous series of observations is desired, a registering apparatus may be attached to the box-gauge. This is similar to a chronograph. The cylinder is turned by clockwork, so as to make one revolution in 24 hours. The recording pencil is attached by a series of levers and strings to a copper float, which moves up and down in the box of the box-gauge, the levers being used to reduce the range of motion of the pencil. An ordinary staff-gauge is set up on the outside of the box, and at intervals, once or twice a day, about the time of stand, the time and reading of the gauge are noted on the paper surrounding the cylinder at the spot then occupied by the pencil. These observations serve to connect the curves on the paper with the zero of the gauge, and so with the plane of reference, and check the movements of the clock. In the survey of newly discovered harbors, or those whose shores are not settled, it is usually impossible to secure a gauge by any of the preceding methods, and the surf prevents the gauge being set near the beach or against rocks. In this case a support must be secured for the gauge by anchors and guys. This method is now in use on the west coast of Lower California, where the tides have a range of from 6 to 14 feet.

225. The gauge is of wood, 4″ wide and 1″ thick, in two sections, each 12 feet long. One has two brass straps screwed to the end, forming a socket into which the other ships, lapping about 1 foot. The marks begin about one foot from the lower end, and are continuous to the top of the staff. The lower section is lashed to a small spar about 3″ diameter, 14 feet long, which has a sounding-shot on its lower end, kept from falling off by a short bolt, and on the upper end a collar having three eye-bolts at equal distances. Three heavy grapnels are used for securing the staff. Each one has a lanyard of 3″ stuff, about 5 fathoms long, spliced to the ring with an eye-splice at the free end. Into each of the eyes on the head of the staff a piece of old deep-sea lead line, about 15 fathoms long, is spliced with a long eye, and a small thimble is seized in the eye. Two of these lines are rove through the eyes of the lanyards, middled, and the ends secured at the head of the staff. The third is made up sea-gasket fashion and secured in the same place. To set up the gauge: Having selected the place desired, pull in the direction one of the grapnels is to be laid out, and drop it at the estimated distance. Move back to the first position, paying out line, and when all is out drop the staff overboard. The shot will anchor the heel, and the buoyancy of the wood will cause the head to show above water. Pull the boat in the direction of the second grapnel's position, and when its line is taut from the staff, drop it. Return to the staff, get the third guy, and reeve it through the remaining lanyard, and secure the end as before. Take this grapnel and pull in the required direction, and when the line is taut drop the grapnel, so that the three will be about at the vertices of an equilateral triangle. Return to the staff, and lift the head until the heel comes vertically under it. Cast off each guy in succession, reeve it through the thimble at the eye and haul it taut, so the lines from the grapnels to the staff may be all taut. Then set the staff upright again, turn the gauge around the staff towards the place of observation, and ship the upper half of the gauge, securing it with a wooden pin. The gauge is read from shore by means of a telescope. If night observations are desired, a boat must be used, but care must be exercised in keeping clear of the guys. With a range of tide of about 8 feet, the gauge is set up in from 7 to 10 feet of water at low-water. This will usually carry it beyond the surf-line, and permit of satisfactory observations at all stages of the tide. If the gauge is to stand very long, thimbles must be used in the eye-bolts at the head of the staff to prevent the guys chafing loose.

226. The gauge being in an exposed position is liable to be carried away by the sea, in which case the tide observers, camped on the beach, would put it up again in as near the same position as possible. The readings of the gauge in the new position are referred to the same plane of reference by finding the height of some permanent mark on the beach above the zero of the gauge. A large rock is suitable for this purpose. Rest the telescope on the top of the rock, and note at what mark on the gauge the horizon crosses it. This gives the depression of the zero below the level of the rock, with a slight error equal to the radius of the telescope; but as this will appear every time that mark is used, it may be disregarded. The change in dip is avoided by observing at the same stage of tide. Take a new reading every time the gauge is displaced, and all the observations are readily referred to the same plane of reference when its position has been determined on the original scale.

227. The plane of reference being purely imaginary, and the tide-gauges subject to removal, it is necessary to leave a permanent mark and record data connecting the position of the plane with the mark. Then, on a resurvey, the soundings may be reduced to the same plane of reference and the changes in the bottom noted. This mark is called a bench-mark, and is usually a flat surface that is not apt to be disturbed. In some parts of the country low brick piers, capped by a square flat stone, were built as bench-marks. By running a line of levels from any mark on the gauge to the bench-mark, the difference of level between the plane of reference and bench-mark is found. A horizontal line on the corner-stone of a stone building makes a good mark, as it is readily described and not liable to be removed or destroyed. A careful description of the bench-mark is put in the record of tidal observations, with its elevation above the plane of reference.

228. In all cases where tidal observations are made for reducing soundings care must be taken that the localities of the gauge and of the soundings are affected by the same kind of tide. The character of the tide in an almost enclosed harbor is usually different from that outside both in range and interval, and the farther inland it travels the more it is altered, until finally it is obliterated entirely, as in our rivers. One gauge, however, may be used over a large area where the depths are not very small, and where there are no marked obstructions to the progress of the tide. When the survey is of considerable extent, several tide stations are established in the vicinity of each division of the work. These are connected with each other by noting the readings of each at high and low water (of the same tide). If the *ranges* are the same, the difference of level of the two zeros is the difference between the corresponding readings. If not, then the difference between the *mean* heights on each gauge is the difference of level. In addition to the reductions of soundings, other very important data may be obtained from the tidal observations.

229. Tides are oscillations of the surface of the ocean caused by the action of the sun and moon. In the ocean the movement is all in a vertical direction, the water having no motion of translation. Near the coast, in shoal water or anywhere that the progress of the undulation, which travels westward, is obstructed, a motion of translation is induced and the tidal currents formed. When the water is flowing into a harbor, it is said to be *flood* tide, and when flowing out, *ebb* tide these words applying only to the horizontal movement of the tidal current. The words *rise* and *fall* are used to express the vertical movement.

High and *low* water need no explanation.

Slack water is when there is no horizontal movement of the water. *Stand* is the interval during which there is no vertical movement.

Set applies to any current, and indicates the compass direction towards which the current is flowing. *Drift* is its velocity in knots per hour. The *range* of a tide is the vertical distance between high and low water of any tide. The *rise* of a tide is the height of its high-water above the plane of reference.

The *age* of the tide is the interval of time between the time of new or full moon and the succeeding spring-tide, or in general is the elapsed time since a meridian passage of the moon until the arrival of the tide due to that passage.

Spring-tides are those having the greatest range, neap-tides are those having the least range, of all the tides.

230. When the sun and moon are in conjunction or in opposition their influences on the waters of the earth are combined and greatest, causing spring-tides. When they are in quadrature their combined influence is least, as their two forces are acting at right angles. This condition causes neap-tides. The *mean* level of the water is, however, practically constant at all times. That is, the level of water at half-tide is always the same whether at springs or neaps, and is important on a bar.

During the first and third quarters of the lunar month the sun's influence tends to draw the tide-wave to the westward of its position under the influence of the moon, and so tends to hasten the time of high-water. This is called *priming*. During the second and fourth quarters the sun has the opposite effect, and tends to delay the time of high-water, and causes "lagging."

231. The interval of time between the moon's meridian passage and the next high-water under that meridian is called the *luni-tidal interval,* and its daily variations are caused by priming and lagging. The mean value of the luni-tidal interval at any port at the times of new and full moon is called the vulgar establishment of the port, and is what is put on H. O. charts as H. W. F. and C. The mean of all the luni-tidal intervals of a lunar month is called the *corrected* establishment, and *this* is put on Coast Survey charts. Besides the irregularities that may be predicted, there are others caused by local disturbances, such as freshets and high winds. The variation of the height of the barometer is accompanied by a variation in the height of tides, the water being depressed when the mercury is elevated, and *vice versa.*

232. To find the luni-tidal interval on any particular day, take from the Nautical Almanac the time of the moon's meridian passage, and subtract it from the time of high-water next succeeding. The time of high-water cannot be observed exactly, owing to the slow movement of the surface preceding and following stand. To get the time accurately, observe the reading of the gauge every ten minutes for half an hour or an hour before and after the high-water, and from these compute the exact time of high-water. This may be done by taking the mean of the times of equal readings before and after the highest point, or it may be done graphically by plotting the successive times as abscissæ, and the readings of the tide-staff as ordinates, drawing a fair curve through the points thus found, and bisecting a horizontal chord of this curve by a vertical line. The abscissæ and ordinate of the point where this line cuts the curve will be the time of high-water and the reading of the staff at that time.

233. To determine the plane of reference. The plane in general use is the level of the water at low-water springs, and on H. O. charts the data is noted thus: *H. W. F. and C.*

X^h VII^m. *Springs rise* 14 *feet.* It will be seen that there is never less water at any point than is shown by the soundings; and the *range* of springs being known, the mean water-level is determined and the depth of water at half-tide is fixed beyond question. If the tidal observations are taken at new or full moon the plane of reference may be determined from the observations. More frequently it happens that observations are not taken at spring-tides. In this case a good approximation to the low spring level may be made by noting, with the eye at the high-water mark on the beach, the mark where the horizon crosses the tide-gauge. This will be the reading of high-water springs. The difference between the high-water reading of that day and this mark subtracted from the low-water reading of the next low-water will be the low-water spring reading, and a foot lower for safety will be the plane of reference. The range of spring-tides will also be obtained approximately. In the Coast Survey the plane of *mean low-water* is used as the plane of reference, and is the mean of all the low-waters of a lunar month.

234. Soundings in harbors of importance are corrected to the nearest foot within 3 fathoms, to ¼ fathom up to 10 fathoms, and ½ fathom up to 15 fathoms. Beyond that the soundings are only altered by whole fathoms, and beyond 35 fathoms the tide corrections may be disregarded, excepting in very special cases, as the approaches to New York Harbor, etc. In ordinary work the soundings are corrected to ¼ fathom up to 10 fathoms, and beyond that as before. Fractions of fathoms are omitted from the charts on all soundings greater than 15 fathoms, the integral part of the sounding being plotted regardless of the size of the fraction. Thus, 17¾ would be plotted as 17 fathoms.

235. To find the time of high-water when the establishment of the port is known. Take from the Nautical Almanac the time of the moon's Greenwich meridian passage, correct it for the longitude, and add the establishment of the port. *Usually* the meridian passage of the Greenwich day preceding the civil date must be taken in order to find the high-water on a given civil date, and it may be necessary to add 12 hours to the longitude, giving the moon's lower culmination, in order to get the A.M. or P.M. high-water that may be desired.

Suppose the time of P.M. high-water on Nov. 19th, at a port whose establishment is 8 hours and longitude 75° W., is wanted. This is, of course, only approximate, as the luni-tidal intervals vary throughout the month.

P.M. Nov. 19 will be less than 12^h of Nov. 19, astronomical time. From the Nautical Almanac the moon's meridian passage is found to be Nov. $19^d\ 14^h\ 9^m$, which is A.M. Nov. 20, or too late; so look up Nov. 18, and the meridian passage is found to be Nov. $18^d\ 13^h\ 28^m$. Adding 8 hours to this brings Nov. $18^d\ 21^h\ 28^m$, which is A.M. Nov. 19. The desired high-water occurs after a lower culmination, so the time $13^h\ 28^m$ is corrected for $75° = 5^h + 12^h$ longitude $= 36^m$, giving $14^h\ 4^m + 12^h = 26^h\ 4^m$. Add the establishment 8 hours, and the required time is Nov. $18^d\ 34^h\ 4^m$, or Nov. $19^d\ 10^h\ 4^m$, which is $10^h\ 4^m$ P.M. Nov. 19.

236. Tidal currents. In addition to the observations on the vertical movements of the tides the horizontal movement must be measured and tabulated. Current observations are made by anchoring in the tide-way and heaving the log at intervals, being careful to get the bearing of the chip before hauling it in. This gives the set and drift of the current, and the observations are taken at quarter-tide, half, and three-quarters, both ebb and flood. The knowledge of the set of currents is of great importance to navigators, particularly in sailing-ships. In a channel-way having shoals on either side the current may be up and down the channel when the water is low, and when the shoals are covered it may set directly athwart the channel, hence a knowledge of the currents would be most valuable. These current observations are taken at various points within the limits of the survey, and are more numerous as the place is of greater importance. At all times, when the ship is at anchor on her working ground, the set and drift of the current should be ascertained at least twice in every watch, and if the currents shift with flood and ebb they should be observed oftener.

CHAPTER XIV.

ASTRONOMICAL WORK.

237. In order to locate a surveyed tract on the chart it is necessary to determine the latitude and longitude of two (or more) points of it, or the position of one point and the azimuth or true bearing of some line of the triangulation through this point. Usually both are done to facilitate plotting. The first thing to be done is the selection of the observation-spot, and there are many conditions which are desirable in its location. It must be in such a position that at least three of the triangulation-points may be seen from it and it from them. Generally it is not desirable to place it at one of the main stations, but rather select a spot on other considerations and connect it with the triangulation by an additional triangle. It should be in rather a sheltered position, but where the view north and south is clear, the soil should be dry, solid, and level; it should be far enough from the beach to be unaffected by the surf (shaking mercury), and it should be convenient to a safe landing-place, unless it is intended to camp on shore during the observations (as it is most disagreeable to embark in a surf at midnight, as well as highly dangerous). It is not desirable to put it at one of the main stations, because of the necessity of removing the signal during the observations, or of not occupying the centre of the station. Usually the latitude is first determined, then the longitude, and lastly the true bearing of some line of the triangulation. A signal is then erected exactly over the spot occupied by the theodolite during the last observations (which should also be the spot occupied by the

horizon during the preceding observations, or by the transit instrument). This signal being cut in from three or more of the main stations, the location of the tract on the chart becomes simple.

238. In the observations it is assumed that a sextant and horizon are to be used, the description of the transit instrument being deferred to Chapter XVII. A sextant stand is a necessity, and should be of such a height that when seated on a stool or box about 8 inches high the observer's eye will be on the level with the telescope of the sextant. The stool should be provided, as much is added to the value of the observations when the observer is in a comfortable position and his personal equation not variable.

239. Having selected the observation-spot, a space about 15 feet square is cleared of bushes, bowlders, etc., and levelled off, and the stand for the horizon firmly fixed in the centre of the space with its long edge in the meridian, as shown by compass. A piece of old canvas large enough to cover the entire space, with a hole in the centre for the horizon, is an excellent thing for the comfort of observers and cleanliness of instruments. Two bulls'-eyes and one deck lantern are provided, and an empty barrel for the lantern. Two bulls'-eyes are provided, so if one goes out the observations will not be interrupted. The barrel is placed on its bilge with its open end away from the observer and the lantern inside, and the recorder sits by the end of it to mark time and give warning of the approach of stars to the meridian. If observations are made on several nights, the instruments, etc., may be stowed in the barrel during the day and covered with the canvas, thus insuring a dry place for the observers.

240. The first observations taken are for latitude, and the method of circum-meridian altitudes is always used. Stars are observed in preference to the sun, as the latter is only in position for a few moments out of the twenty-four hours, while many stars may be observed in a single night. In order to eliminate as many of the errors of observation as possible, the stars are observed in pairs, one north and the other south of the zenith having nearly the same zenith distances, and differing little in R. A. The mean of the latitudes determined from each star will be free from index error, error in estimating refraction, error due to roof of horizon, and generally from personal error, as these all affect the altitudes in the *same* way, but the resulting latitudes in opposite ways, so that one is as much too large as the other is too small, and the mean is a very close approximation to the truth. The same end of the horizon is towards the observer in *all* these observations.

241. Before landing for observations, a list of stars is prepared from the Nautical Almanac or Star Catalogues that are suitable for observing. With the known (approximate) latitude and longitude of the place, the local mean time of meridian passages of the larger stars culminating after dark are computed and tabulated, also their approximate altitudes and their double altitudes, and a note is made at each one showing whether it culminates N. or S. of the zenith. From the table select those stars that may be paired with others, noting that the stars of a pair should differ not less than 15 minutes in R. A., and should not differ more than 5° in altitude. The same table may be used for several days by subtracting 4 minutes from the local mean time of meridian passage for every day after the one for which the table is computed. In selecting stars the limiting angle of the sextant must be considered, and stars above 65° altitude and below 25° rejected. These limits may be extended slightly, but generally altitudes within the limits should be selected if possible. See that the sextant is in adjustment, glasses clean, and that the telescope tube is marked at the proper opening for focus, so it can be adjusted readily on shore. Have plenty of clean mercury provided in the horizon, and the last thing before landing compare the watch to be used in marking time with the standard chronometer, which must also be done on returning on board. The watch should be regulated to local mean time, or the star table should be made out for the time the watch carries.

242. After landing, which should be done half an hour before darkness sets in, arrange the observation-spot. Spread the canvas, set up the horizon, and put the sextant on its stand, with lunar telescope focussed in it. Suppose the first star of the first pair is a south star, then the marked ("A") end of horizon is turned to the N., and the sextant placed there. The sextant is set to the approximate double altitude from the table, the tangent-screw turned to the middle of its run, and moved stand and all, so that by looking along the tube the star may be seen in the mercury, and then after settling the stand on ground, by moving the instrument slightly from side to side on the stand (across the meridian), the reflected image will be seen to cross the field of view, when the instrument is steadied and the contact made. Note that the bubble of the level on the index bar plays near the centre, so as to be sure that both images are of the same star. The observations begin about ten minutes before the time of culmination. The contact having been observed, the sextant is lifted carefully out of the stand and held nearly horizontal for reading. The blue-jacket holds the bull's-eye just above the index-glass, and throws the light on the ground-glass vernier screen, so the angle may be read and the recorder notes the time and angle. Hold the sextant low enough to allow the lamp to be kept level, otherwise the oil will be spilled over the instrument and ruin the index-glass.

243. The sextant must be lifted carefully from the stand, so that the reading may not be disarranged, and that when replaced the stars may appear at once in the field without needing to be searched for. After one reading, turn the tangent-screw of the vernier slightly before replacing the sextant, so

that each contact may be observed independently. The observations after culmination may be carried on for about ten minutes, unless the next star comes on very soon, in which case about five minutes should be allowed to set the instrument for the new star and get it in the field, and the remainder may be divided equally between the two, giving, however, the greater time to the second star in case a difference is made. Time may be easily recorded to quarter seconds, which is quite close enough for these observations.

244. The local mean time must be known within two seconds, and is obtained from the known error and rate of the chronometers. A more satisfactory way, however, is to observe one or two bright stars about 60° from the meridian for time. Two stars, one east and one west of the meridian, will determine the time very accurately, and a third star on same side of meridian, but bearing north if first is south, will give three Sumner lines, and a very good approximation to the true latitude which may be used in subsequent computations. These time stars may be observed before the first pair comes on if there is time, or between pairs, whichever is most convenient. If first star of a pair is missed the second should not be omitted, as it may be used to replace a component of another pair which may not have been satisfactorily observed. The latitude is computed from the observations by the methods given in the text-books on Navigation, to which the student is referred. Each star of a pair is given equal weight in computing the latitude from that pair, but in getting the final results the different pairs may be given relative weights depending on the character of the observations of the stars of the pairs, and the values combined by least squares. The barometer and thermometer are recorded at the beginning of the observations on each star, and used for correcting the refraction.

245. The next problem is to find the longitude of the observation-spot. The longitude referred to the prime meridian may not be found with any degree of accuracy with the instruments usually supplied to surveying vessels, but this is found by finding the difference of longitude between the observation spot and some place whose longitude from prime meridian has been fixed by telegraph. There are many such places, and they constitute secondary meridians on whose positions the longitudes of places in the vicinity depend. The secondary meridian is noted on the chart thus: "Longitudes depend on Astronomical Observation Spot, San Diego, —° —′ —″ W.," etc. These differences of longitude are called "meridian distances," and they are the differences in local mean times at two places at any absolute instant of time. Telegraphic longitudes are determined by finding the local mean time at two places by astronomical observations and, by exchanging signals, finding the difference in time between the two. The time of transmission is eliminated by sending signals alternately from either end of the wire.

246. In chronometric meridian distances the time is carried from one station to the other by chronometer. The errors on local mean time are found at the two places, and if the chronometer kept *true* mean time, i.e., had no rate, the difference of these errors would be the meridian distance. The variable rates of chronometers complicate this problem, however, and several chronometers are used to eliminate errors. In practice the error and rate of the chronometer on local mean time are found at some station of which the longitude is known, and then the errors on local mean time are found at places whose longitudes are desired, and finally the error and rate determined either at the first-named station, or at another whose longitude is known. From these errors and rates the meridian distances of the intervening points are found. Again, if only one point A is to be fixed, find the error there on local mean time; proceed to a point B, whose longitude is known, find the error there on the day of arrival and also of leaving; then return to the first point A and find the error, and the meridian distance may be computed. The time spent at B does not affect the result, but the time spent in transit should be as short as practicable, in order that the change due to rate may be as small as possible, and that the rate may be practically constant.

247. Supposing α_1 and α_2 to be the errors observed at A before sailing, and after return β_1 and β_2 the errors observed at B; the number of days between α_1 and β_1 to be a; β_1 and β_2, b; β_2 and α_2, c,—then the whole change in chronometers due to $a+b+c$ days is $\alpha_2-\alpha_1$. But the change in b days is $\beta_2-\beta_1$, so that the mean rate during transit, or travelling rate, is $(\alpha_2-\alpha_1)-(\beta_2-\beta_1)$ in $a+c$ days, and the mean daily rate is $\frac{(\alpha_2-\alpha_1)-(\beta_2-\beta_1)}{a+c}$, which is used in determining the meridian distances.

248. It will be seen that the accuracy of the longitude depends entirely on the accuracy with which the time is determined, and everything to increase accuracy must be done. The method of equal altitudes is the most accurate means of finding the time with a sextant and horizon, and is employed in all such determinations. The same end of the horizon is towards the observer at both observations. The same instruments, observer, and recorder must be used, and all possible means employed to have the physical conditions the same at both observations. Theoretically, stars are best for equal altitudes, and they give excellent results. In practice, however, the sun is used, for several reasons. It is inconvenient and undesirable to land and embark at night for comparisons which *must* be made before and after each set of observations, besides the difficulty of observing and reading by lamp-light, etc., and the necessity of reducing sidereal intervals for the stars.

249. In observing equal altitudes the following method will be found extremely useful. Having the horizon arranged, sextant in place, etc., bring the two suns into the field so that they are approaching each other. See that the tangent-screw is set well back so as not to run out during the observations, and when all is ready set the vernier to an even degree, say 80°, and "mark" the instant the limbs make contact. Move the vernier ahead 10′ and mark as before, and continue until the sextant reads 80° 50′, or through six observations. Now set the sextant to 80° as at first, and note the instant of *separation* of the limbs, and take six sights in that way, making a set of twelve sights. The first six are upper limb, the remainder lower limb. Sights may be taken at 5′ intervals of double altitude, but nothing is gained, and the hurried sights are apt to be poorer than more deliberate ones. In the forenoon more sets are taken than are needed, in case the afternoon should be cloudy. On returning to the ship, after comparing the time-piece carried on shore, which should be a chronometer, compute the interval between the last sight and apparent noon, and thence find the watch time of the first afternoon sight so as to be on shore in time. Being once more at the observation-spot and ready for work, set the sextant to the *highest* altitude observed in the forenoon, and watch for the suns to come in *contact*, when mark. Set the vernier back 10′, making the final adjustment by turning the tangent-screw in the same direction as in the morning, and observe six contacts. Then set again to highest altitude and observe six separations, which will finish the set. Continue in this way until as many sets as are wanted are observed; seven or ten give a good determination. The interval between the last sight of one limb and the first of the other in these sets is about 1⅓ times that between two consecutive sights on the same limb. Between each observation the recorder notes the elapsed time in seconds, for two reasons: first, to show any irregularities in observation; and second, to show if sun's motion is too slow for good work, which is generally when the rise of 10′ (double altitude) takes more than 30^s.

250. It is not necessary to start a set on an even degree, and the first sights may be thrown out. If the intervals are regular, the recorder calls "*Change*" after the sixth contact (A.M.); but if the first one or two are too great or too small, the observer keeps on for one or two more sights before shifting to the other limb,—of which he then takes only six altitudes, however. In the afternoon the recorder must give notice to change in each set to prevent mistakes and lost sights. The middle chronometer time is obtained by taking the middle time of any two sights at same altitude, A.M. and P.M. for the hours and minutes, and the seconds for each set are found by adding the seconds of each pair of times and taking half the mean for the set. These sums and intervals afford a means of valuing the observations, and a set is good if the extreme sums in last column for each set are within two seconds of each other. The method of finding the equation of equal altitudes and thence the chronometer error is discussed in "Navigation." In any series of observations for meridian distances, the observer, recorder, and instruments must be the same throughout the series in order to eliminate the personal equations.

251. In the comparisons before and after landing between the chronometers, the differences should be noted to the nearest tenth of second. One person does the comparing by eye and ear, and after very little practice one is able to compare to tenths. Suppose all chronometer boxes are closed but the two being compared. If they beat synchronously, the comparison is simple and to half seconds. If they beat alternately at equal intervals, they are separated by a quarter second, and by noting the ratio of the time between one beat of the standard, one of second chronometer, and a second beat of the standard the tenths are easily estimated.

The comparisons of the hack with the standard are checked by comparing Hack and Standard *A*, Hack and *B*, and then comparing *A* and *B*. Then the sum of two of the differences must equal the third or there is some error. In this way the comparison may be brought to the nearest .05^s. In marking time for observations the observer calls "*Mark*" very sharply, not with a drawl, and the time is noted at the first sound. If the recorder will take up the beat of the chronometer and count with it, "Half—one, half—two, half—three," etc., the time may be noted to quarter seconds by noticing whether the *mark* is coincident with a beat or between two. Moving a finger up and down, beating time, is another way, the bottom of a stroke corresponding to a beat of the chronometer and the top to a quarter second. After very little practice tenths of seconds may be estimated.

TRUE BEARINGS.

252. The true bearing, or, as it is often called, the astronomical bearing, of a line or of one object from another is the angle between the plane of the meridian through one object and the vertical plane through the two objects. The measure of this angle is a horizontal angle, and it is found by measuring the horizontal angle between the object and a heavenly body, computing the azimuth of the latter, and thence by addition or subtraction finding the astronomical azimuth of the object, or its true bearing. These horizontal angles are always measured on shore with a theodolite, and with greater or less accuracy, depending on the size and quality of the instruments used, and on the heavenly body selected.

Where great accuracy is desired, large instruments, read by micrometers and fitted for night observations, are used, and stars alone are observed. For purposes of a marine survey any of the theodolites supplied to the party will serve, though one having a vertical circle is to be preferred. If no vertical-circle theodolite is to be had, altitudes of the heavenly body must be observed with sextant and horizon for computing the azimuth, unless the local time is known to the nearest second, when time azimuth might be used instead of altitude azimuth. In any case the time must be known close enough to pick out the declination, and the latitude quite accurately determined.

253. The observations are made thus: Set up and adjust carefully the theodolite over the centre of the station from which the bearing is to be observed. If a double-plate instrument, place the zeros together and point at the signal (which call the "mark") whose bearing is desired, perfect the contact and clamp the lower plate securely. If a single-plate instrument, point at the mark and note the reading. Place a colored shade-glass over the eye-piece of the telescope, unclamp the upper plate, and point at the sun. By means of the tangent-screws on the horizontal and vertical axes bring the vertical wire-tangent to the first limb of the sun, and the horizontal wire-tangent to the upper limb in forenoon, lower limb in afternoon. The sun will seem to move *towards* the intersection of the wires. When both contacts are perfect, "*mark*," and the time is noted; read both verniers on the horizontal circle, then both on the vertical circle, and repeat the operation, making three readings with telescope direct. Transit the telescope, turn the horizontal circle through 180°, and point again at the sun. This is called "telescope reversed," because the ends of the horizontal axis are pointing in opposite directions from their first position. Observe three more contacts, this time observing on the second and lower limb for A.M., or upper limb for P.M. sights, the sun seeming to move *away* from the crossing of the wires. Point again at the mark and record the reading of the horizontal circle, telescope reversed. Three or five sets will give a very good value of the true bearing. After completing one set, as above, the telescope may be placed *direct* and the whole operation repeated, or, what is simpler, having observed the mark *tel. R* at the end of first set, consider that as also the first of the second set and observe three first and upper limb, then, with

EXAMPLE OF RECORD.

STATION, CAPITOL EAST PARK, WASHINGTON, D. C.

Sun near prime vertical, August 15, A.M., 1886. Observer, C. A. S. Instrument, 5-inch magnetic theodolite. Sidereal chronometer.

Chronometer time.	Horizontal circle. A	Horizontal circle. B	Vertical circle. A	Vertical circle. B	Temperature.
SET I.	☉'s upper and first limb. Telescope D.				73° Fahr.
h. m. s.	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
Mark.	00 00 00	180 00 00			
5 02 53.0	25 24 30	205 24 30	61 56 00	61 56 00	(Bar. 30 in., assumed.)
05 34.0	25 50 45	205 51 30	61 24 30	61 25 00	
06 55.5	26 04 30	206 05 15	61 08 45	61 09 30	
	☉'s lower and second limb. Telescope R.				
5 09 12.0	205 54 15	25 54 00	61 19 30	61 18 30	
10 32.0	206 07 15	26 06 45	61 04 00	61 03 00	
11 42.0	206 18 30	26 18 15	60 50 00	60 49 45	
Mark.	180 00 00	00 00 15			
SET II.	☉'s lower and second limb. Telescope R.				
5 13 22.0	206 35 30	26 35 30	60 30 45	60 30 15	
14 32.0	206 47 30	26 47 30	60 17 30	60 17 00	
15 36.5	206 58 30	26 58 00	60 05 15	60 04 30	
	☉'s upper and first limb. Telescope D.				
5 17 07.0	27 47 30	207 48 15	59 11 45	59 12 00	
18 16.5	28 00 00	208 00 30	58 57 45	58 58 00	
19 19.0	28 10 15	208 10 30	58 45 30	58 45 13	
Mark.	00 00 15	180 00 15			
SET III.	☉'s upper and first limb. Telescope D.				
5 20 44.0	28 25 00	208 25 00	58 29 00	58 29 30	
22 01.5	28 37 45	208 38 15	58 14 45	58 14 30	
25 26.5	29 13 30	209 14 00	57 36 00	57 35 45	
	☉'s lower and second limb. Telescope R.				
5 27 32.5	209 01 30	29 00 30	57 48 00	57 47 30	
28 39.5	209 12 45	29 12 15	57 34 30	57 34 15	
30 01.0	209 27 00	29 26 30	57 19 15	57 18 30	78° Fahr.
Mark.	179 59 45	359 59 30			

$\phi = 38° 53' 18''$; $\lambda = 5^h 08^m 01^s.0$ west of Greenwich.

telescope direct, three second and lower limb, and then the mark *tel. D.*

The record is kept as in the form on page 177, which is from the Coast Survey reports.

254. The mean of all the readings of the horizontal limb, less 90°, is the theodolite bearing of the sun's *centre*. The mean of the readings of the mark adjoining each set is the reading of mark for that set, and the mean of *all* the readings of the vertical circle is either the apparent altitude or zenith distance of the sun's *centre*, according to the graduation of vertical circle, at the time when the centre bore as above, which is the mean of the recorded times. The mean altitude corrected for parallax and refraction is the true altitude, and with the known latitude and declination the azimuth of the sun is computed. This is the true bearing of the direction in which the theodolite points when it reads the mean bearing of the sun's centre. The difference between this angle and the reading of the mark is applied to the right or left of this azimuth, according as the sun was to left or right of the mark, and gives the true bearing of the mark.

This method of observing eliminates nearly all instrumental errors—such as collimation, eccentricity, pivots, etc., and semidiameter. Errors of graduation are eliminated by changing the position of the lower plate in each set. In the case of a single-plate instrument the tripod must be turned in azimuth between sets to make this correction. It is immaterial whether the vertical circle reads zero when the telescope is horizontal or not, as the reversal of the telescope eliminates this "index error."

255. In observing both contacts, as these observations are always taken when the sun is near the prime vertical and the motion in altitude is most rapid, the horizontal wire is set slightly in *advance* of the limb, the vertical wire kept *to* its contact, and the "*mark*" given when the other contact is made. If the altitudes are observed with sextant and horizon, the leading limb is observed during half the set, the following limb in the other half, the sextant changing when the theodolite is transited. In this case the contact on the vertical wire is made at the centre of the wire, the other being, as nearly as possible, across the sun's centre.

256. The azimuth, which is measured from the elevated pole, E. or W. according as A.M. or P.M. sights are used, is found from the formula

$$\cos \tfrac{1}{2}Z = \sqrt{\frac{\cos s \cos (s - p)}{\cos L \cos h}},$$

where $s = \frac{1}{2}(L + h + p)$, L = latitude, h = true altitude, and p = polar distance.

257. The oblique angle between the sun and a terrestrial object may be measured with a sextant, reduced to a horizontal angle, and the true bearing found as above; but as this method has no advantages over the foregoing method and has many disadvantages, it is never used for shore observations. For true bearings from a vessel, however, it is the only possible method, and is much used in running surveys and reconnaissances. Two observers are necessary. Simultaneously they observe, one the altitude of the sun and the other the angle between its limb and the nearest point of the mark. Several observations are taken and the means used. The altitude of the mark above the sea horizon is observed and corrected for dip and index error, as is also the sun's altitude, which is further corrected for semidiameter, giving *apparent* altitudes. Then if h = altitude of mark, H = altitude of sun, D = distance corrected for semidiameter, and ϕ = horizontal angle between sun and object,

$$s = \tfrac{1}{2}(h + H + D);$$

$$\cos \tfrac{1}{2}\phi = \sqrt{\frac{\cos s \cos (s - D)}{\cos H \cos h}}.$$

258. The sun's limb should not be brought tangent to a vertical line at the signal, as it necessitates computing an additional angle in order to correct the distance for semidiameter, and again a considerable error is introduced by making the point of tangency higher or lower on the line. If the object presents a sharp mark, it is better to bring each limb to it in half the observations and thus eliminate semidiameter altogether. The object should, if possible, be chosen near the horizon, so that the angle from the sun may be close to 90°, as then the reduction to the horizon is least.

259. In all observations for true bearing low altitudes are better, and the sun should be near the prime vertical. The most distant *well-defined* object in sight should be used as mark to lessen the error caused by phase of object, and to make the error due to imperfect centring over station small. It is convenient to observe the true bearing of a long side of the triangulation from the observation-spot immediately after the afternoon sights for time, the longitude sights being then *completed*. The theodolite is placed over the position of the horizon, and when the sights for true bearing are finished and a careful round of angles observed a stake is driven directly under the centre of the instrument, which becomes the centre of the station, and a signal is erected over this stake and cut in from the neighboring signals. Afterwards a paper containing a record of the spot with the data found for it is placed in a bottle and buried under the centre, and a surface mark made, such as a cairn, brick pier, etc., to enable subsequent visitors to recover the exact position used.

CHAPTER XV.

MAGNETIC OBSERVATIONS.

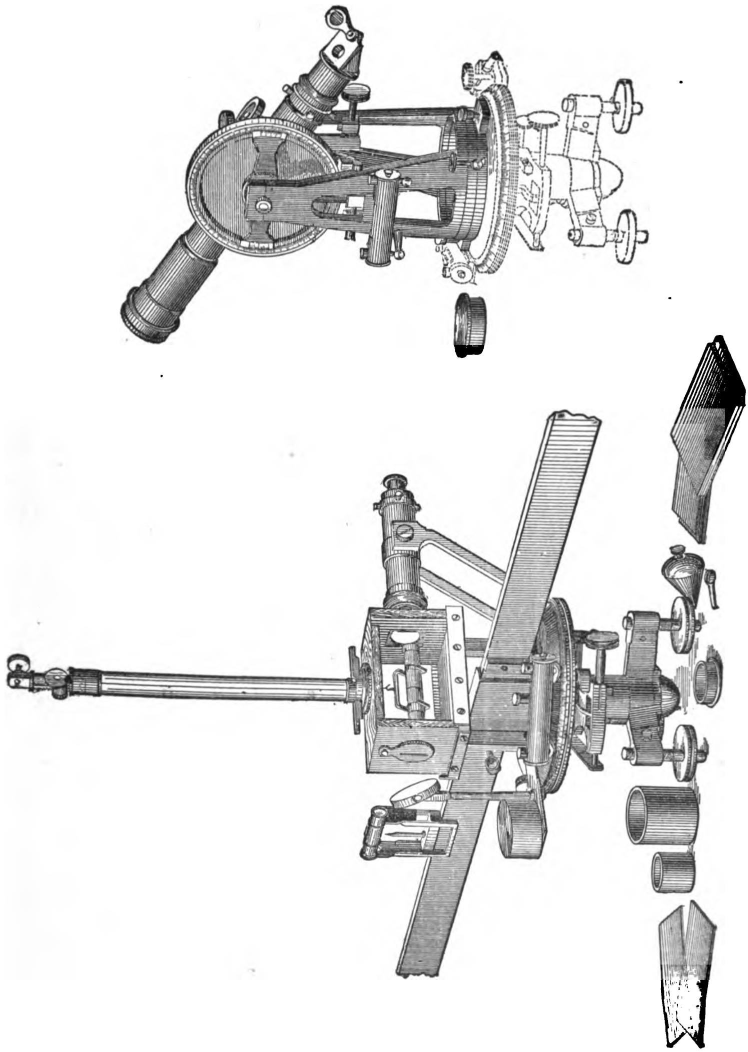
260. If a long magnet be suspended by its centre of gravity so that it is free to take any position, it will place itself with its axis parallel to the lines of magnetic force due to the magnetism of the earth. The determination of the direction and intensity of this force is the object of magnetic observations. The direction is referred to the plane of the meridian and a horizontal plane. The force may be measured in relative or absolute units. The direction of the force will be known if the angle between the vertical plane through the axis of the freely suspended magnet and the meridian, and the angle between the axis and its projection on the horizontal plane, are known. The first angle is called the "magnetic declination" (by seamen called the "variation"), and the second the magnetic inclination or dip.

261. The intensity of the earth's force in the direction of the free needle is called the "total force." Usually it is resolved into two components, horizontal and vertical, and the former made the subject of measurements. For all purposes of surveying, navigation, and chart-making the *direction* of the force is the only part of it which need be considered, so the measurement of intensity will not be discussed. Full instructions as to its measurement will be found in the Coast Survey Report for 1881.

262. The magnetic declination is not a constant quantity, but is subject to several variations, some due to local causes and not subject to laws, others to known causes and of regular periods. In a given place the variation increases or decreases by a fixed amount from year to year, and it also has diurnal variations similar to tides. The north end of the needle oscillates about its mean position, having its greatest eastern elongation about 7 A.M., then moving to the westward and reaching its greatest western elongation about 1.30 P.M., and then moving slowly back, reaching the eastern elongation the next morning, and so on, the daily variation amounting to about 15′. The observations for declination consist essentially in observing the angle which the axis of the magnet makes with the meridian at each elongation, and the mean of the two gives the declination. In practice the observations are conducted in this order: Observe eastern elongation, observe for dip or determine constants, observe western elongation, observe true bearing.

263. The instrument used in field work is called an "alt-azimuth and magnetometer," and consists of a 4½-inch repeating theodolite with vertical circle, all of which above the azimuth plates may be removed by loosening certain screws, and replaced by a metal frame carrying a small glass-sided box surmounted by a glass tube a foot long in which the magnet is suspended by a silk fibre. On one side is a small reading telescope, and on the other a reflector and counterpoise. The magnets used are hollow, about 2 inches long and ¼ inch diameter. In one end is screwed a small lens, and in the other, preferably the N. end, a plate of thin yellow glass having a scale of equal parts engraved on it containing 100 divisions. The glass tube has a metal top, graduated, and movable about its vertical axis, and also carries a rack and pinion by which the magnet may be raised or lowered. The fibre is secured between two plates which are brought in contact by a small screw. At its lower end it is fast to a fine wire frame in which the magnet rests. The bottom of the box contains a piece of cloth by which violent oscillations of the magnet are stopped by lowering it until the friction of the fibres brings it to rest.

When the magnet hangs in the centre of the box with its



ALT-AZIMUTH AND MAGNETOMETER—U. S. COAST SURVEY.

axis parallel to the sides it is in the line of collimation of the telescope outside, and by it the scale is read, light being thrown onto the scale through a slit in the end of the box by the reflector. The magnetometer must always be set up under a tent or other shelter from the wind, as a very slight wind causes violent oscillations of the magnet. With the instrument there is provided a brass or iron non-magnetized weight of the exact size and weight of the magnet, known as the torsion weight, and a small *weak* magnet; a piece of steel wire, or the screw-driver answers every purpose.

264. In taking magnetic observations the station must be carefully selected, so it may be free from magnetic disturbance; the crest of a hill is better than the base, and a level piece of ground, free from volcanic or magnetic rock, must be found. To test a spot for magnetic disturbance set up a compass, surveyor's compass preferred, over the station, and pnt up six or eight marks, about 15 metres distant, in a circle about the station. Observe the magnetic bearing of each of these marks, and then, leaving a mark at the station, go to each of the marks and observe the bearing of the central mark. If the back bearings differ from the original ones by exactly 180°, the station is a good one and may be occupied. If, however, they do not correspond, then there is local attraction in the neighborhood and the station is not good, and another must be found.

Set up the instrument as a theodolite, adjust it carefully, and by means of the compass needle on the instrument point it in the magnetic meridian, and put up some object nearly in that line for a mark, at as great a distance as it may be distinctly seen with the telescope of the magnetometer when adjusted to sidereal focus. Remove the telescope, and put the box and suspension tube in its place, and its levels should show it to be in adjustment when firmly secured. Turn the sides of the box so they may be in the magnetic meridian. Suspend the torsion weight, and by means of the rack and pinion raise it from the bottom of the box, and take the twist out of the fibre by turning the top of the tube, called torsion circle, in azimuth, and steadying the weight by the nap of the cloth. In this way the twist is all taken out, and the torsion circle is set so that the weight hangs in the magnetic meridian. This does not have to be done at every station, as when the instrument is packed the frame on the fibre is slipped under a little spring which prevents the fibre from twisting. Lower the weight on the cloth, remove it and replace it by the magnet, and raise it to the centre of the box, being careful that the divisions of the scale are vertical. Now proceed to determine the *constants* for the instrument.

265. Adjust the telescope to sidereal focus; by means of a suitable screen adjust the width of the slit facing the reflector, slide the shade on the object end of the telescope close up to the box, to exclude all light, and put the dark sides on the box. By means of the spare magnet steady the suspended one, being careful not to bring it too close to the box, as the magnetic axis of the magnet might be disturbed. When nearly quiet (it is never at perfect rest), by means of the tangent-screw of azimuth plate point the telescope so that the vertical wire will be at the middle of the scale, and clamp it securely. Now, as the scale slowly swings back and forth across the field of view, note the readings when the scale is at the limits of its swing. The mean of these will be the division at which the telescope would be pointing if the magnet came to rest. Now turn the magnet on its axis through 180°, which inverts the scale, and get the mean reading as before. The mean of these means would be the magnetic axis but for the constant changes in declination. Place the scale erect and get a third reading. The mean of 1 and 3 will be the scale erect reading at the middle epoch, and combined with the scale inverted

reading will be the axis. In practice 9 to 15 readings are taken with scale alternately erect and inverted, an odd number being always observed. These are combined thus: mean of 1 and 3 combined with 2, mean of 2 and 4 with 3, of 3 and 5 with 4, etc., etc.: and the mean of these results gives the scale reading of the axis of the magnet. In reading the scale, tenths of divisions are estimated. These observations should be taken at the periods when the motion is least, i.e., at the epochs of elongation, preferably the P.M. epoch.

266. Next determine the angular value of one division of the scale. Steady the magnet as carefully as possible, and by turning the azimuth circle point at the 0 of scale and read the circle. Point successively at each of the principal divisions and read the circle, and when the highest division is reached repeat the operation in inverse order. Use the mean of the circle readings of each division for the reading of that division, and the readings will be corrected for change in declination. A small correction for torsion might be applied, but it is a needless refinement in *declination* observations. These constants may be determined in the interval between A.M. and P.M. elongations, if so desired, but are better made on a different day.

267. When making observations for declination the instrument is usually set up in the evening, and the torsion weight left suspended. In the morning, at an hour sufficiently early to be sure of preceding the eastern elongation, set the torsion circle so that the weight hangs in the meridian, lower it to the cloth, and point the telescope at the "mark" by moving the azimuth circle. Read the circle, and then point the telescope approximately in the magnetic meridian; suspend the magnet, steady it, point the telescope at the middle of the scale and clamp the plates. Record every ten minutes the extreme points reached by the wire in the swing of the scale, and note the mean of these readings. When the elongation is fairly passed, which is shown by the mean reading changing from increase to decrease or *vice* *versa,* take two or three readings after the elongation and then suspend the torsion weight. About noon set the torsion circle to the line of detorsion, suspend the magnet, and observe the western elongation in the same way as the eastern. When past the elongation remove the magnet and secure the suspension, to keep it from twisting; read the azimuth circle, to be sure it has not moved from the reading at which the A.M. observations were taken, and then observe the reading of the mark. Note also whether increasing scale readings correspond to increasing circle readings or *vice versa.* If desired, the axis and value of scale division may be determined now, as explained. Remove the box from the azimuth plate and secure the alt-azimuth to it, and when the sun is in proper position observe the *true bearing* of the mark.

268. The mean of the highest and lowest scale readings corresponding to the two elongations gives the mean scale reading; the difference between this and the axis multiplied by the value of one division gives the angle which the line of sight made with the magnetic meridian, and is applied with the proper sign to the circle reading during observations. This reading and the reading of mark give the *magnetic* bearing of mark, and subtracting from the true bearing gives the declination. These observations should be repeated, if possible, on three successive days.

269. Should no magnetometer be at hand, a good value of the declination may be obtained with a surveyor's compass. The station must be chosen, as before, free from local attraction. With a theodolite observe a careful round of angles on from 10 to 15 objects, equally distributed around the horizon, and observe the true bearing of one of them. Replace the theodolite by the compass, and observe the magnetic bearing of each one. The true bearing of each being known, the variation is obtained for each object, and the mean will be the correct variation within 1′ or 2′. The compass admits of reading to 1′.

270. In all magnetic observations care must be taken to have no iron of any kind in the neighborhood of the instruments—magnets of dip circle, etc., must be removed not less than 15 metres, and the observer must be careful to have no knife, keys, metal buttons, etc., about his person; also that there is no iron work about the tent poles or pegs, and that all metal tools are placed at a safe distance.

271. The magnetic inclination or dip is measured by means of a dip circle, of which there are various patterns, the Kew pattern being the one in general use. The lower portion of the instrument is like a theodolite; azimuth plates, levels, and levelling screws. The upper portion consists of a vertical graduated circle, in front of which a needle swings on a horizontal axis in a plane parallel to the circle, the needle being enclosed in a glass case. A revolving arm attached to the circle carries two microscopes with cross-wires and verniers, by which the ends of the needle are observed and the circle read. The needles are flat, about 3″ long, $\frac{1}{4}$″ wide, pointed at the ends. Each one has a letter on one end and side, which are called "marked end" and "face" of the needle. To put it in adjustment the vertical axis is made truly vertical by means of the levels. Also, the plane of the circle and suspended needle should be vertical, and the prolongation of the axis of the needle should pass through the centre of graduation of the circle. This must be assured by the instrument-maker. The microscopes must be focussed on the needles and the wires set in the line of collimation, and they should form when joined by an imaginary line one continuous line through the centre of graduation. This adjustment is made by suspending a weighted silk fibre in the plane of the needles so as to pass over the centre of graduation. Two observations with the microscope direct and turned 180° on its axis will show the collimation error, and it is readily corrected. Finally, the plane of the needle must be in the magnetic meridian. This plane is found thus: Turn the case so it is at right angles to the meridian and suspend the needle, and then turn the azimuth screw until the needle points directly up and down. Read the circle and then reverse the needle on its supports, so the face that was S. may be N., and observe as before. Now turn the azimuth circle through 180° and observe again, reverse the needle and observe. The mean of these four readings +90° and −90° will be the settings of the azimuth circle when the needle swings in the plane of the magnetic meridian. There are two stops on the circle, which can be set so that the case with the needle can be quickly turned through 180° and back without noting the circle. In measuring dip the needle used must have its polarity changed during half the observations, to eliminate errors in the figure and the position of the centre of gravity of the needle. Lay the needle in the reversing block on a level and face up. Take two bar magnets in the hands, bring the opposite poles against the axle of the needle on either side, inclining them outward at an angle of about 30° to horizontal. The marked pole of one bar magnet must be on the N. end of the needle. Draw them slowly and steadily along the ends of the needle parallel to its axis (which is insured by a ledge on the reversing block), so as to reach the ends at the same time and continue beyond. Lift well above the needle, and repeat the operation three times. Now turn the needle face down, and repeat the entire operation. The end of the needle which is rubbed by the marked pole of the magnet will be a south pole. The bar magnets should be handled carefully and secured by soft iron armatures when not in use, and never allowed to come in actual contact.

If the polarity of the needle is to be reversed again very soon, more passes will be required, some to neutralize the existing magnetism, and others to remagnetize it. To neutralize any inequality in the bar magnets change them in the hands during half the operation, remembering, of course, to have the proper poles in contact with the needle.

272. The observations for dip are made in accordance with the annexed form.

MAGNETIC DIP.

STATION, WASHINGTON, D. C.

Date, November 10, 1853. Six-inch Barrow Dip Circle No. 2. Needle No. 1. Observer, S.H. Commenced 10ʰ 15ᵐ A.M.; concluded 10ʰ 33ᵐ A.M.

Mean, circle E. and W., 71° 13'.3.

POLARITY OF MARKED END NORTH.							
Circle East.				Circle West.			
Face East.		Face West.		Face East.		Face West.	
S.	N.	S.	N.	S.	N	S.	N.
° '	° '	° '	° '	° '	° '	° '	° '
71 24	71 08	71 08	71 31	71 08	70 50	70 56	70 42
26	03	08	31	00	58	54	42
71 25	71 05	71 08	71 31	71 04	70 54	70 55	70 42
71 15		71 19.5		70 59		70 48.5	
71 17.3				70 53.7			
71 05.5							
POLARITY OF MARKED END SOUTH.							
Circle West.				Circle East.			
Face West.		Face East.		Face West.		Face East.	
S.	N.	S.	N.	S.	N.	S.	N.
° '	° '	°	° '	° '	° '	° '	° '
71 12	71 17	71 05	71 05	71 41	71 30	71 43	71 18
11	17	04	04	45	25	44	20
71 11	71 17	71 05	71 04	71 43	71 27	71 43	71 19
71 14		71 04.5		71 35		71 31	
71 09.2				71 33.0			
71 21.1							
Resulting dip .... 71° 13'.3							

Mean, circle W. and E., 71° 13'.3.

NOTE.—The magnetic meridian was obtained by horizontal or compass needle, which was removed before commencing dip observations.

The observations are from the Coast Survey Report. "Circle E. or W." is when the vertical circle is E. or W. of the case; "face E. or W." is when the marked face of the needle is E. or W.; and the polarity of the ends of the needle calls for no explanation. N. and S. in the form are respectively the lower and upper ends of the needle (N. latitude). The zero of graduation should be on a horizontal line through the centre of the circle. By this system of reversals the resulting dip is freed from small remaining errors of adjustment and all errors due to irregular form of needle and defect in position of its centre of gravity.

273. Both the instruments just described are used in determining the total intensity and horizontal component of the earth's magnetic force, and the directions for these measurements are given in full in the Coast Survey Report for 1881, Appendix 8.

274. The deviation of the ship's standard compass is determined by the method of reciprocal bearings, as follows: An observer with theodolite and surveyor's compass lands, and occupies the summit of some slight elevation which will, if possible, always have a sky background. A small island that the ship may steam around is to be preferred, as then the theodolite will always bear abeam from the ship, and masts and rigging will not interfere with observations. As soon as the theodolite is in adjustment the angle to some prominent mark is observed, and then the instrument pointed at the ship, and a bluejacket with a large signal-flag stands behind the instrument to make a more prominent mark. He also has a binocular, and watches a flag at the ship's mast-head, telling when it is run up so the observer may sight on the standard compass on board. On board, the ship steaming slowly is steadied on such a course that she may safely turn in a circle from it, and when steady on the course a signal-flag is hoisted at the mizzen-mast-head. The compass bearing of the theodolite is observed by means

of an azimuth circle, and when accurate the word "mark" is given, the flag is dropped from the mast-head to half-mast, and the time noted, and the ship's head by Standard, time, and bearing of theodolite are recorded. The course is then changed one point to starboard or port, and when nearly steady the flag is mast-headed and when steady the bearing is observed as before, and so on for each of the 32 points. Then the operation is repeated and similar observations made on each point but in reverse order, i.e., turn with the other helm. When all the bearings have been observed the flag is hauled down as a signal for the shore observer that the work is finished.

275. On shore, as soon as the flag is reported at the masthead the theodolite is directed at the compass on board, and unless the ship is very close aboard, the flag at the mast-head will be in the field of view, and the motion of the azimuth screw, keeping the vertical wire on the compass, is stopped the instant the flag leaves the mast-head. The observer then notes the time by a watch previously compared with the one used on board ship, reads the theodolite and records time and angle, or an assistant may mark time and record. When the flag is reported up again the observer returns to the theodolite, gets his angle on again and observes as before. At intervals during the work the mark is pointed at and read to see that the adjustment of the theodolite remains perfect. When the flag is finally hauled down the observer takes a round of angles and determines the magnetic bearing of each object with the surveyor's compass, as described in finding declination. From each of these bearings the magnetic bearing of the *zero* of the theodolite is found and the mean bearing found. Then each theodolite angle is added to this mean bearing of zero, and the magnetic bearing of each observation found.

276. On returning to the ship the time columns of the two records are compared to see that no observations were missed. For these observations the time need be noted only to 5 seconds if the shore observer also records. Being compared, the magnetic bearing of the ship at each observation is entered in the column 4 of the form and the deviation written down at once, being the difference of columns 3 and 4. The deviation for S. helm on each course is then entered in the proper column and the mean taken.

1	2	3	4	5	6	7
Time.	Sh. Hd. by Standard. No.	Bearing of Theodolite.	Bearing from Theodolite.	Deviation P. Helm.	Deviation S. Helm.	Mean Deviation.

Two copies of this form are needed on board ship, one for P., one for S. helm. Only one has columns 6 and 7 filled out.

These mean deviations are then plotted on Napier's Dia-

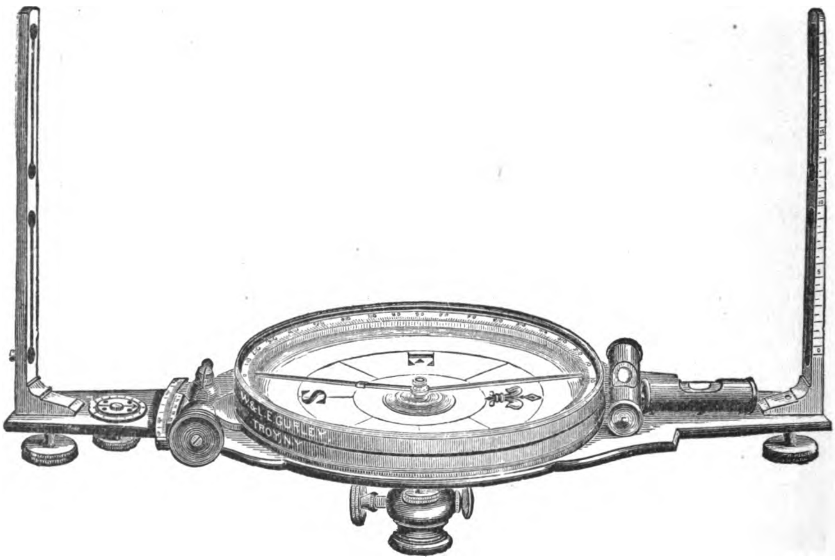
Time.	Theodolite angle.	Magnetic bearing.

Round of Angles.			
Object.	Theodolite angle.	Magnetic bearing.	Magnetic bearing of zero.
		Mean.	

These forms for observer on shore.

gram and a fair curve drawn through the points, and in nearly every case the curve will need very little or no *fairing*. These observations occupy about 2¼ hours, 2 minutes being the average time between observations. They are taken rapidly, because by swinging with both helms, the effects of residual magnetism are eliminated from the final result. If the *ship's head* by the steering or other compasses be observed at every observation, the deviation curves for those compasses may also be drawn.

277. Deviation tables for use on deck are made from the curves. A double table showing on one side the compass course for each magnetic course and on the other side the magnetic course for each compass course, both to quarter points, is most convenient.



S. RVEYOR'S COMPASS.

278. This is an instrument for taking magnetic bearings on shore more accurately than may be with the ordinary azimuth compass. Its appearance is shown by the cut. The instrument is shipped on a staff which is driven in the ground, and by means of the levels and the ball-and-socket joint is made level by hand, no screws being provided. The top then turns about the vertical axis. To use it turn it about the vertical axis until the object to be observed is seen through the two vertical slits in the sight-vanes, the vernier being set at zero. The arc N E S W being marked to degrees, if the needle points to an even degree, then the number of that degree E. or W. of north as shown on the face of the instrument is the correct bearing. If it points between two marks, by means of the tangent-screw turn the circle (which does not turn the vanes nor the needle) until the needle points to the first mark to the northward of its first position, then that number of degrees + the minutes shown by the vernier is the bearing from N.

The adjustments of this instrument are, to place the pivot in the centre of the graduated circle and make a straight line between the ends of the needle pass through the centre of the pivot. To do this, sight at any object bearing about N. or S. and make the N. end of needle coincide with an even degree, and if the S. end does not coincide with the mark 180° from this, make it do so by bending the needle slightly. Now turn the instrument through 180° and sight at the same object with the vanes reversed and see if the needle points to the same marks. If it does not, then half the error is due to the pivot not being central and half to the needle not being straight; so bend the pivot slightly E. or W. and bend the needle until it cuts the even marks. Reverse again and test this. Now repeat the operation, sighting on an object E. or W., and bend the pivot N. or S., and the instrument will be adjusted. The levels are adjusted as in a theodolite. The sight-vane at the S. mark on the circle is the *eye* end in all observations, though by taking each bearing with each vane as eye end the error of the pivot is eliminated. The needle must be made level by moving the balance ring which is on the south end to compensate for dip (in N. latitude).

279. While using the magnetometer it may happen that the scale reading of the axis varies from day to day and cannot be accurately determined at any time. This is caused by the scale being loose from unequal expansion of the glass scale and the brass ring holding the scale. It is remedied by pressing the edge of the ring down to the glass with any smooth-ended metal instrument, being careful not to break the scale.

CHAPTER XVI.

RUNNING SURVEY.

280. AT times it becomes necessary to survey a section of coast when time and other circumstances prevent a survey being made by the methods already described. The work is then done entirely by observations from the ship and boats while running along the coast, and the distances checked by astronomical observations at different points of the coast.

281. The ship being anchored near the end of the work, her position, latitude and longitude, is determined by sextant observations and a round of angles is observed, including all prominent natural objects in sight, tangents to islands, points, etc. Mouths of rivers and any marks near the shore line are observed on, to enable the boats to fix themselves when close in shore. The true bearing of one of the points is observed, also altitudes for working up heights of peaks, and the set and drift of the current are ascertained.

282. She then gets under way and steams along nearly parallel to the coast, on a range if possible, four or five miles, being careful as to steering, and measuring the distance by patent log. At the end of this base she anchors, and angles are observed on all the points angled on at the first station. If a launch is sent ahead to the second station while the ship remains at her first position, the first triangles will not depend on the compass course of the ship and the work will be more accurate. The launch anchors in the selected position and hoists a signal when swinging steadily to her anchor, and then angles on the objects on shore are observed, and the angle between one of them and the ship is observed.

283. On board ship the angle between the launch and one or more shore objects is observed. All these angles are taken in such a way that the angle between *any* two objects may be found by combining them. These observations being taken, the ship steams along to the launch's position and gets the record of the angles observed from her, and the plotting is begun at once on a projection already prepared.

284. The ship's position by latitude and longitude is plotted, and the line to the launch is laid off by its true bearing and mean logged distance, the launch's log and the ship's log over the same space forming two measurements. With this line as a base all the observed angles are plotted, the ship meantime steaming off-shore on a course about four points from the original line, fixing her position by the three-point problem every mile, using the points cut in. Soundings are, of course, taken on *all* lines, at intervals depending on the depth of water. At the end of five miles the ship anchors, or a number of simultaneous angles are observed on the original objects and to any new objects that may have come in sight along the coast. In this way she continues along the coast, running about five points from the direction of the coast off and on shore alternately, keeping between 2½ and 8 miles from the coast, fixing the positions of the ship by objects already located and cutting in objects ahead as fast as they come in sight, being careful to always have not less than four "*fixed*" objects in sight, and checking the positions at the ends of the lines by true bearings whenever the sun is in a favorable position, and, if possible, when at anchor for the night taking a true bearing by star observation in the twilight.

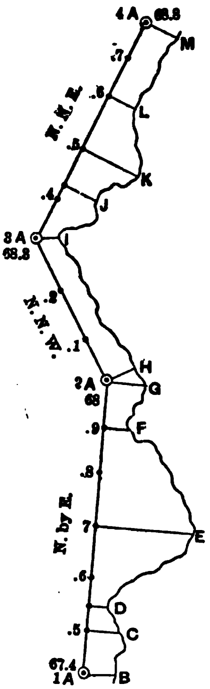
285. As the work proceeds the cuts will become more and more discordant, and the most probable positions for objects must be selected from the large number of cuts on each one, and experience alone can guide one in making the proper selection. At the end of about 50 miles of coast a latitude and longitude position by observation must be established and plotted, and between the two astronomical stations thus fixed the intervening coast is plotted and adjusted by working backwards and forwards, plotting and replotting, until the observed angles agree with the plotted positions as nearly as possible. The work is then continued along the coast in the same manner.

286. If it is possible to land at any point and occupy one of the stations and get a round of angles on a number of others, including the ship, the work will be much improved. If a base can be measured between any two stations and an astronomical position established, it will be of great assistance in the plotting. The more stations that can be occupied the nearer the survey approaches a triangulation survey and, of course, the more accurate it becomes.

If the ship can return as she came, running lines parallel to and half-way between the first series, any discrepancies may be corrected.

287. While the ship is working off shore, the launches, of which there should be two, are engaged running in the shore line and running a line of soundings about half a mile from the beach, fixing their positions by angling on objects near the coast which are cut in by the ship, and if necessary cutting in objects in the same way as described for the ship.

288. From the inshore launch the shore line is run in by course and distance, being careful not to change course without observing angles, and sounding at proper intervals. Suppose the boat starts at position 1*A* and sets course N. by E. On a small block of paper, about 10″ square, select near the lower edge any point, and with a horn protractor lay off a line across the sheet and call it N. by E., and write the *log-reading* abreast the position and call $\frac{1}{4}''$ = .1 mile. Estimate the distance to the shore abeam *B* and mark it. As the launch moves along, record each tenth on the line and estimate the distance to the shore line at every tenth and plot it, also recording the estimated distance on the sheet, and sketch in the shore line as well as possible, estimating the depths of bights and observing angles to tangents. On changing course estimate the distance in two directions, and in this way a fair approximation to the shore line may be drawn. The topography is also represented on the sketch by conventional signs or by words. When course is changed the new course is laid off in the proper direction from the last position on the original line, and the process carried on until the edge of the paper is reached, when it is continued on the next sheet, the sheets being numbered and the numbers entered in the record when changed. The launch keeps as near the shore as is consistent with safety, and all suspicious-looking places in the water, indicating shoals, rocks, etc., are examined, and outlying rocks cut in.



289. The final plotting is not done until the ship's work is plotted, and the plotting adjusted and settled. Then each position by angles is plotted and the spaces between laid off in proportional parts, and the offsets plotted by means of the scale of the projection, thus eliminating errors of compass direction and of distance run by log. Many minor points on the shore line may be cut in by two cuts, and thus the estimated distances checked. If the ship returns over the same ground, the launches may be employed in sounding within the

ship's lines, one of them running a line about 1½ miles off shore, and the other a zigzag line between ½ and 2½ miles from shore.

290. By these methods a very serviceable chart may be made in a short time. If any anchorages or harbors are discovered by the boats, they must be surveyed in the ordinary way by erecting and cutting in signals, running suitable lines of soundings, and running in the shore line by walking over it. The harbor is then connected with the rest of the coast by angles from the minor signals on those used in the main survey. If one or more distant peaks can be fixed by true bearings from two of the astronomical stations, the survey between those points may be made very accurately by observing bearings of these peaks and plotting the others from them and the observed angles. Should the work from the first astronomical station hold well together to the next one, it may not need replotting; but the position as plotted and the true position by observations must be made to coincide by adjusting the points as in a triangulation survey. Altitudes of prominent points are observed and their heights computed as already described.

291. Sketches or photographs of the shore from the different positions of the ship will be of great assistance to the draughtsman in putting in topography, and also for the views shown on charts to enable navigators to recognize the different parts of the coast.

CHAPTER XVII.

THE TRANSIT AND EQUAL-ALTITUDE INSTRUMENT.

292. IN finding latitude and time or difference of longitude two instruments have been used, the zenith telescope and portable transit. The former consists essentially of a telescope which may be made to revolve on its horizontal axis in the plane of the meridian, and which also turns on a vertical axis so as to point N. or S. of the zenith as may be desired. As this instrument is seldom found in surveying ships, and as the improved forms of transit instruments may also be used as zenith telescopes, further discussion of it is unnecessary.

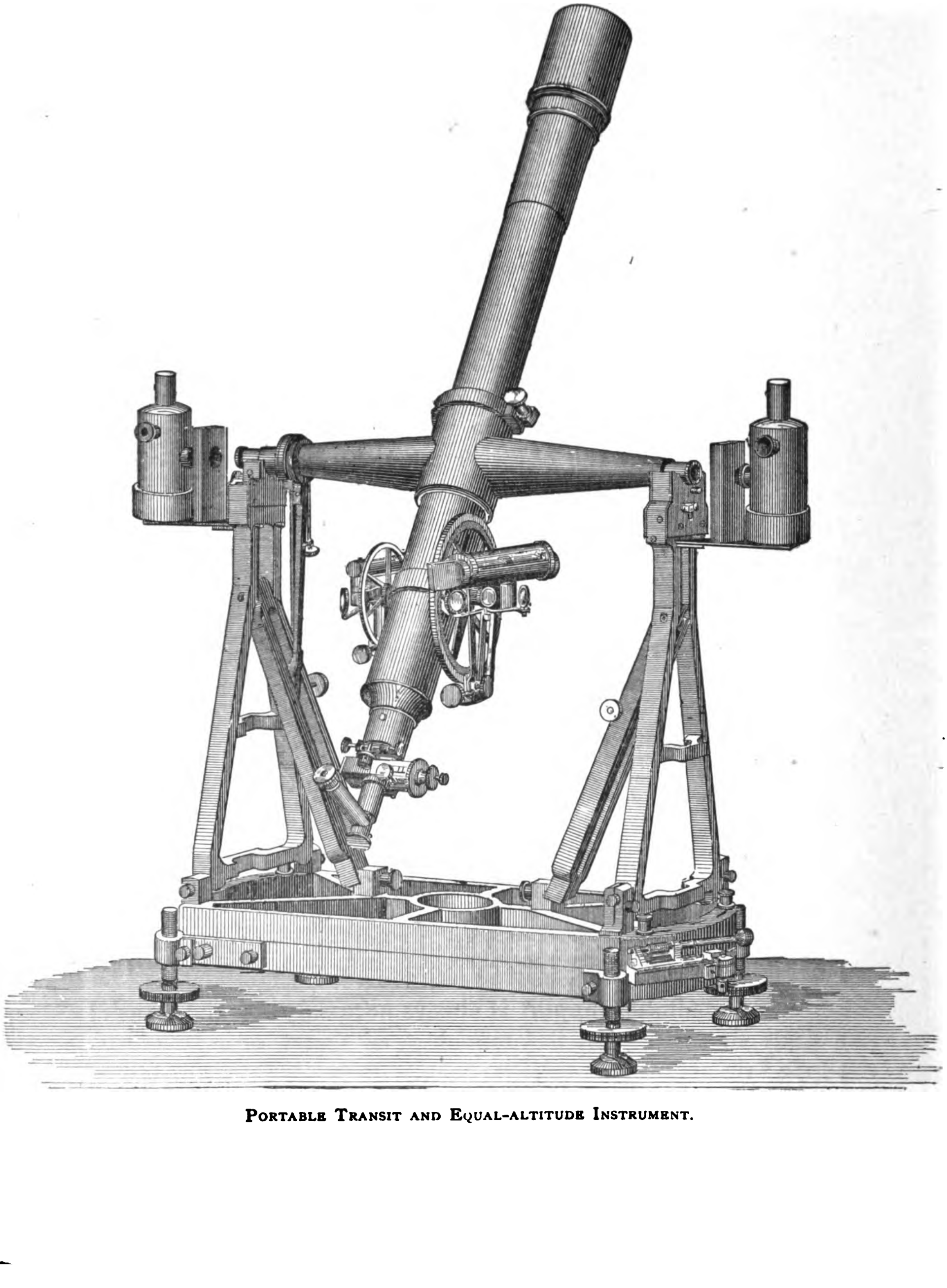
293. The simple portable transit is fitted with a telescope with 2″ objective, and of about 26″ focal length, which is fitted at its centre of gravity with an axis at right angles to its length. The extremities of this axis are supported in Y's on standards which rise from a rectangular base which is fitted with three foot-screws and levels for levelling. The base and standards are made very light and rigid, and may be folded very compactly for transportation. The axis is hollow, and lamps, supported on the standards at its extremities, serve to illuminate the field when taking night observations. Each of the Y's has a very fine slow-motion screw with micrometer head to give a slight and measured motion, one in a vertical direction and the other in a horizontal direction. A clamp and tangent-screw are fitted to one end of the axis to regulate the motion of the telescope. On either side of the telescope, near the eye end and firmly attached to it, are two graduated circles with two verniers having levels attached to the verniers. These are the "finders."

By setting the verniers to any given angle, and moving the telescope until the bubble is in the middle of the tube, the line of sight is placed at the given angle with the horizontal plane. Within the telescope is placed the diaphragm with the cross-wires. Glass diaphragms made very thin are much used, the lines being ruled on them and thus great permanency of lines and spaces secured.

294. The diaphragm usually contains 9, 11, or 13 vertical lines, which may be at equal distances apart but usually are arranged in sets, symmetrically placed with regard to the middle wire. Three horizontal lines also appear in the diaphragm. In addition there is a single wire that may be made to traverse the entire field by means of a micrometer screw. To avoid errors from parallax, from the eye not being directly over the thread, there is fitted a slide with a small circular opening which is moved by the observer successively over each wire or line. The diaphragm may be revolved in any direction necessary to place the wires vertical, and may be moved across the telescope to adjust for collimation. The striding level, having feet which rest on the extremities of the axis, is made very sensitive and has an accurately divided scale attached by which differences may be read. It is filled with ether and has a chamber to regulate the size of the bubble at all temperatures. A prismatic eye-piece is attached to facilitate observations at high altitudes.

295. The improved transit, known as the transit and equal-altitude instrument, differs from the one just described only in the supporting frame, which is made to revolve on a vertical axis and has a scale and micrometer attached to facilitate setting in the plane of the meridian. One of the finders is replaced by a larger circle finely divided, and a delicate ether level is attached for measuring altitudes.

296. A suitable support is always necessary for the transit; a stone or brick pier, a large block of wood, or a large flat-topped tree-stump are excellent when they are to be had. In



PORTABLE TRANSIT AND EQUAL-ALTITUDE INSTRUMENT.

the absence of these a pier may be made by driving four pieces of scantling firmly into the ground at the corners of a square, about 2′ apart, placing two of the sides of the square nearly in the direction of the meridian by a compass needle. Boards being nailed to these stakes, a box is formed which is packed full of rocks and earth and surmounted by a flat stone or heavy piece of wood, which is made as nearly level as may be. On this the frame of the instrument is mounted and placed so that the transit axis coincides as near as may be with the prime vertical. The adjusting screws of the Y's are placed in the middle of their runs, the telescope placed thereon, and the striding level placed on top of the axis. By means of the foot-screws the transit axis of the telescope is made level, the striding level being carefully adjusted, and the final levelling of the axis is done with the fine-motion screw of the Y. The lines are then placed in the focus of the eye-piece, placed vertical and the telescope adjusted to sidereal focus. The adjustment for collimation is made by sighting on a distant object or a mark that is put up, over the middle wire, turning the axis end for end and sighting again. Half the distance the wire appears from the mark is the error, which being corrected the adjustment is repeated, using a new object. A small alt-azimuth instrument may be used to advantage in finding the true bearing of an object, and thus facilitate setting the instrument in the meridian. The local time and latitude, if not approximately known, may be found with sufficient accuracy for adjustments with a sextant.

297. The middle horizontal wire may be placed in the axis of collimation of the instrument and the index error of the finders removed by sighting on an object on the same level as the telescope, placing the adjusted striding level on top of it in such a position that both its feet may rest on parts of equal diameter and bringing the line of sight horizontal by means of it. Turn the telescope over by reversing the axis and note where the wire falls, above or below the first object,

when the telescope is levelled. Move the wire half-way across the intervening space and check by another reversal, and then when level set the finder at 0° or 90° according as it is to read altitudes or zenith distances.

298. To point to any star compute its zenith distance by $z = L - \delta$; a positive value will indicate a star culminating S. of zenith, a negative value, a N. star. The chronometer time of culmination of a slow-moving star, i.e. one whose declination is nearly 90°, is computed, the telescope pointed to it, and the star bisected on the middle thread at the computed time of culmination by using the slow-motion azimuth screw of the Y. The star must not be too near the pole or its motion will be inconveniently slow. The axis having been levelled, two stars which culminate near the zenith but on opposite sides of it are observed, one with the clamp E., the other clamp W., i.e. with the axis turned end for end between observations. These observations will give a close approximation to the chronometer correction on sidereal time. The bisection of the slow-moving star may be repeated or a fast-moving star may be followed and bisected on the meridian, using only the azimuth motion of the Y. After these adjustments the telescope will generally be nearly enough in the plane of the meridian to admit of commencing the regular series of observations. The foot-screws of the base are secured, when the frame is in adjustment, by embedding them in plaster of Paris.

299. If the instrument could be placed in perfect adjustment so that the axis should be truly level and in the prime vertical, and the lines of sight and collimation coincident, then the time of a star's transit over the middle wire and over the meridian would be identical and the observations would be extremely simple. In practice, however, these adjustments may not be perfectly exact, and corrections must be found to apply to the observed times of transit to give the true time of culmination.

300. The series of observations for time commences with transits of stars for instrumental corrections, then the time stars are taken, and then more stars for instrumental corrections. The corrections mentioned are for three errors: the level error, caused by the transit axis not being truly level; the error in azimuth, caused by the transit axis not being truly in the prime vertical; and the collimation error, caused by the lines of sight and collimation not being coincident.

301. The deviation of the transit axis is found by level readings for each star, two readings being taken with the level in opposite directions. The inequality of pivots is also allowed for, being determined from four level readings, with axis and level reversed and direct. The value of a division of the level is found by a level trier if not known. It is secured to a large finely graduated circle in a vertical plane and the bubble made to travel from one end to the other of the tube, the arc of circle necessary to effect this being read with a micrometer.

302. The collimation error is ascertained by observing half the number of stars with the clamp E., and the other half clamp W. The azimuth error is ascertained by observing two stars differing considerably in declination but little in right ascension, or from two circumpolar stars differing nearly 12 hours in R. A., which may be observed at upper and lower culmination respectively. Knowing the reading of the Y azimuth screw for any two positions in which the azimuth error has been determined, the value of a division of the micrometer head is known.

303. The time of transit over the middle thread is not used alone in observations on account of the probable error of a single observation. The time of transit over each thread is observed, and these are each reduced to the mean thread, and the mean of all the times gives the mean time of transit. If the threads were at exactly equal intervals, the mean of all the times would be the same as the time of transit over the middle thread, but this not being possible, an imaginary mean thread

is used and all observations reduced to it and corrections computed for it. This mean thread is an imaginary thread in the field in such a position that the time of a star's transit over it is the mean of the times of transit over all the threads. The time necessary for a star with declination 0° to pass from any given thread to the mean thread is called the equatorial interval of that thread. To determine these intervals, select a complete transit of a star whose declination is considerable; then if $t_1, t_2, t_3, t_4, \ldots, t_n$ be the observed times of transit over the n threads, t_m their mean, and $i_1, i_2, i_3, \ldots, i_n$ their equatorial intervals, and δ the star's declination, we shall have

$$t_m = \frac{1}{n}\{t_1 + t_2 + t_3 + \ldots + t_n\},$$

$$i_1 = \{t_1 - t_m\} \cos \delta,$$

$$i_2 = \{t_2 - t_m\} \cos \delta, \text{ etc.},$$

and $$i_1 + i_2 + i_3 + \text{etc.} = 0.$$

Should a star be missed on some of the threads in an observation for time, the mean thread transit is found by

$$t_m = \text{mean of observed times} + \frac{\text{sum of intervals of missed threads} \times \sec \delta}{\text{number of observed threads}}$$

The rate of the clock must be allowed for in case it is large enough to affect the equatorial intervals.

304. The correction for inclination of the axis is found thus: Let w, e, w', e', represent the west and east readings of the level before and after reversal, d the value of one division of the level in seconds of arc, and b the level error representing the angle of inclination of the axis, which is + when W. end of axis is too high; then

$$b = \tfrac{1}{4}\{(w + w') - (e + e')\}\frac{d}{15} = \{(w+w') - (e+e')\}\frac{d}{60},$$

and the correction for this error in seconds of time will be

$$b \cos (L - \delta) \sec \delta, \text{ or } b \cos z \sec \delta = bB.$$

The factor B is tabulated for values of z and δ and is always positive excepting for stars at lower culmination.

305. The correction for error of collimation is found thus: Let c be the error of collimation in seconds of time. At upper culmination c is $+$ when the mean of threads is E. of the line of collimation for the axis in a given position, as clamp W. The correction then is $\pm c \sec \delta$ or $\pm c\,C$, the factor C being tabulated and $+$ for a star at upper culmination.

To find the collimation error observe a circumpolar star. Note the time of transit over half the threads, excluding the middle one. Reverse the axis of telescope and note the transits over the same threads in reverse order, observing the state of the level for each thread. Find the time of transit over the mean thread before and after reversal, correcting for inclination and rate if necessary, also for inequality of pivots, and let t and t' be these reduced times before and after reversal; then for upper culmination $c = \frac{1}{2}(t' - t) \cos \delta$, for position of axis before reversal.

306. The correction for deviation or azimuth error is found thus: Let a be the azimuthal error in seconds of time, which is $+$ when the line of collimation of the telescope is E. of S. The correction is $a \sin (L - \delta) \sec \delta = a \sin z \sec \delta = a\,A$. Values of A are tabulated for various values of z and δ, and are positive excepting for stars between the zenith and pole.

To find the azimuthal error, observe transits of two stars which differ considerably in declination. Correct the observed times of transit for rate, inclination, collimation, and pivot error, and let α, t, A, and α', t', A' be, respectively, the apparent R. A., mean times of transit, and azimuth factors for the preceding and following star; then

$$a = \frac{(\alpha' - \alpha) - (t' - t)}{A' - A}$$

307. The chronometer correction (on local sidereal time) is found from the observations of stars as follows: Having observed the transit of a star over each thread and noted the times, take the mean of them, which call t_m, as the time of transit over the mean thread. If any threads were missed use the formula of Art. 303 for the mean. Then if α is the R. A. of the star, Δt, the chronometer correction is found from

$$\Delta t = \alpha - (t_m + aA + bB + cC.)$$

308. In determining the latitude with this instrument the *difference* between the zenith distances of two stars culminating on opposite sides of the zenith is observed and the latitude found from $L = \frac{1}{2}(\delta + \delta') + \frac{1}{2}(z - z')$, where z' and δ' are for the northernmost star of the pair. The vertical axis of the instrument is made truly vertical by means of the foot-screws and the striding level, which should not change when the instrument is turned through 360° in azimuth and is also tested by the delicate level on the vertical circle. The transit axis is made horizontal by the striding level, reversing it until correct. The focus of the eye-piece and object-glass are adjusted. The reading of the horizontal circle when the line of collimation is in the meridian is found by bisecting a slow-moving star at its culmination, known by chronometer, and stops are then adjusted so that the telescope may point in the meridian either N. or S. The horizontal wire is made horizontal by noting an equatorial star running along it, or by pointing at a polar star and keeping it bisected when the instrument is turned in azimuth. The value of a division of the level on the vertical circle, and the angular value of a turn of the micrometer screw which moves a horizontal up and down the field, must be determined.

309. Pairs of stars whose zenith distances differ less than 20′ are selected, and when ready to observe, the telescope is set to the zenith distance of first star and the bubble of the

vertical circle brought to the centre. The telescope is placed with the line of collimation in the meridian and pointing on the side of the zenith on which the first star crosses. When the star appears in the field, everything being clamped about the instrument, pick up the beat of the chronometer and bisect the star with the movable thread, and keep it bisected up to the instant of culmination. Read the micrometer and both ends of the level on the vertical circle. Turn the instrument in azimuth until it points to the meridian on the other side of the zenith, and observe the second star in the same way. The clamp and screw of the vertical circle must not be touched, though the tangent-screw of the axis may need to be moved to bring the bubble near the centre when the axis is not truly vertical. The latitude is then found from the formula

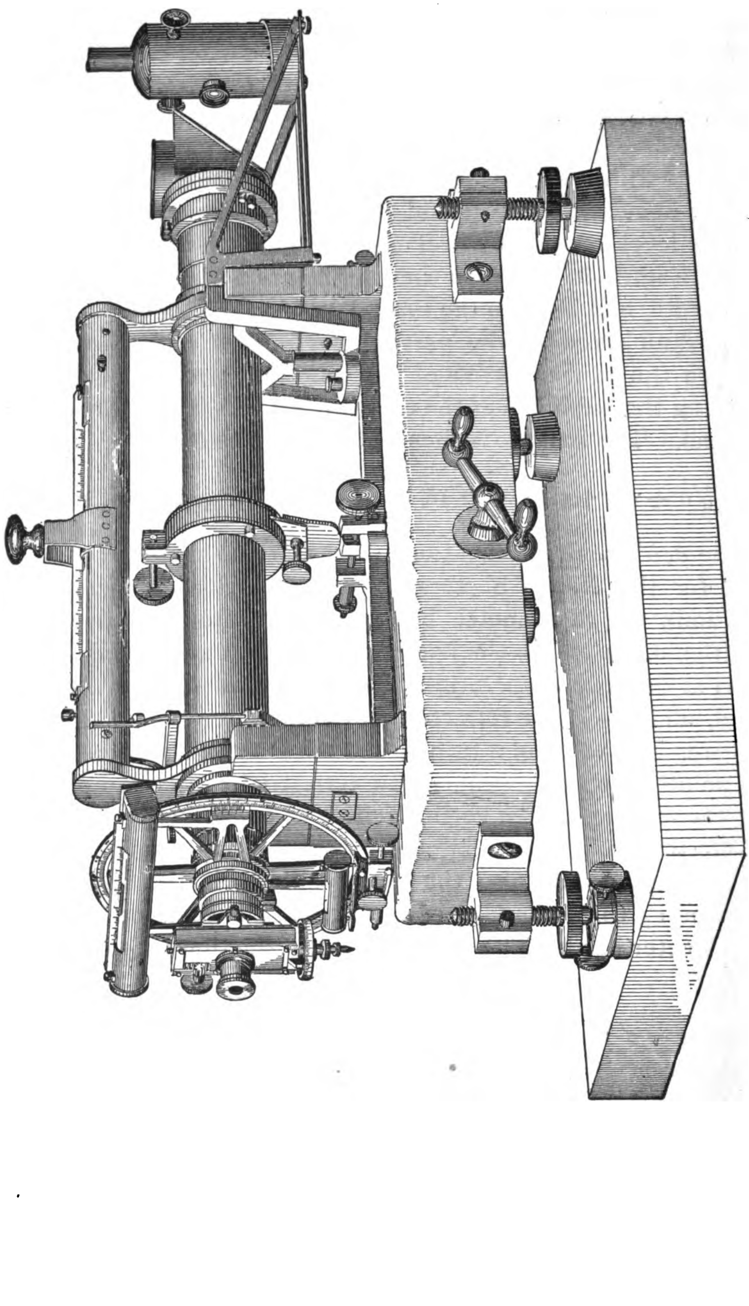
$$L = \tfrac{1}{2}(\delta + \delta') + \tfrac{1}{2}(M - M')R + \frac{b}{4}\{(n + n') - (s + s')\} + \tfrac{1}{2}(r - r'),$$

where δ, δ' are the declinations, M and M' the micrometer readings for the N. and S. stars respectively (R the value of one division), the micrometer being supposed to read *from* the zenith; n, s, n', s' are the readings of the N. and S. ends of the level at the two observations, b the value of one division of level, and $r - r'$ the refraction correction.

310. The value of a turn of the micrometer screw is found by pointing to some well-defined terrestrial object and observing the reading of the vertical circle when the wire is on opposite sides of the field, bisecting the object. The difference in readings, noting also the level readings, is the angle corresponding to the number of turns that have been made by the micrometer head. The correction for refraction is found from

$$r - r' = 57''.7 \sin(z - z') \sec^2 z,$$

where $z - z'$ is the angle measured by the micrometer, and z is the mean zenith distance. This correction is tabulated for different values of $z - z'$ and z.



PRISMATIC TRANSIT AND ZENITH TELESCOPE.

311. In refined observations which must be rigidly calculated, such as the telegraphic determination of longitude, there are other minute corrections which must be applied to the observed times. For a full discussion of the methods of reduction the reader is referred to the Coast Survey Report for 1880, Appendix 14, in which the subject is exhaustively treated.

312. A modification of the transit instrument is shown on page 212. It is very compact and portable, and of great use in mountainous countries. It is fitted for latitude work, as well as for observing transits for time. The horizontal axis is adjusted in the prime vertical and by rotation may be made to point to any zenith distance, so as to bring any desired star in the field when on the meridian. At one end of the tube is a prism almost in contact with the objective. Rays of light are reflected internally by this prism, and directed to the eyepiece at the other end of the tube. The usual diaphragm and micrometer are fitted to it with a lamp for illuminating the cross-wires, and there is a reversing apparatus by which the axis may be turned end for end.

"FINIS CORONAT OPUS."

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