INSTRUCTIONS FOR MAKING PILOT BALLOON OBSERVATIONS

CLIMATOLOGICAL SUBSTATION
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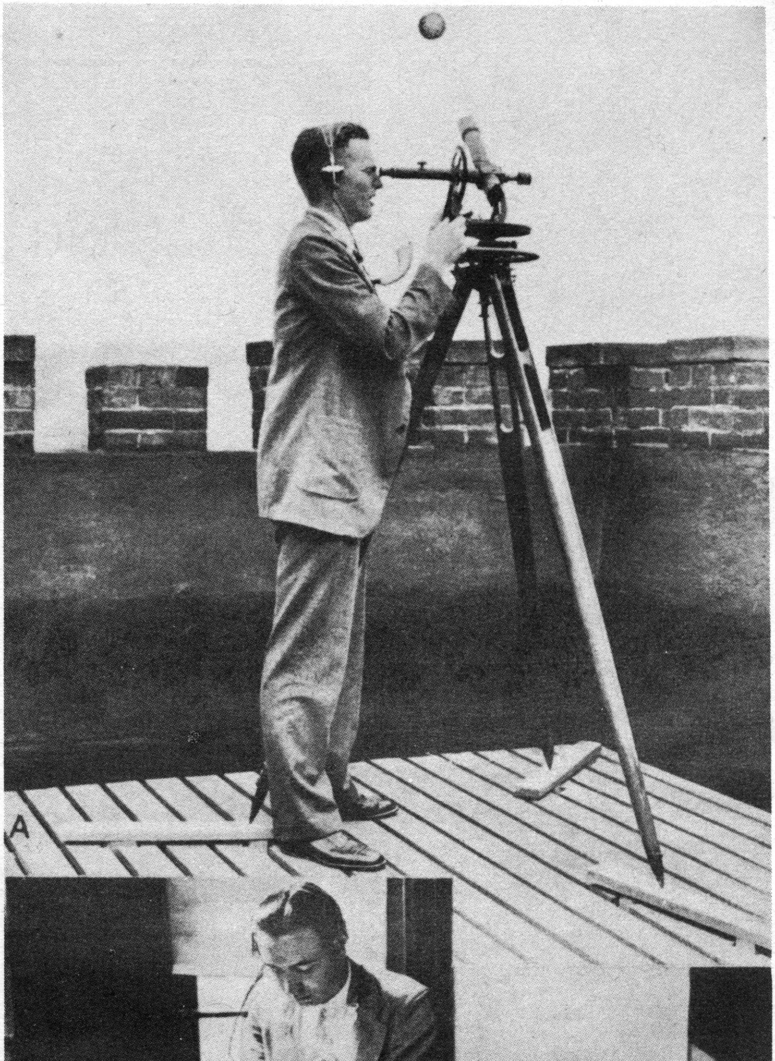
U. S. DEPARTMENT OF COMMERCE

WEATHER BUREAU



Pilot balloon observation. A, observer following balloon; B, computer at plotting board.

W. B. No. 1278

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CIRCULAR O, AEROLOGICAL DIVISION

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1942

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - Price 15 cents

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INTRODUCTION

As the original edition (1928) of this publication has become exhausted and numerous amendments thereto are necessary, it is deemed appropriate to publish a revised edition at this time.

Observations with pilot balloons are made for the purpose of determining wind direction and velocity at various altitudes; also the height, direction, and velocity of clouds whenever the balloons enter their bases. The apparatus and methods used are described in detail in the following sections. Briefly, the observations are made by following with a theodolite the flight of small rubber balloons filled with hydrogen or helium gas. The angles of azimuth and elevation are observed and recorded, and these data, together with the balloon's altitude at successive intervals of time, make possible the construction of a horizontal projection of the path followed and the determination from this projection of wind direction and velocity at various levels.

Pilot-balloon stations are of two kinds, viz, "single-theodolite" and "double-theodolite." Similarly, methods of observation are known as "single-theodolite" and "double-theodolite" methods.

By the first method the theodolite is set over a fixed point and oriented with zero azimuth on the south point. The ballon is assumed to rise at a constant rate of speed. Computation involving the ascensional rate, elevation angle, and azimuth angle determines the position of the balloon. By the double-theodolite method, two theodolites are homogously oriented (that is, with zero azimuth in the same direction), one at either end of a definite base line. Computation involving the length and bearing of the base line and the observed azimuth and elevation angles determines the horizontal position of the balloon and its height above the surface.

Since the two methods have so much in common, and since the majority of the stations now in operation are, and probably most of those of the future will be, of the single-theodolite type, these instructions will treat chiefly of the single-theodolite method. However, departures from this method applicable to the double-theodolite method will be fully considered herein.

In order to facilitate the work, most of the pilot-balloon stations of the Weather Bureau are equipped with portable telephones. (See frontispiece.) By their use the wind data may be obtained while the balloon is being followed.

I. STATIONS AND OBSERVATION POINTS

1. *Selection of observation point.*—The selection of an observation point for single-theodolite work will be determined by the following:

(*a*) Geographical location.
(*b*) Low horizon.
(*c*) Angular altitude of obstructions.
(*d*) Convenience to office.

In addition to the above, double-theodolite work will also depend upon—

(*e*) Base line, length, and bearing.
(*f*) Unobstructed view along base line.
(*g*) Common level of primary and secondary points.

2. The shape of the earth's surface and the obstructions on it influence the surface winds and the winds aloft in the lower levels. When the surface is abnormal or the obstructions are pronounced. the local influences will be met with through 1,000 or 1,500 meters in elevation. Therefore, if these modifying influences are so marked as to cause divergence from the normal wind conditions, the data obtained will be abnormal and local rather than normal and of the general wind circulation near the surface. And, since we are more interested in the conditions of the general circulation than of the local influences, a choice of station must be made which will give as nearly as possible wind data little affected by local influences.

3. An ideal observation point would be in the open, level country or on the crest of a slight rise. The ground should be firm and the position well removed from buildings and tall trees that might interfere with the line of sight upon the balloon. The maximum angular altitude of obstructions such as buildings and trees should never exceed 6° above the sensible horizon. Smokestacks and chimneys in close proximity to the station give much annoyance and should be avoided, if possible, since even slight amounts of smoke therefrom are sufficient to obscure the balloons.

The observation point should be as convenient to the administration office as satisfactory location will permit. In single-theodolite work this may well be on the roof of the office building or one near by. In double-theodolite work either primary or secondary point, and sometimes both, will necessarily be a little distance from the administration office.

4. The observation point for single-theodolite work may be any convenient point from which, as far as possible, an unobstructed view may be obtained. Since most of the administration offices are located in or near cities or large towns, satisfactory ground conditions with convenient location will seldom be found. The next in order will be a position on a flat-roofed, well-exposed building. In the selection of such a site due consideration must be given to superstructures such as towers, penthouses, cupolas, etc. Where it becomes impracticable to observe from the top of the superstructure itself, a position to one side of the structure, and sometimes one also on the opposite side, will answer. Many instances will arise in which the range of vision is affected only by the central structure. When this is not too high, the difficulty may be overcome by erecting upon the main roof a platform from which to observe, but, in general, two points of observation, one on either side, are preferred to one on top, inasmuch as

by the latter method stability and rigidity are likely to be diminished. In selecting the observation points on a roof having a central structure it is well to consider the prevailing wind direction for the station. The observation point should be selected on the leeward side and as far removed from the central structure as extent of roof will permit.

5. *Location of two-theodolite station.*—The geographical location of a double-theodolite station is not materially different from that of a single-theodolite station. Low horizon and angular altitude of obstructions have a similar application in either case. A double-theodolite station is provided with two theodolites, one at either end of a suitable base line. The station at which the balloons are prepared and released may be known as the "primary station," "home station," or "station A." The second may be known as the "secondary station," "field station," or "station B, C, etc." The system of base lines should be carefully laid out and should radiate from the primary station.

The major base line should be about 2,000 meters or more in length and nearly at right angles to the direction of prevailing wind for the station. Minor base lines should be laid out as nearly as possible in a direction that will afford the best possible results when the surface wind direction is other than the prevailing direction. Two base lines are sometimes sufficient, though three or more will afford a wider choice in selecting the base line at the time of observation to give the best results for the current wind conditions. A base line nearly parallel to the wind movement aloft is to be avoided.

6. The view along the base line from either station must be entirely free from obstruction. Each station must be in plain sight of the other in order to facilitate signaling the release of balloon at the primary station and the disappearance of the balloon at either station.

The angular elevation of obstructions at the secondary station, in the direction of the primary station, along either side of the base line must be low enough to prevent interference of line of sight upon the balloon as it moves away from the primary station in strong winds. Under ordinary conditions there will be little difficulty, but when strong surface winds prevail, especially if blowing across the base line, the change in azimuth angle will greatly exceed the change of elevation angle at the secondary station. Therefore the elevation angle at the secondary station for the first few minutes will be low.

7. The stations should be located at approximately the same elevation above sea level. In case they are not, computation becomes more or less complicated in certain instances. This matter is discussed in later paragraphs under "Computation."

8. *Marking observation point.*—The observation points, whether for single or double-theodolite work should be marked permanently. If the point selected is on the bare earth, an iron pipe about 3 feet long may be driven into the ground until quite rigid. A wooden peg is then set in the upper end of this pipe and a small nail or tack in the end of the peg marks the exact point of observation. If the position is on a graveled roof, the point may be marked by setting a small bolt or screw in cement over the point desired. Whenever it becomes necessary to use a platform for observation, a nail may be driven into the planking. Any method whereby the point is permanently marked is acceptable.

If the observation point is on the ground, it will be found convenient in leveling the instrument to have foot blocks on which to set the tripod. Holes should be placed in the blocks to receive the tips of the tripod legs.

9. *Observation platform.*—The theodolite platform should, if practicable, be so constructed that no vibration will be transmitted from it to the theodolite. This is accomplished by building a second platform or support for the theodolite, in such a way that there is a space and no immediate connection between the two. Figure 1 shows a section of such a platform and theodolite stand. Three posts in the form of an equilateral triangle, about 36 inches from center to center, are sub-

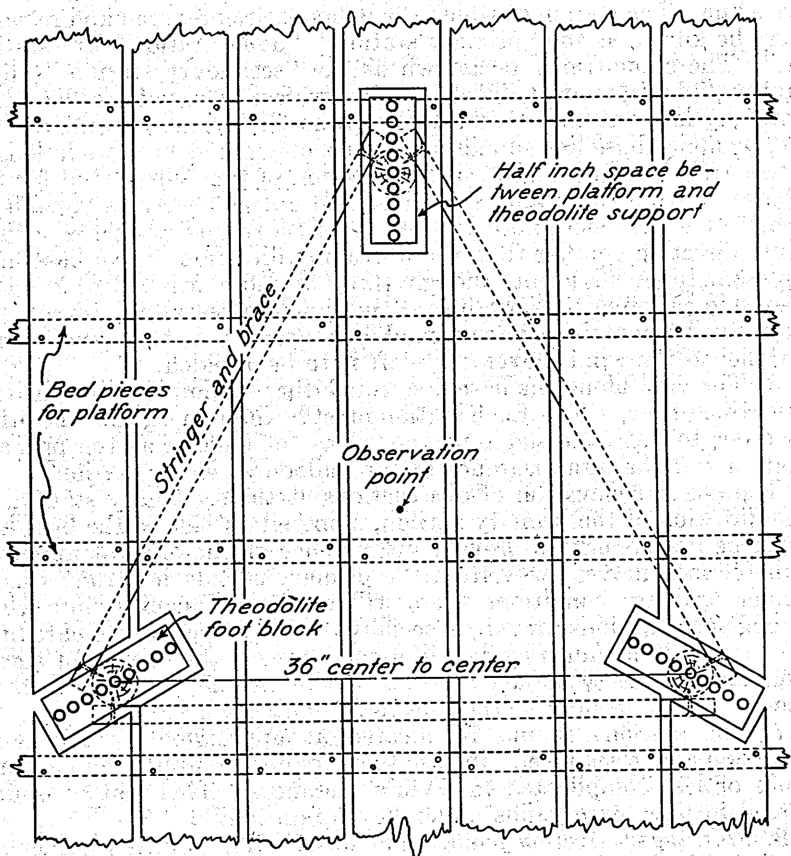

FIGURE 1.—Section of observation platform and theodolite stand, showing the insulation of the one from the other.

stantially arranged and rigidly braced. When secured about the observation point, caps for the theodolite foot blocks are placed over the posts in a common horizontal plane. The observation platform is then constructed with the upper surface of flooring flush with the top of the theodolite foot block but not in any way connected with the theodolite stand. A space of at least half an inch should be left between the two. The observation point will be the common center of this equilateral triangular inclosure. Brass plates, furnished from central office stock, are attached to each of the theodolite foot blocks.

These plates have a row of half-inch holes down the center for receiving the tips of the theodolite legs and for adjusting the height of the theodolite for different observers. The size and shape of the platform may be arranged to suit the needs of the station force, but the general scheme above outlines should be followed and the construction made as rigid as possible. Any plan wherein the observation platform is well insulated from the theodolite stand and rigidly constructed will answer. A suitable windbreak should also be built around the platform to a height of 5 feet, with a door on one side (preferably the leeward) for entrance to the platform.

II. THEODOLITES

10. *Description of theodolites in use.*—The theodolite, one type of which is illustrated in figure 2, is a specially designed and constructed instrument, similar in many respects to the transit, yet possessing distinctive features which make it far superior for balloon work. A small telescope is mounted in such manner that it turns on a horizontal axis, passing through the center of a vertical circle, and revolves about a vertical axis, passing through the center of a horizontal circle.

11. The telescope is bent through an angle of 90°. The eyepiece is produced through the angle of the bend to act as the horizontal axis of the telescope, while the object end turns freely in the vertical plane about this axis. In a cubical chamber about the right-angle bend of the telescope a prism, acting as a mirror, is rigidly fixed in such a position as to turn the line of sight with the bend of the telescope and give a clear, well-defined image. The eyepiece is further provided with cross hairs, stretched over a reticle for centering the objective. Focusing of the adjustable-focus type of telescope is accomplished by means of a rack and pinion gear. The *fixed-focus* type of telescope is automatically focused by means of the cross-hair focusing device on the eyepiece. The objective end terminates in a cylindrical sleeve, which acts as a sunshade to protect the object lens. The mass of both eyepiece and object end of telescope are compensated by counterweights, thus providing a free, even movement of little resistance.

12. The telescope is supported over the center of the horizontal plate by a yoke standard. A vertical circle for elevation and a horizontal circle for direction are provided for determining the relative movement of the telescope. Both vertical and horizontal circles are graduated in whole degrees. More accurate readings may be made by using verniers or micrometers which will be fully described in a later paragraph.

13. The levels are arranged on the horizontal plate, one parallel to the horizontal axis called the plate level, *PL*, figure 2, while the other, perpendicular to the first, is known as the standard level, *SL*, figure 2.

The instrument thus far assembled revolves about a vertical axis, whose bearing is a sleeve and spindle, at the center of a graduated horizontal circle known as the base plate. An extension of the vertical axis, or the sleeve and spindle, passes through the shifting center and terminates in a spring and knurled nut to form the shifting center tension. The base plate is capaable of revolution about this center but is ordinarily held in a rigid position by plate clamp screw, *P*, figure 2. The shifting center, *S*, assembled with and encircled by a

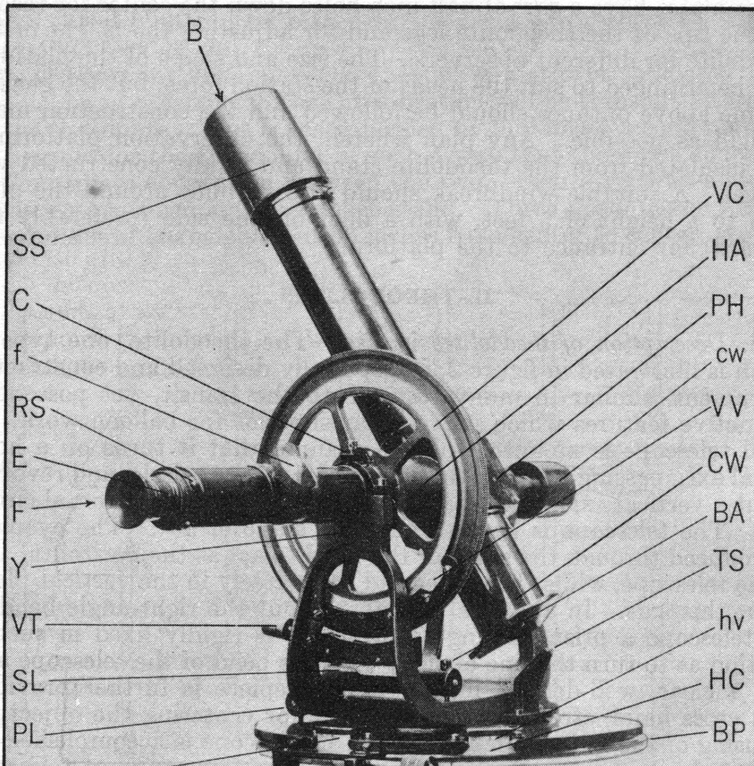

FIGURE 2.—Theodolite used in balloon work (*B*, back of instrument; *BA*, bubble adjustment screw; *BP*, base plate; *C*, cap or cover block; *CR*, clamp ring; *CW*, back counterweight; *cw*, front counterweight; *E*, eyepiece; *f*, focusing screw; *F*, front of instrument; *H*, carrying ring; *HA*, horizontal axis; *HC*, horizontal circle; *hv*, horizontal limb and right or 45° vernier; *HV*, horizontal limb and front vernier; *HT*, horizontal tangent screw; *L*, leveling clamp screw; *LS*, leveling screws; *p*, plumb bob hook; *P*, plate clamp screw; *PL*, plate level or bubble; *PH*, prism housing; *RS*, reticle screws; *S*, shifting center; *SL*, standard level or bubble; *SS*, sun shade; *ST*, shifting center tension; *T*, tripod head; *TS*, telescope stop; *VA*, vertical axis; *VC*, vertical circle; *VV*, vertical limb and vernier; *VT*, vertical tangent screw; *Y*, yoke standard).

heavy ring or handle, *H*, is supported above the tripod head, *T*, by means of three leveling screws, *LS*. Each leveling screw is provided with a tension or clamp screw, *L*. Pendent from the vertical axis and center of instrument *VA* is a small chain and hook, *p*, for the attachment of a plumb bob or anchor rod.

14. *The vernier.*—Essentially, the vernier, figure 3, *hv*, consists of a small graduated scale the unit divisions of which are just a certain amount smaller than the divisions of the scale upon which it is applied. This is accomplished on the circles of the theodolite by taking a space equal to 9°, laying it off on the vernier, and dividing it into 10 equal parts. In figure 3, drawing *A*, let *HC* be the horizontal circle divided into degrees, and *hv* the horizontal vernier. Note that while the zero of both *HC* and *hv* are coincident, the tenth division of *hv* is coincident with only the ninth division on *HC*. Thus, each division

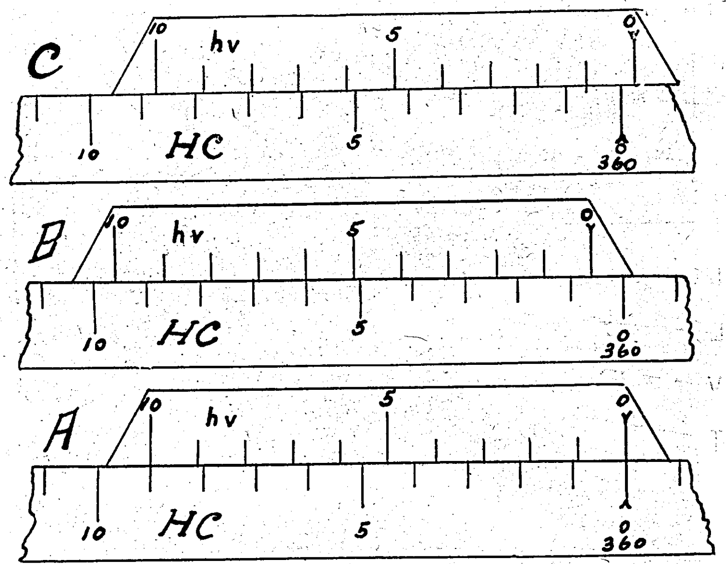

FIGURE 3.—Theodolite vernier.

of *hv* is one-tenth degree less than each division on *HC*. When two such scales are placed together, some particular line of the one will always be coincident, or nearly coincident, with one of the divisions on the other. The position of the coinciding divisions, or the nearly coinciding divisions, determines the vernier reading. For example, when the third, fourth, or sixth division of *hv* is coincident with some division on *HC*, the fractional parts of degree will be 0.3, 0.4, or 0.6, respectively. On drawing *B* of figure 3 the vernier reading is 0.6 of a degree, and on drawing *C* it will be noticed that no one division of *hv* is coincident with any other of the scale *HC* but that the seventh and eighth of *hv* are both between two of the divisions of *HC*, which shows that the vernier reading is more than 0.7 and less than 0.8 of a degree. The second place of the vernier reading must be gained by estimating the fractional part of one of the vernier divisions, which is represented by the space between 6 on *HC*, and 7 on *hv*. In drawing *C* of figure 3, this space is about half of one-tenth, or 0.05 of 1 degree. Thus we see the vernier reading in this particular case is 0.75 of a degree, which, added to the index reading of the scale, determines the degrees and hundredths. The practical application of these verniers is shown by the sectional view of the theodolite in figure 4. The accompanying table gives the reading of each vernier in figures 3 and 4.

	VV	*HV*	*hv*
Figure 3 A			0.00
Figure 3 B			.60
Figure 3 C			359.75
Figure 4	85.71	00.00	315.00

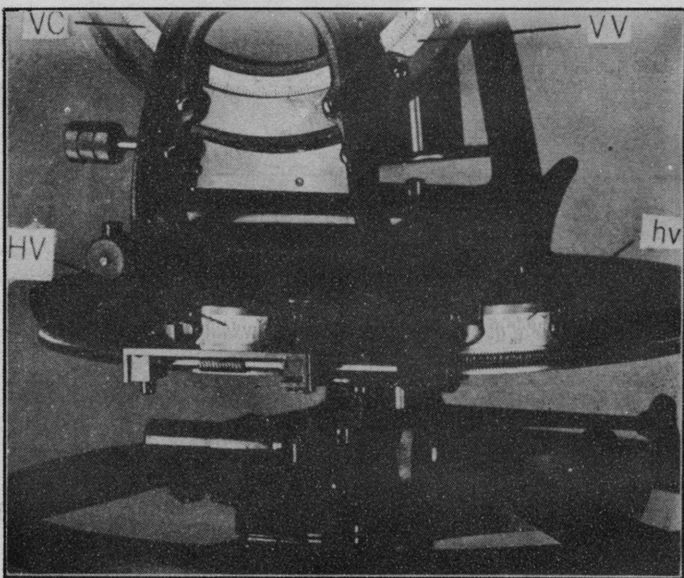

FIGURE 4.—Section of theodolite showing arrangement of verniers with horizontal and vertical circles (*HV*, horizontal limb and front vernier; *hv*, horizontal limb and right or 45° vernier; *VC*, vertical circle; *VV*, vertical limb and vernier).

15. *Micrometers.*—Some of the theodolites now in use are equipped with micrometer drums instead of verniers for the one-tenth degree readings. The drums are graduated to tenths of a degree and the graduations numbered from 0 to 9. In reading such instruments the nearest whole degrees are read from the circles and the tenths directly from the micrometer drums.

16. *Assembling the theodolite.*—Assuming that the crates have been removed and that no damage has been done either in shipping or unpacking, the tripod will be opened up and planted firmly upon the floor with legs well spread and securely set to prevent slipping. Loosen the milled tension nut of the shifting center, figure 2, and run well down to the knurled head of spindle. Then remove the round wooden cap. Loosen the shifting-center nut or clamp ring, *CR*, fig-

ure 2, and adjust the shifting center *S*, so that the seats of the leveling screws, *LS*, are symmetrically arranged over their respective plates of the tripod head, *T*. After tightening the clamp ring to retain the shifting center in that position, the tripod is in readiness for the instrument itself. If the tripod has the screw-thread type head it is necessary only to unscrew and remove the cap to make it ready for the instrument.

17. With the older type of instrument it will be found that the telescope has been removed from its bearings and packed in a separate rack in the case above the carriage. When so packed, remove the telescope rack and lower carriage from the case and remove the base of the instrument from the lower shelf by unscrewing the thumb nut on the underside. To place the telescope in position on the yoke standard, remove the caps or cover blocks, *C*, set the telescope on the standard, and then replace the cover blocks. In this operation great care should be taken that the screws or blocks are not interchanged. To avoid this, markings have been made on the tops of the standards and the bottoms of the blocks. See that these markings agree before fastening the blocks on the standard. Make sure that the telescope is firmly set in its bearings, replace the caps or cover plates in the same position as that from which they were removed. Turn in the screws firmly, but do not force them. Under no consideration should the leatherized bushing screw at the middle of the cover plates, or the Y-block screw on the underside of the left bearing, be touched at this time. These materially affect the adjustment of the instrument and should not be disturbed. (In packing the newer-type instruments the telescope is not separated from the standard, and in unpacking them, therefore, it is necessary only to slide out the shelf to which it is attached and unscrew it from the shelf.) Next, replace the brass cap on the object end of the telescope with the aluminum cylinder, or sunshade, found in a back corner of the shipping case. The function of this shade is to protect the object lens, and the instrument should never be used without it. Direct rays of the sun or strong light will cause the cement between the sections of the object lens to run to one side, causing a "fern leaf," which interferes with the visibility through the lens. The cap on the axis of the telescope, just above the right horizontal tangent screw, is now removed. The eyepiece is taken from its rack in the back of the shipping case, freed from its protecting cap on the lower end, and is screwed to the axis of the telescope in place of the cap which was just removed therefrom. On the newer lightweight type of instruments the eyepiece is not removed in shipping.

18. The assembled instrument is now lifted from the supporting rack and carefully placed upon the tripod, making sure (on the old-type instruments) that the chain and hook, p, figure 2, drop straight through the hollow spindle of the shifting center, *ST*, and that the three leveling screws, *LS*, are properly seated in the grooves in the respective arms of the shifting center plate. Insuring that the tension nut is run down well to the knurled end of the spindle, the shifting center tension, *ST*, is now raised until the threaded socket engages the threaded end of the vertical axis, *VA*, and turned on securely. The tension nut is then run up on the spindle to compress the spring and hold the instrument firmly on the tripod. However, the nut must not be run up too far, so that there is no room left between the

turns of the spring for equalizing the adjustment of the leveling screws. (If the instrument is of the type which has the screw-thread tripod head, it is attached to the tripod by simply screwing it onto the threaded tripod head.) The theodolite is now completely assembled and, after adjustment and checking, will be ready for observation work.

19. *Packing the theodolite.*—Whenever it becomes necessary to ship the theodolite, a great deal of care must be given to the packing and preparation for shipment. The packing cases in which the instrument and tripod are received should be preserved for this purpose. If the style of case used necessitates the separation of the telescope from the standard and base plate, the preparation of the instrument for packing is accomplished by reversing the instructions given in the paragraphs under "Assembling the theodolite." In addition (on the type having a screw-thread drive), the horizontal tangent screw, *HT*, figure 2, is to be thrown into mesh with the base plate, *BP*, and secured there by wrapping and tying a short length of string about the horizontal tangent screw, *HT*, and the telescope stop, *TS*. The vertical tangent screw, *VT*, should be disengaged and the base clamp, *P*, loosened. Place the assembled standard and base plate, which has been secured to the auxiliary shelf for that purpose, in the bottom of the case so that the right horizontal vernier, *HV*, is about midway and toward the front of the case. With the older type of instrument the telescope, with sunshade and eyepiece, is then laid in its supporting rack and placed in the upper part of the shipping case, with a piece of folded paper inserted between the telescope tube and the stay blocks on the underside of the top of the packing case. After closing and locking the door, fasten the key securely to the case. Each theodolite should be packed in its own case; that is, the case bearing the same serial number. The shipping case containing the theodolite must be substantially crated before shipment.

20. *Care of the theodolite.*—The theodolite, being a delicate and costly instrument, should be given particular care and attention. It should never be left standing without the assurance (1) that the instrument is securely fastened on the tripod; (2) that the tripod is well opened; (3) that the legs are firmly planted to prevent slipping—a slight pressure of the foot upon the projecting plate of the tip of the tripod leg will accomplish this; and (4) that on windy days the theodolite should not be left standing unless there is some means of securing it to the surface. All instruments purchased during the past few years have tripods equipped with anchor rods, or chains, for that purpose. Those not so equipped may be fastened by means of ordinary screen-door hooks and eyes. The hooks are fastened to the (inner) side of the tripod legs, near the bottom, and the eyes are screwed into the platform. A theodolite should always be fastened by one of these methods whenever it is left standing alone. When left standing between observations the instrument should also be protected from dust and weather by covering with the special cover furnished by the central office for that purpose. Should it become necessary to remove dust or moisture from the object lens, only a clean, dry chamois or soft cloth should be used. In case the lens cap is removed, care should be taken that it is screwed firmly in place again. On instruments having the screw-thread type of drive, special attention should be given to the tangent screws of both the

vertical and horizontal circles. A little light clock oil, in *limited* amounts and applied properly, will eliminate much friction and reduce the wear on the base plate. Close examination of the instrument from time to time will reveal small parts and screws which have become loosened. These should be attended to immediately, so far as possible without interference with proper adjustment; that is, if the parts which have become loosened materially affect the adjustment, it will be necessary to readjust and check the instrument after such parts have been tightened.

21. The instrument is not to be taken apart more than is necessary for packing and shipment. Further, taking apart for the purpose of cleaning or repairs should be done only by one experienced with the construction of the instrument, or by a competent person, and upon the receipt of authoritative instructions from the central office.

Care should be taken that the hands do not come in contact with silvered surfaces of the circles or the verniers, for the moisture and oil thereby deposited tend to oxidize the surfaces, making the graduations indistinct and difficult to read. If these parts do become tarnished they may be brightened to some extent with a soft rubber pencil eraser, or better, with a good grade of silver polish.

22. *Adjustments of the theodolite.*—Before the new theodolite is used it must be thoroughly adjusted and checked. This is done at the

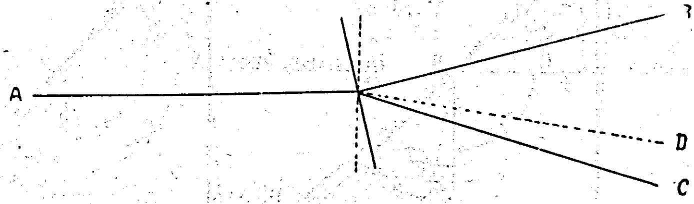

FIGURE 5.—Collimation adjustment.

central office before the instrument is assigned to any station. However, due to rough handling in shipment, it becomes necessary to recheck and sometimes to readjust the theodolite at the field station. An instrument in daily use should be checked occasionally—at least once every 3 or 4 months. If the initial adjustment is carried out carefully and accurately, these periodic corrections will be slight if at all noticeable, yet they should not be neglected. Each time the theodolite is adjusted a statement to that effect should be entered under "Notes" on Form No. 1110A–Aer. for the succeeding observation.

When the theodolite adjustment has been completed, the entire series of tests should be gone over as a means of checking. It will often be found necessary to make slight corrections which exemplify the need of much attention during the initial adjustment. Before making any one of the adjustments, note that the instrument is properly seated at leveling screws and that the horizontal base plate is level. Check for levels before each of adjustments 2, 3, and 4 is attempted.

23. The adjustments of the theodolite are such as to cause (1) the instrument to revolve in a horizontal plane about a vertical axis, (2) the line of collimation to generate a vertical plane through the instrument axis when the telescope is revolved on its horizontal axis, (3) the horizontal axis of the telescope to be perpendicular to the verti-

cal axis, and (4) the vernier on the vertical circle to give true readings of the angle of elevation of the line of collimation. These results may be brought about by the following adjustments:

24. (1) The plate-level adjustment: To make the axis of each plate level lie in a plane perpendicular to the vertical axis, bring one of the level tubes in line with two of the leveling screws. Level the leveling screws, revolve the instrument 180° in azimuth, correct one half the movement of the bubble on the leveling screws and the other half by raising or lowering the adjustable end of the level tube. Now level up again and revolve 180°, and the bubbles should remain in the center. If not, adjust for one-half the amount, as before, and so continue until the bubbles remain in the center for all positions.

25. (2) The collimation adjustment: To make the line of sight perpendicular to the horizontal axis of the telescope. When this is done the line of sight will generate a plane when the telescope is revolved on its horizontal axis. Set up the theodolite on level ground where a view can be had in opposite directions. (If the reference

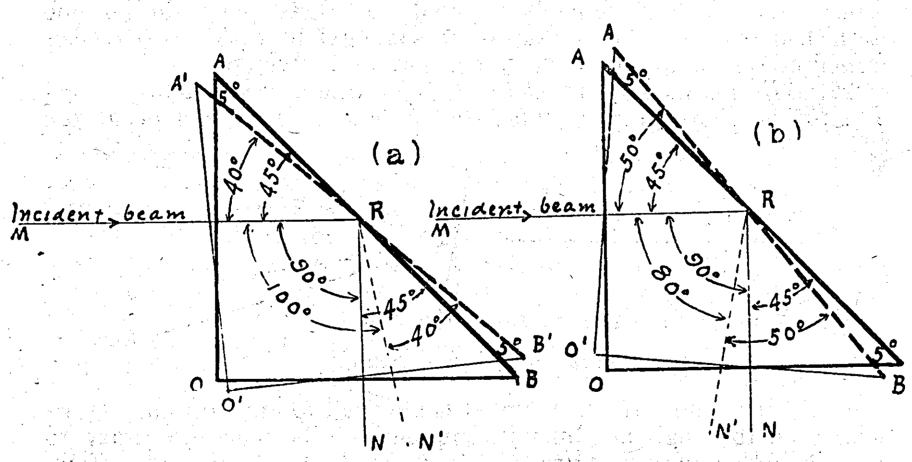

FIGURE 6.—Effect of prism on line of sight.

points selected are not level with the theodolite, or nearly so, a small error will be introduced into this test.) With the telescope pointing to the left, set the line of sight on a definite point *A*, figure 5, a few hundred feet away. Revolve the telescope about its horizontal axis and set another point *B* in the opposite direction. Now rotate the instrument in azimuth until the line of sight comes upon the first point *A*. Revolve the telescope about its horizontal axis again and fix a third point *C* on the line of sight beside the second point *B*. From the last point set, measure off one-fourth the distance between these two points to a point *D* and bring the line of sight to this position by moving the reticle laterally. This movement is reversed in the theodolite, as it is an inverted instrument. This adjustment should be repeated as a check.

26. It is often found that the line of sight cannot be brought to position without moving the reticle too far from the center of the tube. In this case adjustment must be made on the 45° glass prism which is placed in the cube at the axis of the telescope for the purpose of deflecting the line of sight at right angles. Unless the reflecting surface

of the prism makes an angle of 45° with the incident beam of light, the deflection is no longer at right angles, but may be either greater or less than 90°, depending upon the relative position of the prism.

27. Before attempting to adjust the prism, first determine whether the angle of deflection is greater or less than 90°. This may readily be done from the above test. If point *C*, the last point set, falls to the left of point *B* (the observer facing the points), the angle of deflection is apparently less than 90°. If it falls to the right of point *B*, the angle of deflection is apparently greater than 90°. The reverse of the above is actually true, however, because of the fact that the theodolite inverts the objects. In the first case the angle of deflection is in reality greater than 90°, and the prism must be moved so as to increase the angle made by its reflecting surface to that of the incident beam of light. In the second case the angle of deflection is in reality less than 90°, and the reflecting surface must be moved so that it will make a smaller angle with the incident beam. In figure 6 (neglecting the effects of refraction of light in the glass) (*a*) shows position of prism with reference to incident beam of light to cause deflection greater than 90° and (*b*) position to cause deflection less than 90°.

28. To make this adjustment, the prism must be removed from the telescope. This is accomplished by removing the small brass

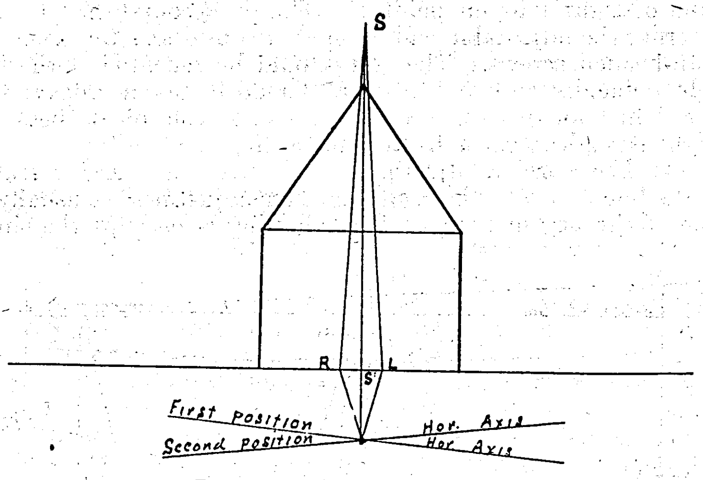

FIGURE 7.—Horizontal axis adjustment.

screws from the plate covering the cube at the axis of the telescope. The prism is attached to this plate and is removed with it. Two set screws hold the prism in position on the plate. Its reflecting surface may be moved with reference to the line of sight by loosening one set screw and tightening the other. Care should be taken not to overadjust the prism, for a glance at figure 6 will show that any movement in the reflecting surface to the incident beam of light will be doubled in the reflected rays. In this instance, the assumed movement of 5° in the reflecting surface produces 10° difference in the angle of deflection. Insofar as the deflection of the line of sight is concerned, the 45° prism produces the same effect as a plane mirror placed in the position of the reflecting surface of the prism. Any refraction that is produced at the entrant face of the prism is nullified by corresponding refraction on emergence of the ray of light. In the later type of instruments, equipped with a 45° prism, adjustment of the prism can be accomplished by means of outside screws, which make it unnecessary to remove the prism from the telescope. With such instruments it is usually more convenient to make even slight collimation adjustments by moving the prism rather than the reticle. Most of the newer theodolites are equipped with pentagonal prisms which do not require adjustment as they always give a 90° angle of deflection of the line of sight.

29. (3) The standard adjustment: To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument, carefully level the theodolite and sight on some high point, as a steeple *S*, figure 7, lower the telescope and set a point *R*, below *S*, on about the same level as the instrument. Revolve the telescope about its horizontal axis and turn the instrument upon its vertical axis and again sight at *S*. Lower the telescope as before and set a point *L* opposite *R*. A point *S′* midway between *R* and *L* must be in the same vertical plane with *S*. If the telescope is now set on *S′* and raised to the elevation of *S*, the line of sight will fall on a point directly above the first point *R*. The low end of the axis is on the same side of *S S′* as the point *R*. Now adjust the horizontal axis until the line of sight falls on point *S*. This is accomplished by raising or lowering the adjustable end of the horizontal axis by means of the capstan-headed screws. The test should be repeated until the line of sight coincides with *S S′*. Care should be taken to leave the cap screws tight enough to insure that the axis rests on its bearing but not tight enough to cause friction in turning the axis.

30. (4) The vernier adjustment: To make the vernier read zero when the line of sight is horizontal. This adjustment is usually made by one of the peg methods. The following is perhaps the simplest:

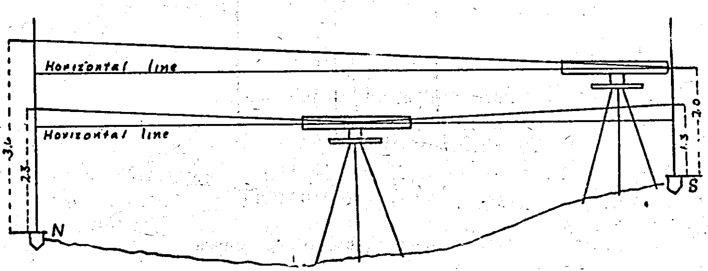

FIGURE 8.—Peg adjustment.

The instrument is set up exactly midway between two pegs *N* and *S*, figure 8. Care should be taken that the vernier setting is not disturbed while making this test. With the vernier set on zero, the instrument is sighted on a rod placed on *N*, and the point marked 1. Then it is sighted on the rod placed on *S*, and the point marked 2. Even if out of adjustment the points 1 and 2 are in the same horizontal plane. The instrument is next set up near *S* so that looking through the telescope with the eye of the object end, a point 3 is marked on the exact center of the small field of view. Now a point 4 is placed on the rod the same distance above or below point 1 as point 3 is above or below point 2. The instrument is now sighted on the rod when placed on *N;* if in adjustment the line of sight should fall on point 4. If in error, set line of sight on point 4, then shift the vernier and carefully adjust it to read zero in the new position.

31. *Setting up and leveling theodolite for observation.*—Place the theodolite over the observation point so that the base plate of the instrument is nearly level and centered over the exact point selected. To do this, see that the tripod is well opened, with legs firmly and symmetrically implanted about, and equidistant from, the exact point. It is well to arrange the theodolite, when setting up for observation, with plate clamp screw, *P*, figure 2, on the opposite side of vertical axis, *VA*, from the orientation point which is being sighted upon. The significance of this will be understood later.

32. To level the theodolite, turn the telescope upon the horizontal axis *HA*, figure 2, until it is about perpendicular to the base plate (the vertical circle set at or near 90°, see reading of *VV*, fig. 4). Disengage the horizontal tangent screw *HT*, figure 2, and turn the instrument about its vertical axis until one of the levels, preferably the standard level *SL*, is parallel with the line joining any two of the leveling screws, *LS*. See that the shifting center tension spring is sufficiently loosened to allow ample adjustment of leveling screws, then bring the bubble between the marks of the standard level by turning the two leveling screws in opposite directions; that is, both in or both out as the occasion demands. While in this position, adjust plate level, *PL*, by raising or lowering with third leveling screw. If necessary, relevel the instrument by the above method, noting that each bubble is equally spaced between the marks on the appropriate tube. Now turn the instrument about its vertical axis successively through 90°, 180° and 270°, and observe that the bubbles are still in the central positions. If they are not, then return the telescope to the initial position and readjust until this is accomplished.

33. The theodolite now being leveled, turn the instrument about its vertical axis until either the front horizontal vernier, *HV*, figure 2, or the 45° or right horizontal vernier, *hv*, figure 2, (depending upon which vernier is to be read), is set on the azimuth bearing of the reference point, then lock by throwing in the horizontal tangent screw, *HT*. Set the vertical circle of the telescope at or near zero, loosen plate clamp screw and turn the locked telescope and base plate about the vertical axis until the telescope is sighted upon reference point of orientation, accomplished by means of the ball and *V* sights along the main tube of the telescope. Be sure that the azimuth setting on base plate for the particular reference point has not been disturbed, then lock base plate to the horizontal axis by tightening the plate clamp screw *P*.

Upon sighting through telescope, if it is found that intersection of cross hairs is not coincident with reference point, raise or lower by means of the vertical tangent screw, *VT*, and shift horizontally by means of the slow-motion or base-plate adjustment screw. This final horizontal adjustment must not be made with the horizontal tangent screw, since this would disturb the orientation setting of the particular reference point.

34. Adjustment of the eyepiece, by turning the aperture disk either in or out, to obtain the maximum sharpness of cross hairs, and focus-

ing the telescope by use of the rack and pinion, will complete the orientation and setting of the theodolite for observation work.

35. *Orientation of theodolite.*—In single theodolite work the azimuth should be set on zero when the telescope points toward the south.

In double-theodolite work, both instruments are set with zero azimuth along the base line that is, the thedolite at station *A* is set with 0° on station *B*, and the theodolite at station *B* is set with 180° on station *A*. This method of orientation greatly simplifies computation as will be brought out in a later paragraph.

However, before orientation can be accomplished, the exact position of the north point must be determined.

36. *Determination of north point.*—Three methods are here given for the determination of the north point. The first method is by the culmination of Delta Cassiopeia and Mizar, the second by setting on Polaris, and the third by determining the time at which the sun is on the meridian.

37. The culmination method is much the simplest of the three, requiring neither computation nor tables; it is necessary to know only the approximate time of culmination. However, during certain periods it will be inconvenient to determine the north-south line by the culmination method, due to clouds obscuring one or both constellations, or culmination occurring at a time when the sky is so well lighted that the stars can not be seen.

38. Whichever method is used, the theodolite must be in perfect adjustment and the actual point of observation selected and permanently marked. The observer's watch will be compared with the standard of time in local use, and corrections made as become necessary. The theodolite will be placed centrally over the point to be determined. Much care and attention should be given to adjustment and leveling of the instrument and determination of angles. All angles should be read to the nearest hundredth of a degree when extreme accuracy is desired.

In either the first or second method, it will be necessary to provide a means of illuminating the cross hairs. Any method whereby a beam of light can be reflected or thrown into the object end of telescope giving sufficient illumination to set forth the intersection of cross hairs and not flood the field with light to the extent that the image of the star is lost will answer the purpose.

39. *First method.*—Delta Cassiopeia is the lower left-hand star in the constellation Cassiopeia, figure 9, when this constellation is in the position of the letter "W". During culmination this star crosses the north-south line 10 minutes in advance of Polaris and at the same time as Mizar, or the middle star in the handle of Ursa Major. These two stars mentioned are on opposite sides and nearly equidistant from Polaris. Culmination of these two stars occurs twice in 24 hours, and is followed within 10 minutes by Polaris crossing the same meridian. These facts, with the aid of an instrument, afford a simple means of determining the north-south line.

40. Having determined the approximate time of culmination of Delta Cassiopeia and Mizar, the theodolite is set over the exact point for which the meridian is to be determined, and leveled very carefully. It is well to do this while it is yet light. Be sure that the base plate is firmly locked and that both vertical and horizontal tangent screws can be turned freely without resistance. Sight the telescope upon

some prominent point, as the tip of church spire, peak of gable roof, sharp corner of building, etc., and note the azimuth reading of this point. Take particular care that all subsequent azimuth readings during this observation are made from the same horizontal vernier. A little time before culmination occurs, say half to three-quarters of an hour, a little practice should be gained by sighting upon the upper of the two stars and rapidly shifting the sight to the lower one. By the time culmination occurs, if the practice of raising and depressing telescope has been carried out, the observer will have gained considerable proficiency in the act, and the final movement at time of culmination will be performed with little or no difficulty.

41. Have the cross hairs illuminated as mentioned above and the telescope properly focused. Engage both vertical and horizontal tangent screws and bring the intersection of the cross hairs centrally over the star in question. Quickly note the readings on the respective verniers and rapidly depress the telescope to elevation of the lower star by turning the vertical tangent screw, but do not disturb the horizontal tangent screw during the depression. The lower of the two stars will appear to the left of the vertical cross hair, but it will gradually approach the vertical hair as the time of culmination is approached. Raise the telescope to the upper of the two stars again, reset, read the angles from the same two verniers, and immediately depress the telescope, as before. Repeat the foregoing operation until it is observed that the lower of the two stars also falls upon the vertical cross hair when the telescope is depressed. When this is obtained, raise the telescope to the altitude position of Polaris, *but do not disturb the azimuth setting* or the result of the observation will be of no avail. As a check, note that Polaris culminates just 10 minutes after the culmination of Delta Cassiopeia and Mizar. Note and record the azimuth setting, then depress the telescope to sight upon some conveniently accessible object where a distinct point coincident with the intersection of cross hairs will be placed. This point so placed will be true north.

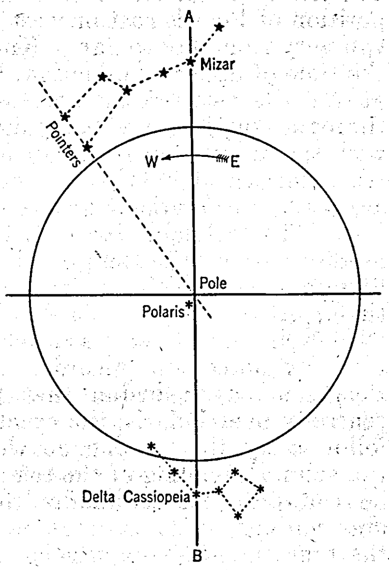

FIGURE 9.—Constellations of Ursa Major and Cassiopeia.

Example 1: Suppose the theodolite is first sighted upon the cross of a church spire to the right of north, and the azimuth bearing, read from the right horizontal vernier, is 126.15°. Let 98.4° be the reading from the same vernier when Delta Cassiopeia and Mizar are in culmination. The difference between these two readings will give the angle at observation point between true north and the reference point, or the bearing of reference point from north: 126.15°−98.4°= 27.75°; thus, when theodolite is set up with zero of base plate on north, the azimuth bearing of cross on church spire will be 27.75°.

But, if the theodolite is set up with zero of base plate on south (which is Weather Bureau practice), then the azimuth bearing of the church spire will be 180° more, or 207.75°.

42. *Second method.*—Polaris, in its apparent counterclockwise revolution about the pole, takes 23 hours 56.1 minutes of our regular 24-hour day, thus culminating or crossing the meridian twice in 24 hours, and nearly 4 minutes earlier each day. From this we see that the position of Polaris east or west of the meridian for any specified time will vary from day to day. Knowing the correct local mean time and the time of upper culmination, the hour angle of Polaris (or the angle at the pole between the north-south line and the hour circle passing through Polaris) may be found. From the hour angle of Polaris, with the aid of the American Ephemeris and Nautical Almanac, the true azimuth of Polaris may be easily computed. The observations are made on Polaris at any convenient time after it becomes visible.

43. The theodolite is carefully set and leveled over the exact point of observation as in the preceding method, the cross hairs are likewise illuminated, and the watch compared with the correct local mean time. After the base plate is locked, the telescope is sighted upon some well-defined point as a reference mark, and the azimuth reading carefully noted and recorded. The telescope is then trained upon Polaris, and at the instant that the intersection of cross hairs is brought centrally over Polaris, the exact watch time to seconds is first noted, followed by the reading on the same azimuth vernier from which the azimuth reading of the reference point was made. All angles will be read to the nearest hundredth of a degree. A series of three or more observations, 10 to 15 minutes apart, should be taken as a check on the first and the computation as a whole. The final result of each computation should be no more than 0.02 or 0.03 of a degree from the mean result.

Example 2: On July 2, 1919, in lat. 42°27′ N., long. 76°29′ W., or 5 h. 06 m. earlier than Greenwich, a series of three observations was made at 8 h. 42 m. 00 s., 8 h. 55 m. 00 s., and 9 h. 10 m. 00 s., seventy-fifth meridian time. The base-plate reading of the right azimuth vernier, when sighted upon a definite point on the left of north, was 189.64°. The azimuth readings from the same vernier when sighted upon Polaris during the observations were 237.80°, 237.89°, and 237.98°, respectively.

Date, July 2, 1919. Position, lat. 42°27′ N., long. 76°29′ W.—5 h. 06 m. earlier than Greenwich.

	H.	m.	s.	H.	m.	s.	H.	m.	s.
Time of observation (St. 75th)	8	42	00	8	55	00	9	10	00
Earlier than seventy-fifth meridian		06	00		06	00		06	00
Local mean time	8	36	00	8	49	00	9	04	00
Reduction to sidereal time (A. E. and N. A., table III)		+01	25		+01	27		+01	29
Sidereal time mean noon Greenwich, or right ascension of mean sun this date (A. E. and N. A., for Greenwich mean noon)	6	37	54	6	37	54	6	37	54
Correction for long., 5 h. 06 m. 00 s., (A. E. and N. A., table III)		+00	50		+00	50		+00	50
Local sidereal time	15	16	09	15	29	11	15	44	13

Apparent right ascension of Polaris this date (A. E. and N. A., apparent place of stars)	H. 1	m. 31	s. 35	H. 1	m. 31	s. 35	H. 1	m. 31	s. 35
Hour angle of Polaris before upper culmination	10	15	25	10	02	25	9	47	25
	H.	m.		H.	m.		H.	m.	
Same in decimals of minutes	10	15.42		10	02.42		9	47.42	
Azimuth of Polaris at this hour angle and latitude (A. E. and N. A., table IV)		39.58			44.23			50.29	
Same reduced to degrees		.66			.74			.84	
Observed azimuth of Polaris		237.80°			237.89°			237.98°	
True north on base plate		237.14°			237.15°			237.14°	

44. Accepting 237.14° as the direction of true north when the theodolite is set with 189.64° on the reference point, the bearing, or horizontal angle between the reference point and true north, will be the difference between 237.14° and 189.64°, or 47.50°. Now, then, with the zero of base-plate setting on north, the azimuth bearing of the reference point is 360°, minus 47.50°, or 312.50°. In preparation for an observation the *theodolite setting* on this point would be 132.50.°

45. *Third method.*—The south point may be determined by pointing the theodolite at the sun at true solar noon. To do this it will be necessary to protect the object glass with a piece of smoked or colored glass. In order to determine the time the sun crosses the meridian, the observer must ascertain the exact difference between the standard time in use at his station and the true local time. To this difference must then be added or subtracted, as the case may require, the so-called equation of time, which is the number of minutes before or after local noon at which the sun passes the meridian. The equation of time (Mean—App.) for Washington may be found in the Nautical Almanac or in Circular D, Instrument Division. When the equation of time is +, the sun is slower than the clock and the specified number of minutes must be added to the true local noon time to give the time at which the sun passes the meridian, and, similarly when the sign is —, the number of minutes must be subtracted from local noon.

For example, suppose the south point is to be located at some station on October 3, and where the local time is 24 minutes faster than standard time in use—

Difference between standard and local time is —24′00″ (use + when standard meridian is east of station and — when west).

Equation of time, October 3	= —11′ 00″
Total correction	= —35′ 00″

Therefore the sun will be exactly on the meridian at 12 o'clock minus 35 minutes = 11.25 a. m., and if the theodolite is pointed at the sun at this time it will be pointing due south. Of course the north point is found by reversing the telescope of the instrument.

Note that the equation of time as given from Greenwich is App. — Mean. In this case the signs must be changed before it is applied.

46. *Orientation points, base lines, etc.*—When the true north point has been determined, the bearing or azimuth of reference point from the north point with at least two or three others at different distances from the observation point should be determined. These points with their bearings from north will constitute the orientation points of

the station. A plan of these points will be constructed to some convenient scale and mailed to the central office for file along with a brief description of the arrangement of equipment, obstructions to view, etc. At two-theodolite stations an additional report will show the length, bearing, and arrangement of base lines, and the exact altitude of all secondary stations. A copy of the above reports should be retained for the station record.

Note that the bearing of orientation points and base lines should always be measured in degrees from the north toward the right. In orienting the theodolite for an observation, however, the azimuth angle must read zero, or 360.0°, when the telescope points toward the *south*. Consequently the *theodolite setting* on all orientation points will be 180°, plus or minus the bearing of these points from *north*. A list and diagramatic plan of the theodolite setting on all orientation points should be posted in the balloon inflation shelter and a copy kept in the station file for reference.

III. PILOT BALLOONS

47. *Size, color, etc., of balloons.*—The balloons generally used in pilot-balloon work are 6 inches in diameter when uninflated and weigh approximately 30 grams. They are of five different shades—uncolored, or pure gum, yellow, orange, red, and black. They are manufactured in such a manner that they are without seams and are nearly spherical in shape when inflated. An extension of the longer axis, about 2 inches in length, forms the neck or appendix through which inflation is accomplished. When these balloons are inflated to ascend at the rate of 180 meters per minute, they will ascend at a fairly constant rate up to 15 or 16 kilometers. For higher ascensional rates larger balloons are used, weighing approximately 100 grams each.

48. *Selection of color of balloon for observation.*—The proper color of balloon to use for a particular observation is determined by the appearance of the sky. When the sky is free from clouds, a pure gum balloon gives the most satisfactory results. This is true, even when haze, smoke, or dust is present in the lower levels, due to the fact that this type of balloon gives the maximum reflection of sunlight, which is the most important factor in observing balloons to great distances. When the sky is partly or completely overcast with thin cirrus clouds, giving a white or gray background, yellow or orange balloons are best suited for the condition. In this connection it is desired to point out that there seems to be a tendency on the part of some observers to use the yellow or orange balloons when there are no clouds but when haze, dust, or smoke are present. As previously stated, it is believed that the pure gum balloons will, on the average, give better results in such cases. The red balloons are best adapted for all-round use. However, they are most easily seen against a background of white or gray clouds. The black balloons should be used when the sky is completely overcast with clouds or when the portion of the sky serving as a background is overcast. They are also found to be especially satisfactory for observations made in the early morning, just before sunrise. In general, the uncolored, yellow, and orange balloons are to be used upon comparatively clear days when there is assurance that the sun will shine on the balloon throughout the ascension, and the red and black balloons are to be used on days when clouds form the background for the observation.

49. *Patching balloons.*—Occasionally balloons, when received from the manufacturers, will be found to have small "pinholes." In some cases such holes may develop during inflation due to small "air bubbles" or other defects. These defective balloons should not be discarded, but can and should be patched for use on days when clouds are low or a short observation is anticipated for any reason. Pieces of burst balloons, with ordinary rubber cement, may be used for this purpose. Better results are obtained when the patch is placed on the inside of the balloon.

50. *Coloring balloons.*—Occasions may arise when the supply of colored balloons will become exhausted. One of the uncolored type may be satisfactorily colored in the following manner: Take a small quantity of printer's ink, red, blue, or black as desired, and add a sufficient quantity of linseed oil to make a thick sirup or paste. Place a small quantity of the mixture within the balloon and knead until the color is evenly distributed over the inside.

51. *Deterioration of pilot balloons.*—Pilot balloons deteriorate rapidly with age, especially during the summer months. If possible, they should be kept in a cool place of more or less even temperature. As far as possible, the balloons should be used while fresh, and when a new supply of balloons is received at a station the old supply should be exhausted before the fresh ones are used.

52. *Ascensional rate of pilot balloons.*—The ascensional rate of the 30-gram pilot balloons is determined by the following formula:

$$V=72\left(\frac{l}{L^{2/3}}\right)^{5/8}$$

which may also be written

$$V=72\left(\frac{l^3}{L^2}\right)^{0.208}$$

wherein

V=ascensional rate in meters per minute.
l=the free lift, or the actual lifting force in grams of the inflated balloon.
L=the total lift, or the free lift, l, plus the weight of the balloon.

53. It has been found that the altitudes of balloons, as determined by the above formula, agrees best with the actual altitudes (i.e., for 30-gram balloons with a free lift of 125 grams) if the rate of ascent for the first minute be increased by 20 percent, the second and third minutes by 10 percent, and the fourth and fifth minutes by 5 percent. These additive corrections are used by the Weather Bureau.

54. To provide more wind information for higher levels without increasing the observation time, the use of larger (100-gram) pilot balloons was recently inaugurated by the Weather Bureau. They have been used, thus far, for only the 5:00 p. m. (E. S. T.) observations at a selected list of stations, but the extension of their use to all stations and all observations is contemplated. The following *tentative* ascensional rate formula for these balloons has been developed:

$$V=22.7\left(\frac{l^{1/2}}{L^{1/3}}\right)^{2.32}$$

This formula has not as yet been completely verified, except for a limited range of free lifts. A free lift of 450 grams with hydrogen gas or 503 grams with helium is now being used, however, which have been determined quite definitely to give an ascensional rate of 280 meters per minute. For observations made with these balloons (with such free lifts) the additive corrections to the ascensional rate for the first 5 minutes are: 25, 14, 10, 7, and 4 percent, respectively.

55. For higher free lifts the tentative ascensional rates of the 100-gram balloons, when inflated with helium gas, are as follows:

Free lift (grams)	600	700	800	900	1,000	1,100
Ascensional rate (meters per minute)	311	342	371	394	417	432

56. *Inflation of balloons.*—The balloon may either be filled to a convenient size and the ascensional rate determined from the weight of the balloon and the free lift, or the ascensional rate may be decided beforehand and the proper free lift given to the balloon. The former method is known as "indefinite" inflation, and the latter method as "definite" inflation. The ascensional rate in either case may be readily determined from table 2. Definite inflation can be accomplished only with the aid of some filling apparatus, which should be sufficiently sensitive to register the weight of the balloon and the free lift to the nearest whole gram.

57. Balloons should always be inflated in a well-ventilated place, but one well sheltered from drafts and currents. The presence of these disturbances, though small, materially affects the determination of the proper ascensional rate.

58. *Inflation balance.*—The Weather Bureau has adopted a standard ascensional rate of 180 meters per minute for the 30-gram balloons. The proper inflation is accomplished by means of a special inflation balance shown in figure 10. This is an ordinary gram balance, which is adapted for this use by placing a hydrogen line on the balance which terminates in a nozzle on one of the balance pans for attaching the balloon. The ordinary weighing bar is replaced by a special bar upon which are engraved two scales, one above the other. The lower scale is an ordinary gram scale for weighing the balloon, the upper scale is graduated in accordance with the ascensional rate formula, in this case to give an ascensional rate of 180 meters per minute. For other ascensional rates, different graduations must be made for this scale.

59. The graduations of the ascensional rate scale are based on the principle of moments, thus $(M-l)\ a=rx$, where M=the mass of the counterweight; l=free lift of the balloon; a=10 cm. lever arm of balance; r=20 gram rider; and x=distance in centimeters graduation is from the fulcrum.

60. In order to allow greater range for the lower scale (gram scale), the right-hand pan of the balance is weighted in such a manner as to throw the zero point on the bar under the left-hand knife edge.

61. A three-way stopcock is placed in the gas line in order that gas may be released in case the balloon is accidentally overfilled.

62. This balance may be used also for the inflation of larger balloons, such as the 100-gram pilot balloon, in which case it is equipped with an

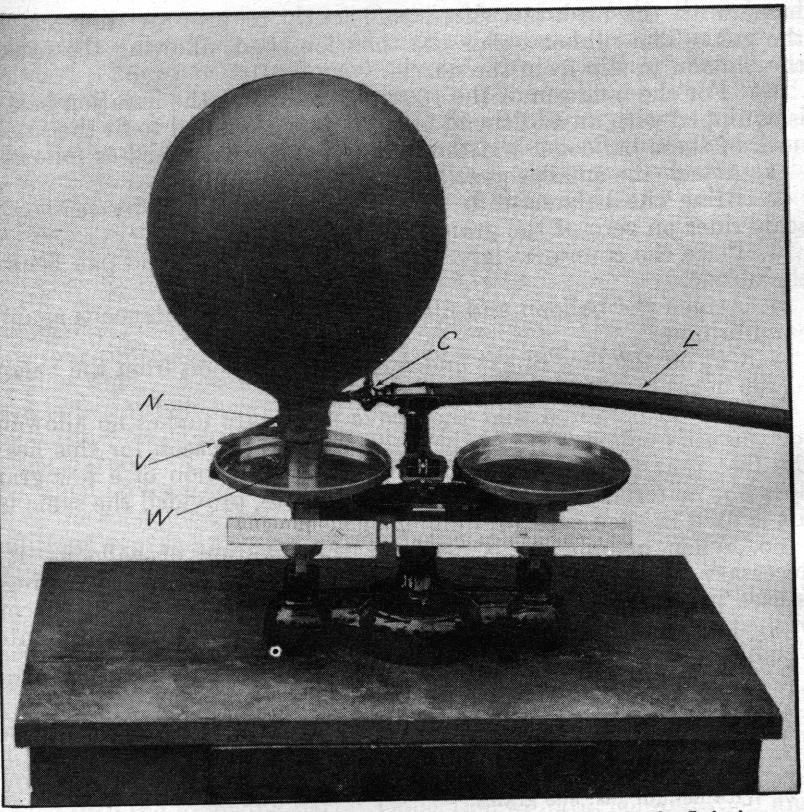

FIGURE 10.—Inflation balance used for "definite" inflation (*C*, three-way stopcock: *L*, hydrogen line; *N*, filler nozzle; *V*, small rubber tube; *W*, counterweight).

additional inflation nozzle to fit the neck of the larger balloons and another brass weight corresponding to the free lift desired.

63. *Use of inflation balance.*—After the rider is set on zero of the lower scale and the counterweight removed from the balance pan, the balance should be adjusted to equilibrium. The balloon is now folded to exclude the air and fastened to the nozzle on the balance pan by means of two or three No. 18 rubber bands. It is now carefully weighted in the usual manner on the lower scale by moving the rider to the right. The rider is now set on the upper scale on the number representing the weight of the balloon. The counterweight is placed on the pan beneath the balloon and the inflation is begun by first opening the valve of the hydrogen cylinder, care being taken that the regulator valve is closed, and then by slowly opening the regulator valve. The balloon should not be inflated too rapidly as many burstings during inflation are due to too rapid filling. When equilibrium is reached the flow of gas is stopped by closing the regulator valve. The cylinder valve should then be closed to relieve the pressure from the regulator diaphram. The balloon is now removed from the nozzle by holding the neck on the nozzle firmly with one hand while the balloon is lifted slightly and turned a few times with the other

hand until the neck is twisted sufficiently to prevent the escape of the gas. The rubber bands are then loosened, allowing the neck of the balloon to slip from the nozzle.

64. For the inflation of the 100-gram balloons, the inflation balance is equipped with an additional filling nozzle, designed to fit the smaller neck of these balloons, and the inflation is accomplished as follows:

1. Attach the smaller nozzle to the balance.
2. Bring the balance into the equilibrium position by setting the scale rider on zero of the gram scale.
3. Place the counterweight (503 gm.) on the left-hand pan beneath the nozzle.
4. Attach the balloon and fill with gas until the balance is again in equilibrium.
5. Cut off the flow of gas and remove the balloon from the balance in the usual manner.

65. It will be noted that the above procedure makes no allowance for the different weights of the balloons. The reason for this lies in the fact that for balloons of this weight a variation of a few grams does not materially affect the ascensional rate, provided the same free lift is used in each case.

66. When helium gas is used for the inflation of balloons, it is necessary to give the balloons greater free lifts than when hydrogen is used in order to obtain the same ascensional rates. This is accomplished by using heavier counterweights on the balance. The counterweights used are:

1. For 30-gram balloons—ascensional rate, 180 meters per minute:
   - *a.* With hydrogen gas, 140 grams.
   - *b.* With helium gas, 154 grams.
2. For 100-gram balloons—ascensional rate, 280 meters per minute.
   - *a.* With hydrogen gas, 450 grams.
   - *b.* With helium gas, 503 grams.

67. *Fastening neck of balloon.*—The neck should be twisted several times and secured by means of three No. 17 rubber bands. The rubber bands are slipped over the twisted portion of the neck and tightly wrapped by a series of alternating half twists and loopings, accompanied by a firm tension to insure a tight joint. If proper care is exercised in this operation, there will be no possibility of leakage of gas through the neck of the balloon. Cord or tape should never be used for tying the neck of balloons.

68. *Danger of explosions.*—It is a well-known fact that hydrogen and air when mixed in the proper proportion make a very explosive mixture. Therefore, the following instructions should be adopted and rigidly enforced:

Smoking should be prohibited at all times in or near the balloon shelter or room where the ballons are being filled or where hydrogen is stored.

Whenever a balloon during the process of inflation is found leaking it should at once be detached from the filling apparatus, taken outside, and exhausted of hydrogen in the open air.

In case of a balloon that bursts while being filled, the doors and windows of the shelter, or room used for the purpose, should be opened in order that all of the hydrogen may be driven out by the wind.

So far as possible, doors and windows of the balloon shelter or room should be kept open each time that the balloon is filled. During windy weather it would probably be possible to have only one window or door open, but even this would provide for some ventilation.

A sign, somewhat as follows, "Danger—No Smoking," should be posted in a conspicuous place where the pilot balloons are inflated. If practicable, both the inflation balance and the hydrogen cylinder should be grounded to carry off any accumulation of static electricity and thereby eliminate as far as possible the occurrence of static sparks. The need for the above precautions is, of course, greatly reduced if helium gas is used instead of hydrogen.

IV. THE OBSERVATION

69. *Time of observation.*—Pilot-balloon observations are usually made four times daily at 5:00 and 11:00 a. m. and p. m., seventy-fifth meridian time. A leeway of 1 hour either way from these scheduled times is permitted, however, for the purpose of adjusting the observation times as closely as possible to airway flight schedules and also for the purpose of obtaining the maximum number of observations, even when adverse weather conditions prevail or are expected to prevail at the scheduled starting times. Furthermore, if adverse weather conditions prevent an observation being made during the scheduled 2-hour periods (4:00 to 6:00 and 10:00 to 12:00 a. m. and p. m., E. S. T.), a *delayed* observation is to be made at the first opportunity thereafter, but not later than 9:00 a. m. or p. m., E. S. T., for the scheduled 5:00 o'clock observations and not later than 3:00 a. m. or p. m. for the special 11:00 o'clock observations. A *delayed* observation will not be made, however, unless an altitude of at least 2,000 feet above the surface can be attained, as previously determined by ceiling balloon or ceiling light.

70. *Steps in observation.*—A pilot-balloon observation may be divided into the following parts: Collection of data, computation and plotting, and reduction and tabulation.

The first part, collection of data, is the making of the observation itself, and involves the taking and recording the balloon data, meteorological data, and observed readings of azimuth and elevation angles.

Computation and plotting, the second part of the observation, involves the work necessary to prepare the observed data for obtaining the wind direction and velocity; that is, computing the horizontal distance of the balloon and plotting these distances on the plotting board.

The third part of the observation consists of determining the wind direction and velocity from the plotted data and of recording wind data on the various forms, including the preparation of Form No. 1115-Aer.

71. *Recording meteorological data.*—After the setting up of the theodolite is completed, the observer will record the current meteorological data comprising clouds, the velocity of the wind, the current and wet-bulb temperatures, the barometric pressure, and the relative humidity. The surface wind direction will be determined from the azimuth of the balloon a few seconds after it has been released and should be recorded both in degrees and to the nearest 16 points of the compass. Where a regular meteorological observation has been taken within 15 minutes of the actual starting time of the balloon ascension (time of balloon release) that meteorological observation may be used instead of taking another. But in the event that a period of more

than 15 minutes of time has elapsed, a separate and complete meteorological observation will be made. The results of this meteorological observation and the settings of the theodolite will be entered in the respective spaces upon the data sheet, or Form No. 1110A–Aer.

72. The next step is the selection of the proper color of balloon to be used and its inflation, as previously described under paragraph 48. The data relative to the type and weight of balloon are then entered on Form No. 1110A–Aer.

73. *Timing of observation.*—It is important in theodolite work that the timing for the angle readings be accurate. A watch may be used for marking the time, but it is not as satisfactory as some device whereby a buzz or signal is given at minute intervals. Without some such automatic signal, there is always a possibility of allowing the

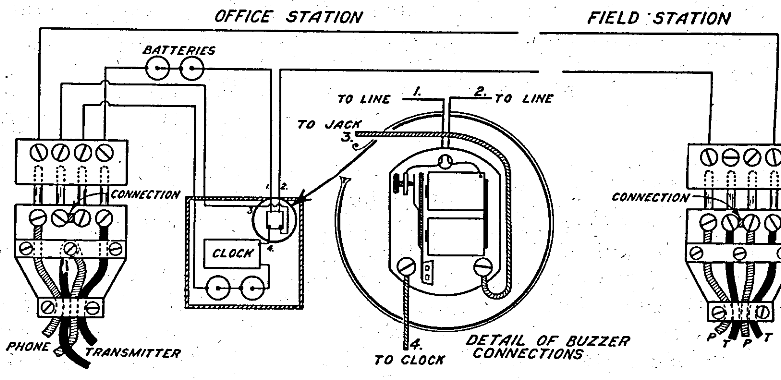

FIG. 11.—Telephone circuit with time signaler installed.

proper reading second to pass by or even to miss a minute entirely. The timing device or time signaler used in the Weather Bureau is described in paragraph 74.

If a time-interval clock is not used it will be necessary to keep close watch of the time, in which case the "warning" signal will be called by the recorder about 5 seconds before the expiration of the minute, or the "read," signal. Generally the balloon is released on the full minute, therefore the "read" signal would occur at the sixtieth second and the "warning" signal on the fifty-fifth second.

74. *Time signaler.*—The time signaler consists essentially of a single-register clock, buzzer, and two dry cells encased in a small wooden box. Two electrical contacts are made 5 seconds apart whereby a buzz or signal is given at the fifty-fifth and sixtieth second. It is so arranged that the first buzz will be a little long and quite loud, and the second buzz much shorter. The first buzz is known as the "warning" signal and the second buzz as the "read" signal. This "warning" signal will give ample time for the observer to center the balloon and the recorder to prepare for the reading of the angles.

As most of the stations of the Weather Bureau are equipped with telephones, the timing device or time signaler is usually installed in the telephone circuit, thus enabling both the observer and computer or recorder to hear the signal.

75. *Installation of telephones with time signaler in circuit.*—In figure 11 is shown the wiring of the telephone circuit with the time

signaler installed. In order to reduce the volume of sound from the buzzer it is necessary to tap off 20 or 30 turns of wire from one of the buzzer magnet coils and to place them in the circuit. To do this the circuit is broken and one end is soldered to the mounting of the "make and break" device and the other is soldered to the surface at the opposite end of the adjacent coil, as shown in diagram.

The buzzer switch is incorporated in the plug, the two otherwise unnecessary prongs on the plug are connected together, and the two wires which formerly led to the switch are connected to the indicated posts on the jack. Thus when the plug is inserted in the office station the time signaler is turned on and all is ready for the observer to plug in and start the observation.

One battery in the circuit consisting of two or three dry cells is all that is necessary.

76. *Releasing balloon.*—When all is in readiness for the observation the balloon will be released. The recorder will be provided with Forms No. 1110A–Aer. on a clip board, hard pencil, slide rule, and timing device. The observer will hold the inflated balloon near the theodolite until the signal of "read" (or release) is given by the timing device. If the time signaler is used the balloon will be held in readiness at the first buzz, and released on the second buzz. The exact time of release to the nearest minute is noted and recorded in the proper space at the top of Form No. 1110A–Aer. If a watch is depended upon for time, then the recorder will be forced to watch the time and call out the signals "warning" and "read" as they occur.

77. A few seconds after the balloon is released the surface wind direction will be determined by pointing the telescope at the balloon and noting the azimuth to the nearest degree. Both the azimuth reading and the direction to the nearest 16 points will be recorded on Form No. 1110A–Aer.

78. *Sighting and following balloon.*—As soon as the balloon has moved away from the observation point sufficiently, the observer will sight the telescope upon the balloon by means of the sights on the telescope, then throwing in both tangent screws (not required on "friction drive" type of theodolite), continue to sight the balloon over the telescope tube, while turning the tangent screws or drives to keep the theodolite trained upon the balloon. Note that the object end of the telescope is always inclined toward the left as the observer looks through the eyepiece; that is, the elevation angle must never be greater than 90°. When the rate and character of the motion to keep the balloon in the line of sight have been attained, continue the movement and quickly change the position of the eye to look through the eyepiece. If the rate of movement has been properly judged, the balloon will appear in the field near the intersection of the cross hairs. Thereafter the observer will keep the balloon in the field by suitable movement of the tangent screws or drives.

79. When the surface wind is very low the elevation angle may be so high that the base plate of the theodolite interferes with the sighting of the balloon with the regular sights. In such cases the high-angle sights, with which all instruments are equipped, must be used.

80. Fifty-five seconds after the release of the balloon, a signal of "warning" will be given, either by the recorder or by the time-interval clock. When this signal is given, the observer will bring the intersection of the cross hairs directly over the balloon and keep

it there until the second signal of "read" is given, when the motion will be stopped to allow the reading of the angles. The recorder, at the "warning" signal, will post himself just behind the observer and a little to the right, so that he can easily see both elevation and azimuth verniers, and make a mental note of the degrees of each. Then at the signal "read," as quickly as possible after the motion of tangent screws has been stopped, the angles of elevation and azimuth will be read and recorded on Form No. 1110A–Aer. Always read the azimuth angle from the same horizontal vernier by which the theodolite has been oriented.

81. The observer will find that much relief is obtained, and much eye-strain eliminated, by observing with both eyes open. Do not squint or close the unused eye. A little practice will enable the observer to keep one eye at the instrument and read one angle with the other eye without difficulty. When he becomes proficient, even though the gaze of the one eye may be directed upon one or the other of the verniers, the other eye will gain and register an impression of the movement of the balloon, and should the balloon pass a little from the field during the reading, it may be regained readily by aid of the movement just mentally registered.

82. Instances will arise, however, wherein the inexperienced observer will be unable to read either angle, due to the fact that the balloon movement is so rapid as to require his full attention. In such cases, the recorder will read both angles, reading that first which the observer indicates is changing the more rapidly. A reading should be missed rather than be the means of losing the balloon. During the first 2 to 4 minutes the balloon can generally be seen by the naked eye, and thus easily placed in the field again. In a few instances, principally when the balloon turns and comes back directly over the station, the balloon movement will be more rapid than can be followed by turning of the tangent screws. In this case the tangent screw should be disengaged and the theodolite revolved directly. Care should be taken that the motion is steady and uniform so that the balloon is not turned out of the field. When the movement of the balloon has diminished sufficiently, the tangent screw is thrown in again and the ordinary procedure followed.

83. *Reading and recording angles.*—In single-theodolite observations the angles will be read to the nearest tenth of a degree (see description of vernier and figs. 3 and 4), and only at the completion of the minute as signaled by the time-interval clock or the recorder. However, when the angles are comparatively low, say 20 or below, they should be read to five-hundredths of a degree whenever possible. At the signal "warning" it is well to read the angles to the point of ascertaining the whole degrees, then the final reading or the reading to tenths of degrees can be made in much less time and directly at the "read" signal. It is practically necessary that the angles be read quickly and accurately. Comparatively small errors in reading angles can be detected when the run is carefully plotted. Thus the necessity for quick and accurate work.

84. As soon as the angles are read, the observer will bring the balloon near the center of the field by means of the tangent screws, where he will keep it until the following "warning" signal is given.

In the meantime the recorder will enter the reading that he has made in the proper column on Form No. 1110A–Aer., and opposite the corresponding minute. Suppose the azimuth angle for the first minute, read by the recorder, is 203.4°; this he will record in the column under "Azimuth angle" and opposite "1" in the minute column. The observer then calls out the angle which he has read, and the recorder enters this; e. g., "16.7°" in the column headed "Elevation angle."

85. During the time that is left between the readings, the recorder will compute the values of the column headed "Distance from observation point" with the slide rule or look up the value in the horizontal-distance tables. Explanation of the slide-rule process will be taken up in following paragraphs. At the recurrence of the "warning" signal all other duties will be suspended and the full attention of both men given to the placing of the balloon on the cross hairs and the accurate determination of angles. This same procedure obtains so long as the observation is in progress.

86. *Use of telephones.*—When the station is equipped with telephones, the observer communicates the angles as read from the theodolite to the computer at the plotting board. The computer records the angles as received on Form No. 1110A–Aer., computes the horizontal distance of the balloon for each minute by slide rule, or looks up the value in the tables, plots these distances on the plotting board, and obtains the wind directions and velocities therefrom while the observation is in progress. The data necessary for telegraphic or other purposes are, therefore, available immediately after the balloon ceases to be observed. A computer with sufficient experience may also accomplish the next step in the observation; that is, plot the wind direction and velocity on Form No. 1115–Aer.

87. In order to obtain maximum efficiency with telephones, the following procedure should be followed: The computer first sets the slide rule on the altitude to be read, then when the recorder reads the elevation angle he immediately sets it on the slide rule while the recorder is reading the azimuth angle. Next he records, on Form No. 1110A–Aer., the elevation angle, azimuth angle, and the distance which is already set on the rule. Note the elevation angle should always be read first. The next step is to plot the distance on the plotting board and to secure the direction and velocity for the preceding minute. These data should be entered on Form No. 1110A–Aer. and plotted on Form No. 1115–Aer. The altitude of the next minute is now set on the slide rule and the procedure above described repeated for each succeeding minute of the observation.

88. *One-man observations.*—It is now the custom at most stations for pilot-balloon observations to be made single-handed. In such cases great care must be exercised to avoid losing the balloon while the angles and horizontal distances are being recorded on Form No. 1110A–Aer. The most efficient procedure to follow each minute, especially when the balloon is moving rapidly across the field, is to (1) read both angles, (2) move the balloon back near the portion of the field *from* which it is moving, (3) record the angular readings on Form No. 1110A–Aer., (4) again move the balloon back in the field, (5) compute the horizontal distance by means of the slide rule or look

up the value in the tables and record the distance on Form No. 1110A–Aer. For such observations a hook or rack, which can be attached to the theodolite, should be used to hold the clipboard, to which Forms 1110A and 1115–Aer. are attached; also the slide rule or distance tables, so that the observer's hands may be free to follow the balloon when not engaged in recording data.

89. *Disappearance of balloon.*—The cause of disappearance will be recorded according to the following reasons. They stand in their order of frequency and relative importance.

1. Clouds:
   - Against.
   - In base of.
   - Obscured by.
2. Burst.
3. Distance.
4. Haze, smoke, fog, dust, etc.
5. Sun.
6. Obscured by—
   - Tower.
   - Chimney.
   - Etc.
7. Overhead:
   - High elevation angle.
   - Rapid change of angles.
8. Accident:
   - Kicking of theodolite.
   - Allowed to pass off field.
   - Vibration of theodolite, etc.
9. Abandoned.

90. *Disappearance of balloon due to clouds.*—When the disappearance is due to clouds it will be specifically stated whether against, in, or behind clouds. If this is not known, a statement to that effect should be made. If the balloon is seen to enter the base of clouds, particular attention will be given to the azimuth and elevation angles of the balloon, and the fractional part of the minute of the balloon's disappearance after the last minute reading. The product of this fraction of a minute into the rate of ascent, when added to the altitude of balloon for the last minute observed, will give the altitude of the cloud base. The direction and velocity of clouds is then computed in the same manner as for any other specific point of the projection. Care should be taken that the cloud direction as recorded on the various forms agrees with the computed direction. If for any reason it does not, a note to that effect should be made on the forms.

91. When the cloud bases are dense and compact the balloons disappear into them immediately upon reaching the cloud level, but when there is no definite cloud base, as with fog-like stratus, the moment of disappearance of the balloon is not the moment of reaching the cloud base. In furnishing data for aviation purposes, the height at which the balloon first enters cloud should be considered as the true "ceiling" for the aviator.

92. *Disappearance of balloon due to distance, haze, etc.*—Disappearance due to distance will not occur during a short flight, except in rare cases where there is a very strong wind at the surface and aloft. A distance of 10 kilometers is the minimum value for this entry.

Disappearances with horizontal distances of less than that amount are usually due to other causes, such as haze, smoke, fog, etc. Occasionally the balloon will move directly across the sun's disk, making observation extremely difficult. In such cases the amount of light entering the object lens should be reduced. This may be accomplished by means of a movable disk attached to the end of the sunshade or by partially covering the end of the sunshade by any other means, such as holding the fingers of one hand over it and allowing the light to enter between the fingers. Other instances will occur when the balloon will be lost behind the anemometer, chimney, or other obstruction. At a properly selected station, possessing low-angle obstructions, this reason for disappearance will be of small frequency. The entry will be made, "obscured by ----------." During periods of low, surface wind velocity the elevation angles for the first few minutes will be relatively high. In fact, the balloon may be directly overhead. The balloon may change its course and come back directly over the observation station. The change of the angles, especially the azimuth angle, will then be rapid. In case of disappearance due to either of these causes an explanatory note should be entered after the entry "Overhead." There will be a certain amount of loss due to accident, which is caused by the kicking or knocking of theodolite sufficiently to throw the balloon out of the field. This disappearance is due to carelessness, and with due attention to the work at hand will be eliminated altogether. Strong surface winds will sometimes throw the theodolite into such a state of vibration that the balloon cannot be accurately placed at the cross hairs, and this will finally result in the loss of balloon altogether. An explanatory note must also accompany the entry of accident. In some cases the balloon will be abandoned to permit the early file of a coded message containing the observed data. In order that the observations may provide as much datum as possible for high levels and still not interfere with other scheduled station duties, it is requested that the one daily observation scheduled to begin at 5:00 p. m. (E. S. T.) be continued to the greatest possible height. Observations made at other times may be abandoned when absolutely necessary but must be continued at least 22 minutes for the intermediate (11:00 a. m., E. S. T.) observations and at least 30 minutes for the 5:00 a. m. (E. S. T.) observations, unless cut short by adverse atmospheric conditions. Furthermore, during that part of the year when lanterns must be used for the 5:00 p. m. observations by stations located in the 75th-meridian-time zone, the 11:00 a. m. observations are to be continued to the greatest possible height by those stations.

93. *Checking theodolite setting.*—The setting or orientation of the theodolite should be carefully checked immediately after the observation, before the theodolite has been disturbed. If there is no change in the setting within a few tenths of a degree, the readings will be entered in their proper columns on the second line under the last entry of the observed angles, and the word "Check" written directly below. Otherwise, corrections will be made on the observed data. It should also be noted that the azimuth angles have been read from the same vernier used in the original orientation or setting.

94. *Recording visibility.*—At any convenient time during the ascension the visibility will be noted and recorded according to the following scales:

Visibility scale

Scale	Descriptive term	Limiting distances (meters)
0	Dense fog.—prominent objects not visible at	50
1	Very bad.—prominent objects not visible at	200
2	Bad—prominent objects not visible at	500
3	Very poor—prominent objects not visible at	1, 000
4	Poor—prominent objects not visible at	2, 000
5	Indifferent—prominent objects not visible at	4, 000
6	Fair—prominent objects not visible at	10, 000
7	Good—prominent objects not visible at	20, 000
8	Very good—prominent objects not visible at	50, 000
9	Excellent—prominent objects visible beyond	50, 000

This scale is nearly self-explanatory. The distances can be laid off on a map of the section of the country, and prominent objects selected as the points of reference.

95. At night the visibility will be determined from the farthest light that may be seen by the observer, and its distance recorded according to the visibility scale.

96. *Omission of observation.*—It sometimes happens that, at the time of the scheduled pilot-balloon observation the weather conditions are such that an observer might carelessly or indifferently call off an ascension when it is really possible to make a satisfactory observation. For example, a light sprinkle of rain might be used as an excuse by the observer to call off the ascension, even when the drops are so few as to cause neither injury to the theodolite, discomfort to the observer, the early disappearance of the balloon, nor appreciable retardation in the ascensional rate of the balloon. Snow flurries of short duration often preclude an ascension at the scheduled time, when shortly thereafter an ascension would be easily possible and worth while. It is expected, therefore, that an ascension will be made within 1 hour before or 4 hours after the scheduled time, as indicated in paragraph No. 69, if weather conditions are such as not positively to forbid the making of an ascension. It is recognized that there are times when it would be a waste of balloon and gas to attempt an ascension; but, on the other hand, conditions must not be too easily and quickly dismissed as belonging to this class. In general, it may be said that an ascension should be made under all conditions except those which incur danger to the instrument, marked discomfort and possible injury to the health of the observer, or a loss of the balloon below 1,000 feet above the surface if within the scheduled 2-hour period or below 2,000 feet if it is a *delayed* observation. See paragraph No. 69.

97. It is recognized that, in the last analysis, the question of omitting an ascension is one that must be decided locally, and that no ironclad rules can be set down in instructions. But it is a question that has a strong personal element, and is one that must be answered conscientiously by those concerned. Times when ascensions are likely to be omitted owing to unfavorable weather conditions are often those which would be of greatest scientific value. The observer should bear in mind at all times the value of the data he is securing and the many uses to which they may be put, and he should try to cultivate such a spirit of sincerity. This, coupled with good judg-

ment, is certain to result in the satisfactory collection of aerological data.

98. *Night observations.*—In order to provide upper-air wind data every 6 hours, as is now required along the airways, approximately half of all pilot-balloon observations must be made during the hours of darkness. Such observations are made possible by attaching a suitable light to the balloon. A small paper lantern and candle are usually used for this purpose. The combined weight of the lantern and candle is 18 to 20 grams. Normally the candles will burn approximately 40 minutes. Lanterns and candles are packed in separate packages for shipment to stations, the former being folded or crushed nearly flat for that purpose. Before using, therefore, it is necessary to attach the candle to the inside bottom of the lantern while the lantern is still in the folded position. A simple method of doing this is to open the flap in the top of the lantern, light the candle and tip it so that a few drops of melted wax will fall on the bottom of the lantern; then extinguish the candle and quickly press it down on the melted wax and hold it there until the cooling wax holds it fast. One end of a piece of small cord, or thread, 3 to 5 feet long, should then be tied to the wire handle or bail of the lantern. The other end of the cord is to be tied to the balloon after the latter has been inflated. The use of two pieces of cord with two or three lengths of small rubber bands inserted between them has been found to be advantageous in releasing balloons with lanterns attached. The rubber bands reduce the usual jerk given to the lantern upon release and the swinging of the lantern after release. An electric-lighting device, consisting of a small two-cell battery and flashlight lamp, is also used by the Weather Bureau at certain Pacific coast stations during the season of forest-fire hazard, and at other stations during the winter months when high surface winds make it difficult to light and release the usual paper lantern. The electric devices are, however, heavier, more expensive, and less efficient than the paper lanterns.

99. *Inflation of balloons when lanterns or electric lights are used.*—In obtaining the weight of the combination, the additional weight of the lantern, or electric device, should be considered as part of the weight of the balloon; that is, if the weight of the balloon is 30 grams and the lantern 10 grams, the balloon should be filled the same as if it weighed 40 grams. It is necessary, of course, to have the equivalent weight of the lantern or electric device on the pan of the balance beneath the balloon when it is inflated. When lanterns are used, that fact should be indicated on Forms No. 1110A–Aer.

100. *Lighting lanterns.*—Care should be taken not to light the candle too near the hydrogen supply or the inflated balloon. Whenever possible this should be done in the open air, or, if this is not practicable, in a well-ventilated room. (See paragraph No. 68.) Experience has shown that the candle may be successfully lighted in the open air, even when high surface winds are blowing, if placed in a cylindrical receptacle such as a waste-paper basket or bucket.

101. *Theodolite-lighting device.*—In order to make night observations, as is now the practice at all stations, it is necessary to provide for the illumination of the cross hairs and verniers. To that end, all of the older theodolites have been so equipped, and all those purchased in recent years have been supplied with suitable lighting devices by the manufacturer. Current for the operation of the lighting

devices may be supplied by dry cells or by the regular house current. In case the latter is used it is, of course, necessary to reduce the voltage by means of a transformer. If the field of view is too bright, the light which is being observed does not show up plainly and, therefore, cannot be followed to such a great distance. This difficulty may be remedied by using a higher-voltage bulb for lighting the cross hairs or by placing a rheostat in the theodolite-lighting circuit by which the current may be reduced as desired during the observation.

102. *Methods of computation.*—The computation of the horizontal distances of the balloon at the end of each minute may be accomplished by the slide-rule method, graphical method, logarithmic computation, or by reference to tables (table No. 1043 used for ascensional rate of 180 meters per minute). In the Weather Bureau either the tables or the slide-rule method are used. The only computations made by logarithms or by natural functions are for checking purposes.

103. *Slide rule used in theodolite observations.* The slide rule used by the Weather Bureau for computation of single-theodolite observations is an ordinary polyphase duplex, 10-inch rule. The principle of the slide rule is purely logarithmic, and each scale is graduated according to that principle, but the manipulation of it and the work done with it is purely mechanical and can be readily taken up without the slightest knowledge of logarithms. The scales of this rule used in single-theodolite computation are the tangent scale T, the sine scale S, and their associate scales, D and A, respectively. The tangent scale ranges from approximately 6° to 45° and the sine scale from ½° to 90°. These scales are graduated into degrees and minutes.

104. A complete manual of instructions is furnished with each slide rule, and for that reason but little attention need be given here to the manipulation of the slide rule. The supplement at the end of the manual will give much information of practical interest.

105. *Single-theodolite computation.*—In single-theodolite computation, usually only the T and D scales will be used, and these in conjunction with the formula—

$\tan e = \frac{h}{d}$, will be sufficient.

e = the observed elevation angle for any one minute, which is found on T scale of central slide of rule.

h = the assumed altitude or height of balloon at end of each minute. It is the product of ascensional rate into time in minutes from release of balloon. This value is found on the lower or D scale of the slide rule.

d = the horizontal distance from the observation point to a point directly underneath the balloon.

106. Slide-rule computation for pilot-balloon work is affected to some extent by the magnitude of the elevation angle, which separates the work into two phases, namely, elevation angles less than 45° and elevation angles greater than 45°. While an explanation of computation involving an elevation angle of more than 45° is given early in section 7 of the Manual, the direct application to pilot-balloon computation can be stated in simpler form, and will follow later. In ordinary computation, the elevation angle is less than 45°, and in such cases the procedure is simple enough.

107. *Elevation angles below 45°.*—To compute the value d from the formula, $\tan e = \frac{h}{d}$, where e is less than 45°, the runner of the slide rule, is set at h, in meters, on the D scale of slide rule, and then central slide is moved until the elevation, angle e (for the same minute) on scale T is brought under the hair line of runner. The value of d is then read from the D scale of slide rule under the index of the central slide. In some instances this will be the right index and at other times it will be the left index. With reference to data sheet for single-theodolite observation, table 1, to compute the distance out for the first minute, set the runner of slide rule on 216 of the D scale then adjust the central slide until 27.6 (the elevation angle for the same minute) on the tangent scale is placed under the hair line of runner and coincident with 216 on the D scale. Under the right index of slide and on the D scale read 413 meters. Notice that the subdivisions on the T scale for angles less than 20° are equivalent to 5 minutes of arc and those subdivisions from 20° to 45° are equivalent to 10 minutes of arc, while the divisions of angles as read from the theodolite are in degrees and tenths of degrees. Therefore, it will be necessary to convert the tenths of degrees to minutes in order to make the settings of T scale accurate. This is a simple mental operation accomplished by multiplying the tenths of the angle by 6 the resulting product being the fractional part of the angle converted to minutes.

108. *Elevation angles above 45°.*—When the elevation angle is above 45°, set the index of the T scale over h found on D scale, set the hair line of the runner over the elevation angle found on T scale, and read the value d under the hair line of runner on D scale. This value is the quantity sought, and is to be recorded in the corresponding space on Form No. 1110A–Aer. As an example, suppose the elevation angle is 54°.9 and the altitude of the balloon in 600 meters. To compute the value of d for this case we would set the index of central slide over 600 on the D scale, then on the T scale of the central slide we would find the angle 54.9° and place the hair line of the runner thereon. Under the hair line and on the D scale we would read off the value of d, or 422 meters. It will be noticed that the T scale provided only for angles of 45° or less, and since the function of an angle is equal to the cofunction of the complementary angle, the operation involves a reversal of the method when an angle of more than 45° is recorded. To simplify the settings when the angles are greater than 45°, let the 5° divisions of the tangent scale be re-marked beginning at the 40° division which will be designated as 50°; 30° will be 60°, etc. It these divisions are marked upon the celluloid surface of the rule in red ink, it will be found to assist greatly in the settings for angles greater than 45°. Let it be noticed and used as a check that the results of all slide-rule computations made on angles of elevation *less* than 45° will be *greater* than the h value on which the computation was made. Similarly, the results of all slide-rule computations made on angles of elevation *greater* than 45° will be *less* than the corresponding h factor.

109. It will be noted that the T scale does not contain angles below 6°. In computations involving elevation angles below 6° and above 84° the sine scale may be used instead of the tanget scale, since the natural sines and tangents of angles up to approximately 6° are equal to at least the third decimal place. It must be remembered, however,

that the sine scale is set with reference to the A scale, whereas the tangent scale refers to the D scale.

110. In case there is doubt as to the accuracy of the result of any of the slide-rule computations, it may be readily checked by dividing the assumed height of the balloon by the natural tangent of the elevation angle. A table of natural tangents may be found in any book of logarithms.

111. *Plotting board.*—In order to obtain the wind direction and velocity from a pilot-balloon observation, some kind of a plotting board is usually employed. The standard Weather Bureau plotting board consists of a wooden base, 42 inches square. Over the central area of the base a circular sheet of cross-section paper is pasted, rubber cement being used for the latter to prevent the stretching of the cross-section paper. At the center of the area, and set into the board, is a brass bearing and pin. From the center of the pin two distance scales (one on either side of a heavy index line) are printed to the edge of the paper. One of these is numbered on the basis of 1 cm.=200 meters and the other on the basis of 1 cm.=400 meters. The former extends to 10,000 meters and the latter to 20,000 meters. Over the circular area of the paper and fastened to the brass pin as a center is placed a disk of frosted celluloid with the circumference graduated in half degrees. The celluloid disk or protractor is frosted on the upper surface in order that the points representing the horizontal projection of the balloon's path may be plotted thereon with a soft pencil. In case the surface becomes too smooth with use to readily take the pencil marks, it may be refrosted or roughened satisfactorily by rubbing with very fine sandpaper.

112. *Constructing the horizontal projection of balloon's path.*—To plot the computed distances of the balloon for the various minutes of the ascent, or to construct the horizontal projection of the flight, the plotting board should be arranged so that the index line and distance scales are directly in front of the operator. The celluloid surface is then cleared of all previous records by erasing the pencil marks with a piece of soft eraser or art gum. Hard erasers containing any abrasive substance should not be used for this purpose. The celluloid protractor is then revolved about the center until the observed azimuth angle for the minute to be plotted is located on the edge of the disk and placed over the index line. Then, taking the computed horizontal distance of the balloon for the same minute as the second factor, a point is plotted on the celluloid protractor directly over the index line and opposite the corresponding value on the distance scale. The point is set off, or made more prominent, by encircling it. The point should then be numbered to correspond to the number of the minute involved. Only very soft and well-sharpened pencils should be used on the celluloid protractor as it is difficult to mark a point accurately on the protractor with a dull point.

113. The distance scale selected for use in plotting should, of course, depend upon the maximum horizontal distance attained by the balloon. Usually if this is less than 10,000 meters the 10,000 meter distance scale should be used, and if greater than 10,000 meters the 20,000-meter distance scale should be used. Both distance scales should be used when the horizontal distances are relatively small during the first few minutes but the maximum distance attained is greater than 10,000 meters. In such cases greater accuracy will

result if the 10,000-meter distance scale is used for the early portion of the observation and the 20,000-meter scale during the latter part. In changing from one scale to the other it is necessary to repeat the last two points on the first scale and plot them again as the first two points on the second scale. When very light, variable winds prevail it sometimes becomes necessary, in order to avoid the crowding of the points on the protractor, to multiply the horizontal distances by some convenient factor such as 2, 5, or 10 before plotting. When this is done the velocities as measured by the special velocity scale must, of course, be divided by the same factor before recording them on Form No. 1110A–Aer.

114. *The horizontal projection of the balloon.*—The immediate result of the horizontal projection is to furnish a plan of the horizontal movement of the balloon throughout the period during which it was observed. On a very much smaller scale, each point represents the actual horizontal position of the balloon at the time when the angles were read on the theodolite. Since the balloon travels with the wind, and since the horizontal projection is a scaled plan of the horizontal movement, the direction and velocity of the wind movement may be measured from the scaled plan. Special scales, graduated with reference to the distance scales on the plotting board, are furnished each station for use in measuring wind velocities. Wind directions are taken directly from the protractor, as will be explained later.

115. The horizontal projection will nearly always be a smooth, even curve, though decided bends and sharp angles often exist. The difference between an actual bend of the projection, even though it be sharp, and a wavering of the projection due to poor data can generally be detected. The projection should be examined carefully for errors in computation and angle readings before the wind data is taken from it. Any points that look doubtful should be checked. In this manner many errors may be corrected which otherwise would not be detected.

116. *Velocity scales.*—The scales used to determine the wind velocity from the horizontal projection of the balloon on the plotting board, are small cardboard scales, similar to those used to determine the surface wind velocity from the triple-register sheets (Form No. 1017–Metl.). They are graduated to indicate velocities in meters per second when 2 minute intervals are measured, as will be explained in the next paragraph. The graduations are at intervals of 0.6 cm. on one edge of the scale and at intervals of 0.3 cm. on the other edge, the former being used with the 10,000-meter distance scale and the latter with the 20,000-meter distance scale. The division on the velocity scales are subdivided in halves in order that the velocity may be more readily read to meters and tenths.

117. *Obtaining wind data from horizontal projection.*—The method adopted by the Weather Bureau to obtain the wind data from the horizontal projection for any point or minute is to take the mean resultant direction and velocity over a 2-minute interval of time extending from the beginning of the preceding minute to the end of the following minute, thus placing the minute in question between these limits. For instance, the direction and velocity for the fifth minute is assumed to be the mean of the resultant from the fourth to the sixth minute.

118. *Measuring wind velocity.*—In using the wind velocity scales, particular attention must be given that the wind scale used is that corresponding to the scale upon which the plot was made. If the projection is constructed upon the scale of 1 cm.=200 m., then the wind scale of the same base should be used. In applying the wind scale always apply it to alternating points, or connect the points on either side of the one being measured, from 0 to 2, from 1 to 3, and from 2 to 4, etc. The zero of the wind scale will be placed on the earlier of the three points under consideration, and the graduated edge will then be adjusted until it coincides with the last of the three points. Note that the point being measured is the point between. At the point of coincidence between the set scale and the last of the group, the velocity for the intermediate point will be read off to tenths of meters per second. The velocity of the last point may be determined either by placing an auxiliary point in a position beyond the last point, which will approximately satisfy the character of the last portion of the projection, and measuring as before, or by applying the velocity scale to the last minute interval and doubling the scale reading. The latter method is sufficiently accurate when the final portion of the projection is nearly a straight line and the points are evenly spaced, but when the projection is curved the auxiliary point should be used. The same rules should be followed when the balloon enters a cloud layer and the final point represents a fractional part of a minute. When the balloon enters a cloud, however, extreme care should be exercised in extrapolating for the auxiliary point due to the fact that the bases of cloud layers are frequently located at or just above a level where an abrupt shift in wind direction occurs. This can be checked to some extent by noting the change in azimuth angles just prior to the disappearance of the balloon and by eye observation of the cloud movement.

119. *Determining the wind direction.*—Measurement of the wind direction is no more difficult than measurement of the wind velocity, though until thoroughly understood is more confusing. The direction to be determined, like the velocity, is the mean or resultant direction from the point or minute in question, for the two-minute interval extending from the beginning of the previous minute to the end of the succeeding minute; thus, the direction of the wind for the first, second, third, etc., minutes will be the resultant direction between the points 0 to 2, 1 to 3, 2 to 4, etc., respectively.

To measure the resultant direction for point 1, it is only necessary to rotate the protractor until the points 0 to 2 are on the same straight line. For instance, set both of these points over the scale base or index line of scale, and read the direction in degrees from the edge of the protractor over the index of the scale. To determine the direction for succeeding minutes 2, 3, 4, etc., rotate the protractor until the preceding and succeeding points to that being determined are arranged on the same straight line parallel to the scale base; that is, to measure the direction of point 2, arrange the points 1 and 3 so that they are in the same imaginary line parallel to the index of distance scale. For point 3, arrange 2 and 4 on the imaginary parallel line. Note that the later numbered minute is always toward the operator when determining these directions, otherwise the directions will be 180° in error. Read the direction of movement in whole degrees from the edge of the protractor over the same index of distance scale as for the first minute.

In general it may be stated, to find the wind direction for any one minute rotate the protractor until the adjacent points of horizontal projection on either side, with the latest numbered point of the group toward the operator, are directly over the scale base or a line parallel to the scale base, and read the direction in degrees on the edge of the protractor coincident with the index line of the scale base.

120. A north wind will be designated as 360°, east as 90°, south as 180°, and west as 270°, etc. Since the balloon travels with the wind,

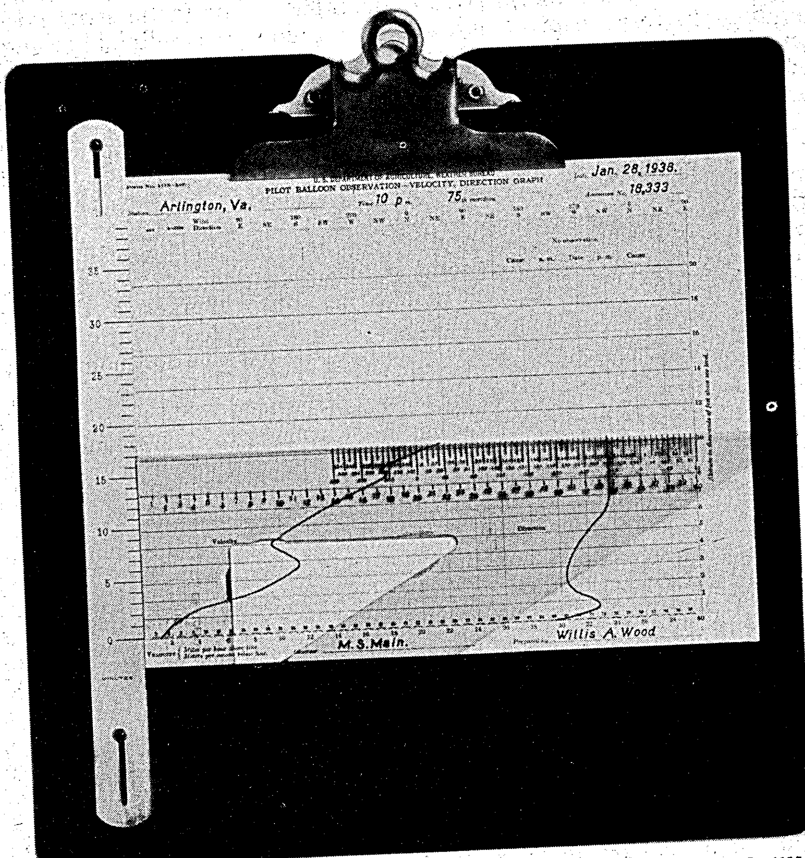

FIGURE 12.—Graphing board for construction of wind direction and velocity graphs on Form No. 1115-Aer.

it usually moves away from the observer and, owing to the fact that angles of azimuth are read on the opposite side of the instrument from the balloon, it has been found best to set the zero of the base plate on south when orienting the theodolite for an observation. This is well borne out when determining the direction of the wind movement from the plotting board, as described above. When the theodolite has been oriented with zero on south, the resulting direction of points can be read from the index of the scale base on the near edge of the board.

121. Some operators may prefer to apply the wind scale to the points for velocity and then, using the scale as a straight-edge to aid

in lining up the points parallel to the initial line, determine the direction for the same minute. This method is recommended as a time saver.

122. *Graphing board.*—The wind-direction and velocity data are represented graphically on a sheet of cross-section paper (Form No. 1115–Aer.). A simple graphing board is furnished to all pilot-balloon stations to aid in the preparation of these graphs. (See fig. 12.) It consists of an ordinary clipboard, 14 inches square, on one side of which a metal strip is mounted. The metal strip aids in holding the form in place and acts as a guide for a celluloid triangle, on which wind directions in degrees are graduated. An altitude scale, indicating the assumed height of the balloon at the end of each minute, is also graduated on the metal strip.

123. *Preparation of velocity-direction graph.*—In preparing the velocity-direction graph, Form No. 1115–Aer. is first placed on the graphing board with the left-hand edge inserted beneath the metal strip and the top inserted beneath the spring clip so that the left-hand edge of the cross-section ruling is in line with and directly beneath the right-hand edge of the metal strip. In order to graph the data for levels above sea level, as is Weather Bureau practice, the form must be adjusted downward until the zero or surface elevation on the metal strip coincides with the altitude of the observation point above sea level, as indicated on the altitude scale along the left-hand edge of the form. The graphs are then constructed from this point as a base. The first step in preparing the graphs is to plot pencil points on the cross-section paper representing the direction (in degrees) and velocity (in meters per second) of the surface wind and then the same data for each successive minute. The pencil points are plotted along the edge of the graduated triangle by placing the short leg of the triangle flush against the metal altitude scale and then by referring to the degree and velocity scales on the triangle to locate the points.

124. When all points have been plotted, a smooth, curved line is drawn in ink through the points. Decided irregularities and bumps in either the velocity curve or the direction curve are to be checked over by reference to the original data on Form No. 1110A–Aer. to see that no errors have been made in computation. The velocity curve is likely to be more irregular than the direction curve; in fact, it may be said that the actual direction curve will nearly always be smooth, though irregularities, when at all present, are generally very prominent.

125. Care should be exercised in locating the points for the direction graph when changes in direction of 360° or more occur during the observation in order to avoid breaking the graph at the right-hand edge of the form. On some occasions it will, of course, be impossible to avoid breaking the graph. In such cases the last point nearest the edge of the form is to be plotted again at the proper location to the left and the two points should then be joined by a horizontal dotted line. The remaining points are then plotted with reference to the same portion of the direction scale as that used in plotting the latter of the above two points.

126. In case the maximum altitude is over 7,000 meters above sea level, that portion of the graph above 7,000 meters should be drawn downward from the top of the form, and if the maximum altitude is over 14,000 meters above sea level, that portion above 14,000 should be drawn upward from the bottom of the form. The down-

ward portion of the graph should be drawn in red ink and the seccond upward portion in purple, green, or any other available color which will distinguish it from the first portion of the graph.

127. When the wind velocity is "calm" (i. e., less than 0.5 m. p. s.) the corresponding portion of the *direction* graph will be broken and the word "calm" written in the space. If the surface wind is calm when the balloon is released and the balloon ascends directly overhead, the approximate time elapsing between the release and the time the balloon is observed to start moving away from the vertical position should be noted. The azimuth angle of the initial horizontal movement should also be noted by quickly sighting the theodolite on the balloon. The velocity graph should then be drawn vertically along the zero line up to the altitude at which the first horizontal movement of the balloon was observed to take place. The direction graph should, in such cases, be started at the point where the velocity graph first indicates a velocity of 0.5 m. p. s. In extracting data from Form No. 1115–Aer. for entries to the nearest whole meter per second on Form No. 1114–Aer., 0.4 m. p. s. or less will be recorded as calm and 0.5 m. p. s. as 1 m. p. s.

V. FORMS AND REDUCTION TABLES

128. *Forms used in pilot-balloon work.*—The forms used in pilot-balloon work are Nos. 1110–Aer. 1110A–Aer., and 1115–Aer. (combined), 1113–Aer., 1114A–Aer., 1114B–Aer., 1116–Aer., 1117–Aer., and 1124–Aer.

129. *Form No. 1110A–Aer.*–This form, combined with Form No. 1115–Aer., is used for the recording of all original data in any way connected with the observation. (See table 1.) The headings must be carefully made out and the remaining spaces filled in as far as data are available. The station altitude to be entered at the top of this form and on all other pilot-balloon forms is the altitude above sea level of the theodolite platform. Particular attention is to be given to the recording of the disappearance of the balloon. When it is due to clouds, it should be distinctly stated whether the balloon disappeared against, entered base of, or passed behind them. The exact type of cloud should also be given in such cases, using the abbreviations Ci, Cs, Cc, etc. The balloon data and the auxilliary meteorological data are to be entered in complete form in each case. Clouds or sky conditions are to be recorded in accordance with the international code for reporting clouds, i. e., in numbers from 0 to 9 and classified according to height (high, middle, or low). The surface wind direction is to be recorded both to the nearest whole degree and to one of the 16 compass points, i. e., 283° WNW. and the velocity in meters per second and tenths. The temperatures (both dry and wet-bulb readings) are to be recorded to the nearest tenth degree, Centigrade. For conversion from Fahrenheit to Centigrade, see table 4. Pressures are to be entered to the nearest tenth millibar, table 6 being used to make the conversion from inches. Form No. 1110A-Aer. will be rendered only when the observation reaches at least 1,000 feet above the surface.

130. Note that the ascension numbers on Form No. 1110A–Aer. are always one greater than those of the graphs (Form No. 1115–Aer.), on the reverse side of the form. In inaugurating pilot-balloon observa-

tions at a station, the graph (Form No. 1115–Aer.) of the first form used and on the reverse side of which the data are entered for ascension No. 1 will be left blank. The graph for ascension No. 1 will then be drawn on the second form, on the reverse side of which the data for ascension No. 2 are to be entered. For the last observation on December 31 of each year the Form No. 1110A–Aer., on the reverse side of which the graph for the last observation is drawn, should be left blank and a new form used for the first observation on January 1 of the next year. Only the data on Form No. 1110A–Aer. are to be entered on this first form of the year, the reverse side (Form No. 1115–Aer.) being left blank. Carbon copies on plain paper are to be made of all original entries on Form 1110A–Aer., and these copies are to be retained as a permanent station file. When time does not permit the construction of the graph, immediately after completing Form No. 1110A–Aer., data for current use and teletype or telegraph reports may be taken directly from the latter form by interpolation. A quick and convenient mental conversion of meters per second into miles per hour may be made as follows: Double the m. p. s., take the tens of the result (disregarding decimals), plus 1, and add to the figure obtained from doubling the m. p. s. The result is miles per hour. To convert 17.4 m. p. s. to m. p. h., for example: Multiply 17.4 by 2 and we have 34.8 (i. e., 3 tens); adding one to the 3 tens makes 4, and adding 4 to 34.8 gives a total of 38.8 m. p. h. (reported as 39).

131. *Form No. 1115-Aer.* (combined with Form No. 1110A-Aer.) figure 14, is a graphical representation of the data obtained from the ascension. The construction of the graphs has already been explained in section IV. The heading on this form should agree in all details with that of the corresponding Form No. 1110A–Aer. Form No. 1115–Aer. will be rendered only when an ascension is made. When an observation results in no ascension (i. e., the balloon is lost before reaching an altitude of 1,000 feet above the surface) the reason for same will be entered in the upper right-hand corner of the succeeding form under the heading printed thereon for that purpose, as follows:

No ascension for—

Cause	a. m.	Date	p. m.	Cause
		10	11:00	Rain
Fog	5:00	11		

132. To facilitate the extraction of data in English units for current reports, an overprint of black, dotted lines has been made on this form to indicate altitudes in thousands of feet; also, a scale of wind velocities in miles per hour has been added along the bottom of the form.

133. *Form No. 1110-Aer.* (table 2) is used for recording the data of two-theodolite observations. Care should be exercised that all data called for thereon are furnished insofar as they are available. It is especially important that the designation, length, and bearing (azimuth) of the base line be given; also, the rate of ascent data. Additional instructions regarding the use of this form will be found in section VI.

134. *Form No. 1113–Aer.* is used for the tabulation of cloud heights determined during each month. Great care should be exer-

cised in selecting data to be entered on this form. Questionable data should not be recorded. To augment the data regularly obtained by means of pilot-balloon observations, when a scheduled pilot-balloon observation is missed because of low clouds and the height of the clouds at that time (i. e., within 1 hour before or after) is obtained by ceiling balloon or ceiling light, the data so obtained are to be entered on Form No. 1113–Aer. and included in the summary on the reverse side of the form. For such entries the words "ceiling light" or "ceiling balloon," as the case may be, are to be entered under "Remarks". The velocity of the cloud will, of course, be omitted from such entries. Cloud-height data obtained from "delayed" pilot-balloon observations (more than 1 hour before or after the scheduled time) are also to be entered on this form and included in the summary by combining them with those of the nearest scheduled time. When all entries for the month have been made, the cloud data are to be tabulated according to cloud types and grouped into the four scheduled observation times. In tabulating the entries according to types altocumulus castellatus (Acc) will be classed as altocumulus (Ac), fractostratus (Fs) as stratus (St), fractocumulus (Fc) as cumulus (Cu) and cumulonimbus mammatus (Cm) as cumulonimbus (Cb). The average hights and number of entries are then to be obtained for each category and the results entered in the summary on the upper half of the reverse side of the form. Copies of these tabulations and computations are to be retained in the station file each month and *yearly* values, obtained therefrom are to be rendered on a separate blank form with the December records each year. On the lower half of this same form the *yearly* maximum altitude and maximum velocity data are to be entered as indicated below.

135. All cloud entries on Form No. 1113–Aer. resulting from pilot-balloon observations are to be converted into the punch-card code and then copied onto the appropriate Form No. 1114A–Aer. The following values are to be used in converting the cloud data into the punch card code:

Cloud types:	Code No.
Ci	1
Cs	2
Cc	3
Ac, Acc	4
As	5
Sc	6
Ns	7
Cu, Fc	8
Cb, Cm	9
St, Fs	0

Cloud directions:	Code No.
NNE	01
NE	02
ENE	03
E	04
ESE	05
SE	06
SSE	07
S	08
SSW	09
SW	10
WSW	11
W	12
WNW	13
NW	14
NNW	15
N	16
CALM	20

136. The cloud velocities as entered on Form No. 1113–Aer. are to be converted to whole numbers and entered on Form No. 1114A–Aer. as two-digit figures i. e., 01, 02—09, 10—58, etc.

137. *Maximum altitude and maximum velocity data.*—On the lower half of the reverse side of Form No. 1113–Aer. the following summary data are to be entered:

1. Absolute maximum altitude *above sea level* reached during the month.
   a. Corresponding wind direction and velocity.
   b. Date and time.
2. Maximum wind velocities for the month as follows:

	Surface–2,500 meter (mean sea level)	2,501–5,000 meter (mean sea level)	Above 5,000 meter (mean sea level)
Maximum velocity (to tenths)			
Direction (16 points)			
Altitude (mean sea level) to nearest 10 meters			
Date			
Time			

In addition to the above *monthly* data, similar data for the year, as a whole, as determined from the 12 monthly records, are also to be entered on a blank Form No. 1113-Aer. and forwarded with other forms for the month of December. Copies of the monthly values from which the yearly data are to be determined, must, therefore, be retained each month in the station files.

138. *Forms No. 1114A–Aer. and 1114B–Aer.* are designed for the monthly tabulation of the upper air wind data for specific levels above sea level in the code used on punch cards. Separate forms are employed for each of the four scheduled observation times. Form No. 1114A–Aer. provides for entries for all levels up to and including 10 kilometers; while Form No. 1114B–Aer. provides for such entries at 11 kilometers and above. The data entered on these forms are taken from Form No. 1115–Aer., the directions are recorded in code corresponding to the 16 compass points and the velocities to the nearest whole meter per second. (See instructions for coding under Form No. 1113–Aer. above.) The station number (first column) is to be entered for each observation. This will be taken from the list of index numbers appearing in the 1939 Weather Code (numeral system). In the second column the number of the month is to be entered as a two-digit figure, i. e., January is to be designated by 01, February by 02, December by 12, etc. In the year column the last two digits of the year are to be entered i. e., for 1939 enter 39, for 1940, enter 40, etc. In the time column, the time of the observation is to be entered to the nearest hour (using the 24-hour system) seventy-fifth meridian time. Thus an observation made at 2:50 p. m. one hundred and fifth meridian time will be coded as 17 (2:50 p. m. one hundred and fifth meridian time converted to seventy-fifth meridian time becomes 4:50 p. m.—the nearest hour is 5:00 p. m. or 17 on the 24-hour clock). When no ascension is made the word "None" followed by the reason for no observation will be entered in the appropriate space as follows: "None—Low clouds," "None—Rain," etc. (surface wind data should be omitted in such cases). "No observation" entries are not to be made, however, if a delayed (more than 1 hour after the scheduled time) observation is made which can be entered on the form. Delayed observations are to be entered on Form No. 1114A–Aer. for the nearest scheduled time, unless this would result in two entries for the same date, in which case the delayed observation is not to be entered.

When an observation is not entered on Form No. 1114A–Aer. the "No observation" note on the Form No. 1114A–Aer. for the previous scheduled time will, for example, read as follows: "None—Low clouds—Observation made at 8:20 a. m." The time of each delayed observation entered on these forms is to be entered in red ink. In entering the maximum altitude wind data on Form No. 1114A–Aer. the following rules shall apply:

1. For levels between surface and 1,000 meters mean sea level, inclusive, if the maximum altitude reached is *100* meters, or less, below one of the standard levels, the wind data for the maximum altitude shall be entered on Form No. 1114 for that standard level.

2. For levels of 1,500 meters, or above, if the maximum altitude reached is *250* meters, or less, below a standard level, the data for the maximum altitude shall be entered for that standard level.

139. In the "maximum altitude" column at the right-hand side of Form No. 1114A–Aer. both the maximum altitude reached (to the nearest meter) and the wind data at that level are to be entered, thus:

5672, 14716, etc.
12—13 14—22

140. When the maximum altitude reached is more than 10,000 meters above sea level, data for each 1,000-meter level above 10,000 meters (11,000, 12,000, etc.) are to be entered on Form No. 1114B–Aer.

141. *Form No. 1116–Aer.* is for station file and is designed to assist in the preparation of wind-aloft reports as transmitted by teletype or telegraph and to serve as a station record of such reports.

142. *Form No. 1124–Aer.* is used for the tabulation of wind velocities according to directions and for the computation of resultant winds (by those stations specifically instructed to do so). In the columns under "Velocities" will be entered the individual velocities, each quarter of a sheet representing one level. After the velocities have been added and canceled, that is, the difference between diametrically opposite directions obtained, these differences are multiplied by the sine and cosine values given on the form. The algebraic sums and means of these products are then obtained. The resultant wind direction and velocity may be obtained either graphically or trigonometrically from these sums.

143. *Graphical method.*—Set protractor of plotting board on zero if the north component is plus, on 180° if it is minus, and plot its length along the initial line; then set the protractor on 270° if the west component is plus, on 90° if it is minus, and add its length along the vertical line from the first point. The resultant direction and distance is read from the protractor when the second point is brought on the initial line. In order to obtain the resultant velocity, the distance must be divided by the number of observations. In cases where the means exceed 2.0, they may be used instead of the sums, and in this case the velocity is given directly without dividing by the number of observations.

144. *Trigonometric method.*—Tan $X = W/N$, where N is the north component and W the west component, and X the angle between the north-south line and the resultant, or the bearing of the wind required. The resultant distance may be found by $W/\sin X$, $N/\cos X$, or $\sqrt{N^2 + W^2}$. The resultant distance, of course, must be divided by the number of observations to obtain the mean resultant

velocity. If the means are used, as in the graphical method, the required velocity is obtained directly, the computation may be done by slide rule.

145. *Form No. 1117–Aer.* is used for the tabulation of wind-aloft data into velocity groups for each direction. Particular attention is called to the fact that the second level on this form provides for data at 500 meters *above the surface*, while all other levels refer to *sea level.*

146. The data for the level 500 meters above the surface are to be entered regardless of the altitude of the station above sea level. For some stations it will be necessary to take the data for this level from Form No. 1110A–Aer. or Form No. 1115–Aer. However, the altitudes of several stations are such that these data can be copied from some one of the standard levels above sea level. The data may be so copied when one of the standard levels above sea level is 50 meters or less above or below the 500-meter level above surface. For example, at stations with altitudes of 50 meters or less above sea level, the data for the 500-meter level above surface are to be copied from the 500-meter level above sea level; while at stations with altitudes between 200 and 300 meters above sea level, the data for the 500-meter level above surface are to be tabulated from those entered on Form No. 1124–Aer. for the 750-meter level above sea level, etc.

147. Data for all levels, except as indicated for the 500-meter level above surface, are to be taken from Form No. 1124–Aer. To tabulate the data the number of velocity entries on Form No. 1124–Aer. opposite each direction, falling within each of the five velocity groups, are counted separately and the number counted entered in the appropriate squares on Form No. 1117–Aer. For example, if the velocities opposite "N" on Form No. 1124–Aer. are as follows: 2, 1, 6, 9, 4, 18, 11, 22, the entries to be made opposite "N" on Form No. 1117–Aer. would be as follows: Under (2–7), 3; under (8–14), 2; under (15–21), 1; and under (>21), 1. The same procedure is to be followed for each of the other directions. All velocities of 1 meter per second or less, including calms, are then to be counted and entered in the lower left-hand square under the heading "0–1." These data may also be taken directly from Forms1114A–Aer. and 1114B–Aer. by counting the number of velocities in each velocity category for each direction. The final step is to total the entries both vertically and horizontally and to enter the combined total in the lower right-hand square. This last entry should, of course, check with the "total number of observations" appearing on Form No. 1124–Aer.

148. *Mailing forms to the central office.*—At the conclusion of each month all pilot-balloon forms are to be carefully checked and prepared for mailing to the central office. All forms for the month (except Form No. 1116–Aer.) are to be mailed not later than the 10th of the following month. The last *combined* form (1110A and 1115–Aer.) to be included, will be the one having the graph (Form 1115) for the last observation of the month and the data (Form 1110A) for the first observation of the following month. Duplicate copies of Form No. 1110A–Aer. are to be retained in the station file; also any other data needed for special summaries, such as normal resultant winds, mean wind roses, etc., are to be copied off the forms before mailing.

149. *Tables used in pilot-balloon work.*—A brief description of the tables which are used regularly in pilot-balloon work is given below.

Tables 1 and 2 were described above under Form No. 1110A–Aer. and Form No. 1110–Aer., respectively.

Table 3, "Rate of ascent in meters per minute," gives the ascensional rates for different weight balloons and for different free lifts. The argument "free lift" (l), ranging from 75 to 195 grams, is found in the vertical column at the extreme left of the table, while the weight of the balloon (w), ranging from 22 to 60 grams at intervals of two grams, is found along the first horizontal line heading each column.

Table 4 aids in the conversion of Fahrenheit temperatures in degrees and tenths to centigrade degrees and tenths. The range of the table in Fahrenheit temperature is from −36° to 100°, by tenths of degrees. Note that each column of centigrade temperatures is arranged with two columns of Fahrenheit temperatures, one on either side. The values in the centigrade column, when associated with the Fahrenheit column on the left, are as they appear in print, but when associated with the Fahrenheit column on the right the value is reversed. That is 5°.0 C. when associated with 41° F. is above zero, but when associated with 23° F. is below zero. The tenths of Fahrenheit degrees are converted by noting the ending of the centigrade temperature for the whole Fahrenheit degree, finding this in the column headed "P. P.," and moving down the scale the number of spaces equivalent to the number of tenths of degrees to be converted. For instance, a temperature of 58°.8 F. is equivalent to 14°.9 C. Opposite the whole degree 58 and in the C. column is found 14°.44. The ending .44 is found in column "P. P." Since the tenths of a degree to be converted are 8, we move down the column 8 spaces and there find .89; this, when substituted for the ending .44 of the C. value 14.44, gives us the temperature 14.89, or 14°.9 C. Likewise, any Fahrenheit temperature within the limits stated can be converted to degrees and tenths of the centigrade scale.

Tables 5 and 6 are self-explanatory.

VI. TWO-THEODOLITE OBSERVATIONS

150. *Two-theodolite observations.*—In two-theodolite observations the balloon is followed by two instruments, one placed at either end of an accurately measured base line. Simultaneous readings of the azimuth and elevation angles of both instruments are recorded at the end of each minute. From these angles the position of the balloon at the end of each minute is determined by triangulation.

151. Two-theodolite observations require the cooperation of three or four men, depending upon the arrangement of stations and scope of work at hand. The prevailing arrangement of double-theodolite stations requires four men for the observational work—an observer and a recorder posted at each station. Their respective duties are nearly identical with those in a single-theodolite observation. When the observing stations are connected by telephone, then an observation can be carried on with three men. But if computation and plotting are carried on during the flight, four will be needed.

152. *Time signaling.*—In two-theodolite observations some method of signaling by which the signals are transmitted simultaneously to both stations is absolutely necessary. Regardless of how accurately the angle readings are made, unless they are made at the same instant the results of computations based thereon will be unsatisfactory. The

most satisfactory arrangement is to have the two stations connected by telephone or radio. A timing buzzer or other device (preferably operated by an electric clock) can easily be installed in the telephone line or radio-transmitter circuit which will serve to mark the release of the balloon and the reading signals for each of the successive minutes and make possible the simultaneous readings of both instruments.

153. In case the stations are not connected by telephone or radio, some visual method of signaling should be adopted. Timing the readings by watches is usually found to be unsatisfactory.

154. *Reading angles.*—The angles should be read very carefully and estimated to the nearest hundredth of a degree, especially the azimuth angles. It is important that the azimuth angles be read closely, especially when the "C" angle is small.

155. *Recording the data.*—The data at the primary station will be entered on left-hand half of Form No. 1110–Aer., table 1, and, when that half of the sheet is filled up, a second sheet will be used, as the second half of the sheet is reserved for the entry of the data of the other station. Thus we have all the observed data for any one minute at both stations, on the same sheet and in the same lines. The data at the secondary station will be entered on the right-hand side of the sheet only. At the completion of the observation the data from the one station will be copied on Form No. 1110–Aer. of the other. Also the C angle (difference between azimuth angles) for each minute should be found and copied in the velocity column on the right-hand half of this form, as it is used in the computation.

156. The balloon will be followed as long as it can be kept in sight. Never should it be abandoned at either station before disappearance, without strong reasons for doing so. However, as soon as the balloon is lost at either station, that fact should be signaled to the other station. In cases where the balloon is lost sight of at one station for an appreciably longer period than at the other, the remainder of the flight beyond the time of disappearance at the one station may be computed by the single-theodolite method, using for the ascensional rate the actual rate of ascent as computed from the two-theodolite portion of the observation.

157. Following the disappearance of the balloon, and before the theodolite is disturbed from its setting, a check of the levels and orientation will be made the same as in single-theodolite observations. (See par. 93.) Note that the azimuth bearing is read from the same vernier by which the theodolite was oriented. If there are no corrections to be made, the "check" will follow in the second line after the last line of observed data. The data will then be plotted and reduced in the same way as in the making of a single-theodolite observation. The methods of plotting vary to some extent, however, and will be taken up in regular order in subsequent paragraphs.

158. *Two-theodolite computation.*—The computation of two-theodolite observations is tedious and laborious at best and full advantage should be taken, therefore, of all devices and methods which will simplify and reduce the work thereof. With this in mind, the following methods have been developed and adopted by the Weather Bureau.

159. *Slide rule.*—The computation is done with an ordinary 20-inch slide rule of which the sine and tangent scales were specially designed and arranged for the work. The scales are arranged as

follows: The A scale is double and above, and the D scale is below the slide. The sine and tangent scales are on the same side of the slide, and both refer to the double A scale. They are graduated in degrees and tenths to agree with the graduations on the theodolites. The sine scale ranges from 0.57° to 90°, and the tangent scale from 0.57° to 45°. Cofunctions are numbered in red. This slide rule may be purchased from one of the leading slide-rule manufacturers.

160. *Theodolite setting.*—The theodolite at station A is set with 0° azimuth on station B, and the theodolite at station B with 180° azimuth on station A; thereby both instruments point in the same *direction in the vertical* plane of the base line when set on 0° azimuth. Computation is simplified by this method or orientation, as the angle C of the horizontal triangle is obtained by merely subtracting the smaller azimuth angle from the larger. See figure 13.

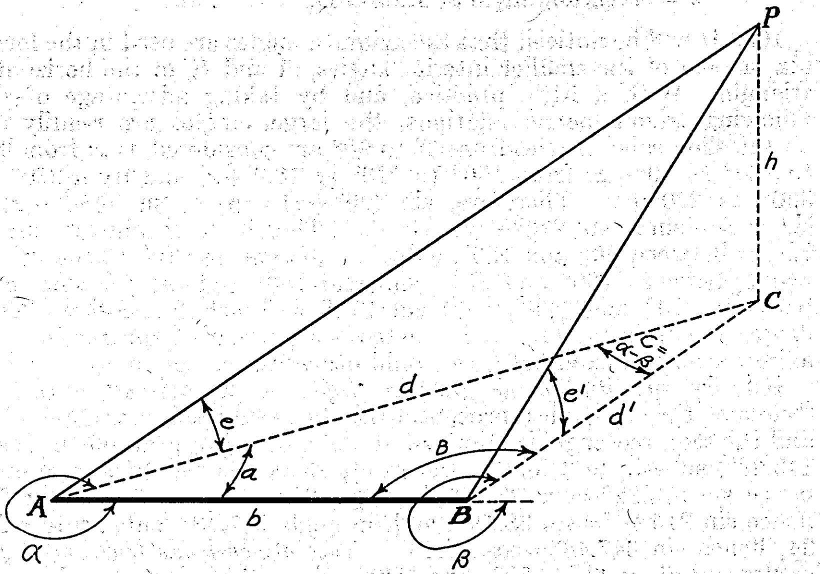

FIGURE 13. Plan of triangulation in two-theodolite observation, showing position of balloon, *P*, and azimuth angles *α* and *β*, and elevation angles *e* and *e′*, read from the theodolites at A and B station respectively.

161. *General formula used in computation.*—See figure 13 for general plan of triangulation. In the triangle *ABC*, angle $ACB=\alpha-\beta$. Since sin $A=\alpha$, and sin $B=\sin\beta$, then

$$\frac{d}{\sin\beta}=\frac{b}{\sin(\alpha-\beta)} \text{ or } d=\frac{b\sin\beta}{\sin(\alpha-\beta)} \quad (1)$$

and

$$\frac{d'}{\sin\alpha}=\frac{b}{\sin(\alpha-\beta)} \text{ or } d'=\frac{b\sin\alpha}{\sin(\alpha-\beta)} \quad (2)$$

then

$$h=d\tan e=\frac{b\sin\beta\tan e}{\sin(\alpha-\beta)} \quad (3)$$

and

$$h'=d'\tan e'=\frac{b\sin\alpha\tan e'}{\sin(\alpha-\beta)} \quad (4)$$

Wherein A=primary station.
B=secondary station.
b=base line.
A=angle of triangle at A.
B=angle of triangle at B.
C=angle of triangle at C.
α=azimuth angle read at station A.
β=azimuth angle read at station B.
d=horizontal distance of balloon from station A.
d'=horizontal distance of balloon from station B.
h=altitude of balloon above station A.
h'=altitude of balloon above station B.
h''=difference in elevation of stations A and B.
e=elevation angle at station A.
e'=elevation angle at station B.

162. It will be noticed that the azimuth angles are used in the formula instead of the smaller interior angles, A and B, of the horizontal triangle. With a little practice, and by taking advantage of the following trigonometric relations, the larger angles are readily set on the slide rule: Angles from 0° to 90° are considered as x; from 90° to 180° as $90°+x$; from 180° to 270° as $180°+x$; and from 270° to 360° as $270°+x$. Therefore, $\sin (90°+x)=\cos x$; $\sin (180°+x)=\sin x$; $=-\sin x$; $\sin 270°+x=-\cos x$. That is, to obtain the sine of angles between 90° and 180°, subtract 90° and use the cosine of the result; between 180° and 270°, subtract 180° and use the sine and between 270° and 360°, subtract 270° and use the cosine. This device is employed to avoid the tedious process of subtracting the angles from 180° and 360°, as would otherwise be necessary.

163. By *substituting the first two digits* of the *azimuth angles by their sum*, the mechanical process of the above subtraction is eliminated and the required angle is obtained at a glance. For example, in angle 113.38°, substitute 2 for 11, the result 23.38°, is the angle required; hence sin 113.38°=cos 23.38°; in angle 213.18°, substitute 3 for 21, hence sin 213.18°=sin 33.18°; and, in angle 347.48°, substitute 7 for 34, hence sin 347.48°=cos 77.48°. *This device holds true except for angles just above* 90°, 180°, and 270°, where the subtraction is made without mental effort. Moreover, when the sum of the first two digits of the angle is 10 or 11 a second addition of these digits must be made, i. e., use 1 or 2 respectively.

164. Obviously, the methods used in preparing the angles for slide rule are great time savers in computation. The *only mechanical work* required is in obtaining $\alpha-\beta$, and this subtraction is done for the entire observation in advance of the computation.

165. If the stations are at the same elevation, h and h' should agree closely; otherwise, they will differ by an amount equal to the difference in the elevation of the stations above sea level. A comparison of h and h' enables the computer to check his results with more or less accuracy. Ordinarily the computation is done from the A station only, the height, h' being computed from B station, say every fifth or tenth minute as a check.

Special formulas used in computation.—Even with the most carefully selected base line, instances will arise in which the movement of the balloon will be in a nearly vertical plane through the base line. In such cases the azimuth angles cannot be read with sufficient accuracy to avoid appreciable errors in the calculation, and more accurate results are obtained by using the triangle in the vertical plane. See figures 14, 15, 16, and 17 for the plan of triangulation.

FORMULAS USED WHEN THE TWO STATIONS ARE AT APPROXIMATELY THE SAME ELEVATION

Figure 14, in triangle ABP, angle $APB=(e-e')$, then

$$\frac{AP}{\sin e'}=\frac{b}{\sin (e-e')} \text{ or } AP=\frac{b \sin e'}{\sin (e-e')}$$

$$d=AP \cos e=\frac{b \sin e' \cos e}{\sin (e-e')} \qquad (5)$$

and

$$h=AP \sin e=\frac{b \sin e' \sin e}{\sin (e-e')} \qquad (6)$$

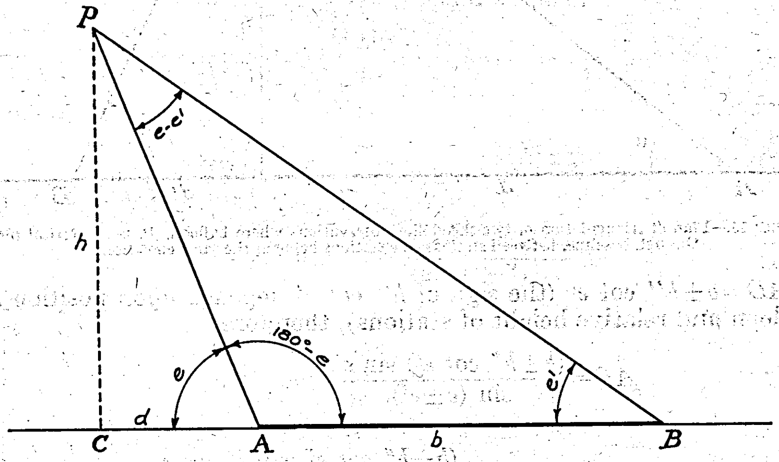

FIGURE 14.—Plan of triangulation of two-theodolite observations where balloon, *P*, is in a vertical plane through base line, the stations being at the same elevation.

Figure 15, in triangle ABP, angle $ABP=180°-(e+e')$;

Since $\sin 180°-(e+e')=\sin (e+e')$, then

$$\frac{AP}{\sin e'}=\frac{b}{\sin (e+e')} \text{ or } AP=\frac{b \sin e'}{\sin (e+e')}$$

$$d=AP \cos e=\frac{b \sin e' \cos e}{\sin (e+e')} \qquad (7)$$

$$h=AP \sin e=\frac{b \sin e' \sin e}{\sin (e+e')} \qquad (8)$$

FORMULAS USED WHEN THE TWO STATIONS ARE NOT AT THE SAME ELEVATION

166. *First method* (fig. 16).—In triangle $B'DB$, h''=difference in elevation of stations; angle $B'DB=e'$, elevation angle at B station.

In triangle ADP, angle $APD=e-e'$ or $180°-(e+e')$; the latter being when balloon is between stations, then

$$\frac{AP}{\sin e'}=\frac{AD}{\sin (e\pm e')} \text{ or } AP=\frac{AD \sin e'}{\sin (e\pm e')}$$

Since $AD=AB'+B'D$, $AB'=b$, and $B'D=h'' \cot e'$, then,

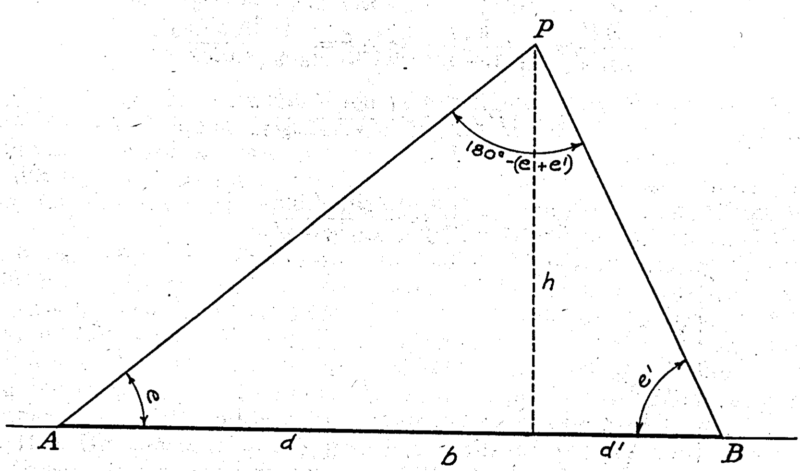

FIGURE 15.—Plan of triangulation of two-theodolite observations where balloon, P, is in vertical plane through baseline, between stations, the stations being at the same elevation.

$AD=b\pm h'' \cot e'$ (the sign of $h'' \cot e'$ depends upon position of balloon and relative height of stations), therefore

$$AP=\frac{(b\pm h'' \cot e') \sin e'}{\sin (e\pm e')},$$

then

$$d=AP \cos e\frac{(b\pm h'' \cot e') \sin e' \cos e}{\sin (e\pm e')} \qquad (9),$$

and

$$h=AP \sin e\frac{(b\pm h'' \cot e') \sin e' \sin e}{\sin (e\pm e')} \qquad (10)$$

167. *Second method.*—Another method of computation may be employed where the length of the hypotenuse (shortest distance) between the stations is used as the base instead of the horizontal distance.

Figure 17.—In triangle ABB', h''=the difference of elevation between stations, b=base line; θ=angle of elevation of station B above base line b.

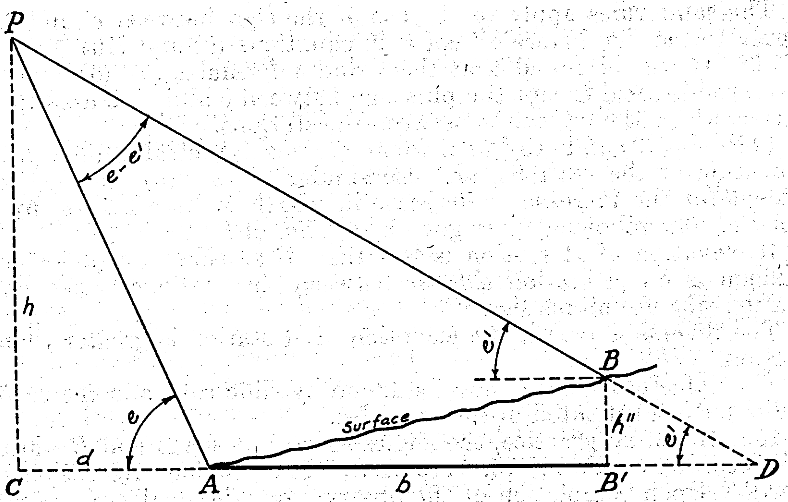

Figure 16.—Plan of triangulation of two-theodolite observations where balloon, *P*, is in a vertical plane through base line, and stations not at the same elevation.

In triangle *APB*, angle $ABP=e'\pm\theta$ and angle $APB=e\pm e'$

$$\frac{AP}{\sin e'\pm\theta}=\frac{b'}{\sin (e\pm e')} \text{ or } AP=\frac{b' \sin (e\pm\theta)}{(\sin e\pm e')}$$

therefore

$$d=AP \cos e=\frac{b' \sin (e'\pm\theta) \cos e}{\sin (e\pm e')} \qquad (11)$$

and

$$h=AP \sin e=\frac{b' \sin (e'\pm\theta) \sin e}{\sin (e\pm e')} \qquad (12)$$

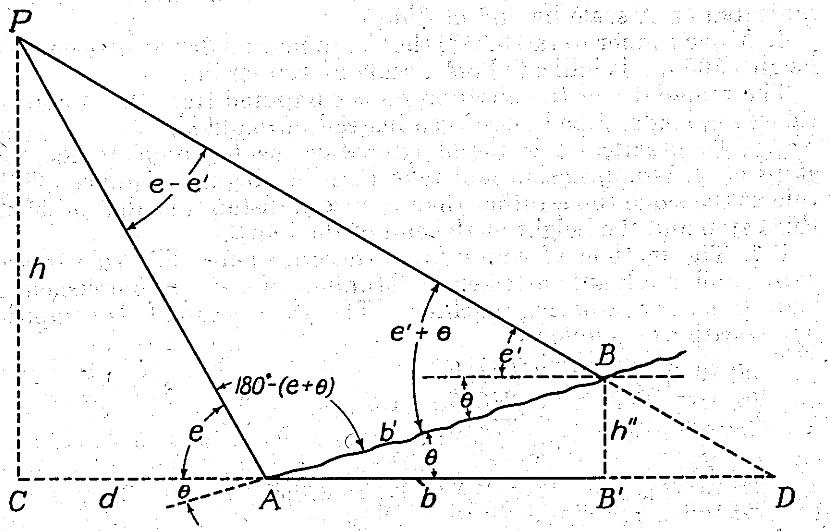

Figure 17.—Plan of triangulation for formulas 11 and 12 where balloon *P* is in a vertical plane through base line and stations are not at the same elevation.

The same rules apply to the use of the sign between e' and θ, as apply to the sign before h'' cot e' in equations (9) and (10).

168. It will be noted that the d and h formulas (5), (6), and (7), (8), are identical except the plus sign between e and e' is used in the latter, where the balloon is between the stations.

Formulas (9) and (10), used where there is appreciable difference in elevation of the stations, are also similar to (5), (6), and (7), (8), except for the increase or decrease in length of base line, b, by h'' cot e'. The following rules govern the sign of h'' cot e':

If elevation of A station is less than B station, use plus sign if balloon is on A station side or between the stations; when on B station side use minus sign.

The reverse is true if the elevation of A station is greater than B station.

The value of h'' cot e' may be found by slide rule, and the correct value for b substituted in the formulas.

169. In actual practice, the angles as read at the A and B stations are recorded on Form No. 1110–Aer., "Pilot Balloon Ascension Report." Upon completion of the observation, the angles recorded at the B station are copied upon the form used at the A station, and the C angles $(\alpha-\beta)$ determined for the observation. See figure 5.

170. *Computation.*—The first minute of the observation shown on this form (table 2) was computed from the B station by formula (4), as the azimuth angle β for this minute is beyond the range of the sine scale of the slide rule. The remainder of the observation is computed from the A station by formula (3).

The computation for the first minute is accomplished by the special slide rule, as follows:

1. Set right end of slide on $b=4949$ m., on A scale.
2. Move runner to sin 169.90°=cos 79.90°, that is to red 79.90° on S scale.
3. Move slide to bring sin 9.59 under runner; that is, bring black 9.59° on S scale under runner. (The horizontal distance, 5209 m., is indicated on A scale by end of slide.)
4. Move runner to tan 3.35°; that is, to black 3.35° on T scale. The height, 305 m., is indicated on A scale by runner line.

The remainder of the observation is computed from the A station; therefore, angles β and e are used instead of α and e'.

171. In practice it is found advantageous to complete the four steps of the computation and take both height and distance off the rule at the same time, rather than to record distance at the end of the third step and the height at the end of the fourth.

172. The method of computation described for slide rule is used with similar advantage when the computation is accomplished by logarithms or computing machine. The above example is computed by logarithms, as follows:

$$\begin{aligned}
\log 4949 &= 3.69452 \\
\log \cos 79.90 &= 9.24395-10 \\
\text{colog} \sin 9.59 &= .77833 \\
\hline
\log d' &= 13.71680-10 \quad d'=5{,}209 \text{ m.} \\
\log \tan 3.35 &= 8.76742-10 \\
\hline
\log h' &= 22.48422-20 \quad h'=305 \text{ m.}
\end{aligned}$$

Unless metric tables of trigonometric functions are available, it will be necessary to multiply the decimal part of the angle by 6 in order to covert it into minutes.

173. *Constructing the horizontal projection of two-theodolite observation.*—The horizontal projection of a two-theodolite observation is constructed in exactly the same manner as that of the single. (See pars. 112 and 113.) The azimuth angle and the computed distance from the *A* station are usually plotted, although the same data from the *B* station may be plotted if desired.

174. *Obtaining wind data from horizontal projection of two-theodolite observation.*—Whether the horizontal projection be of a single- or a double-theodolite observation, the same method of determining the wind direction and velocity is used, except in obtaining the wind direction from a double-theodolite plot, the bearing of the base line must be taken into consideration. In order to do this, instead of reading the direction in the usual manner at the initial line, it is read at a point whose bearing clockwise from the initial line is equal to the bearing of the base line, plus or minus 180°. A simple method of *locating* the point at which the desired protractor reading is to be made is to set the 180° line of the protractor on the initial line and mark a point on the board where the protractor reads an angle equal to the bearing of the base line from north.

175. *The effects of the curvature of the earth upon two-theodolite observations.*—In common practice, the baseline is the horizontal distance between the stations. The theodolites are set up on either end of the baseline with their primary axes having the direction of gravity, and forming an angle at the center of the earth, which becomes greater as the distance between the stations increases. When this divergence angle is small as is usually the case in two-theodolite work, its magnitude in degrees is found by dividing the length of the baseline by the circumference of the earth and multiplying the result by 360. The divergence angle is given by the equation:

$$\theta=\frac{b}{2\pi R}\times 360$$

where θ is the divergence angle in degrees; b, the baseline; and R, the radius of the earth in kilometers (from American Ephemeris).

176. In the case of a baseline of 5 km. in length, the divergence angle is found to be:

$$\theta=\frac{5}{40092}\times 360=0.045$$

degree, which is significant since the angles are usually read to minutes or to hundredths of a degree.

Therefore, with a comparatively long baseline, in order for the altitudes of the balloon computed from the *B* station to be comparable to those computed from the *A* station, it is necessary to apply a correction to the vertical angles at the *B* station. The vertical angle is corrected by subtracting the product of the divergence angle and the cosine of the azimuth angle at the B station. That is, the corrected angle is given by the equation:

$$e''=e'-\theta \cos \beta,$$

where e'' is the corrected angle; e', the vertical angle at the B station; θ, divergence angle; and β, azimuth angle at the B station. When the angle β is 0° or 180°, the cosine is 1 or -1, respectively, and therefore the full amount of the divergence angle is subtracted in the former case and added in the latter. When the azimuth angle is 90° or 270°, the correction is zero in either case. For azimuth angles between 270° and 90° (first and fourth quadrants) the cosine is plus, therefore the fractional part of the divergence angle should be subtracted, and for azimuth angles between 90° and 270° (second and third quadrants) the cosine is minus, therefore the fractional part of the divergence angle should be added to the vertical angle. This correction does not influence the height computation to *a very great extent* unless the divergence angle is *comparatively large*.

177. However, at greater horizontal distances and greater heights the influence of the curvature of the earth becomes more pronounced because the computed height of the balloon is based on the horizontal plane of the station. If P_1' (Fig. 18) is the determined projection point of the balloon at a distance d from the A station, then, according to the usual formula and the measured vertical angle e, the computed height of the balloon is:

$$h_1=P_1 P_1'=d \tan e$$

178. However, the real height above the surface is not h_1, but may be represented by h_2 $P_2 P_2'$. This height h_2 can be computed very nearly from the triangle $A P_2 P_2'$ if the difference between d and s is neglected, which is usually permissible in actual practice.

Therefore, from the triangle $A P_2 P_2'$

$$\frac{h_2}{\sin (e+\theta/2)}=\frac{d}{\cos (e+\theta)},$$

or

$$h_2=d\frac{\sin (e+\theta/2)}{\cos (e+\theta)} \text{ in which } \sin \theta/2=\frac{d}{2R}$$

and R is the radius of the earth.

179. At a vertical angle of 18° and a height of 20 km. the correction becomes approximately plus *360* meters. The determination of the horizontal distance is, in such a case, so uncertain that even this great height correction may be of more theoretical than practical value.

180. *Influence of optical refraction.*—Since the rays of light are bent in passing from a less dense to a denser medium, the balloon appears under a somewhat too great a vertical angle. The deviation, increasing with zenith distance and height of the balloon, can be deducted from the measured vertical angle. In connection with cases occurring in actual practice of pilot-balloon observations, this amounts at most to between one- and two-hundredths of a degree of angle and can be neglected, especially because the influence of the curvature of the earth acts oppositely.

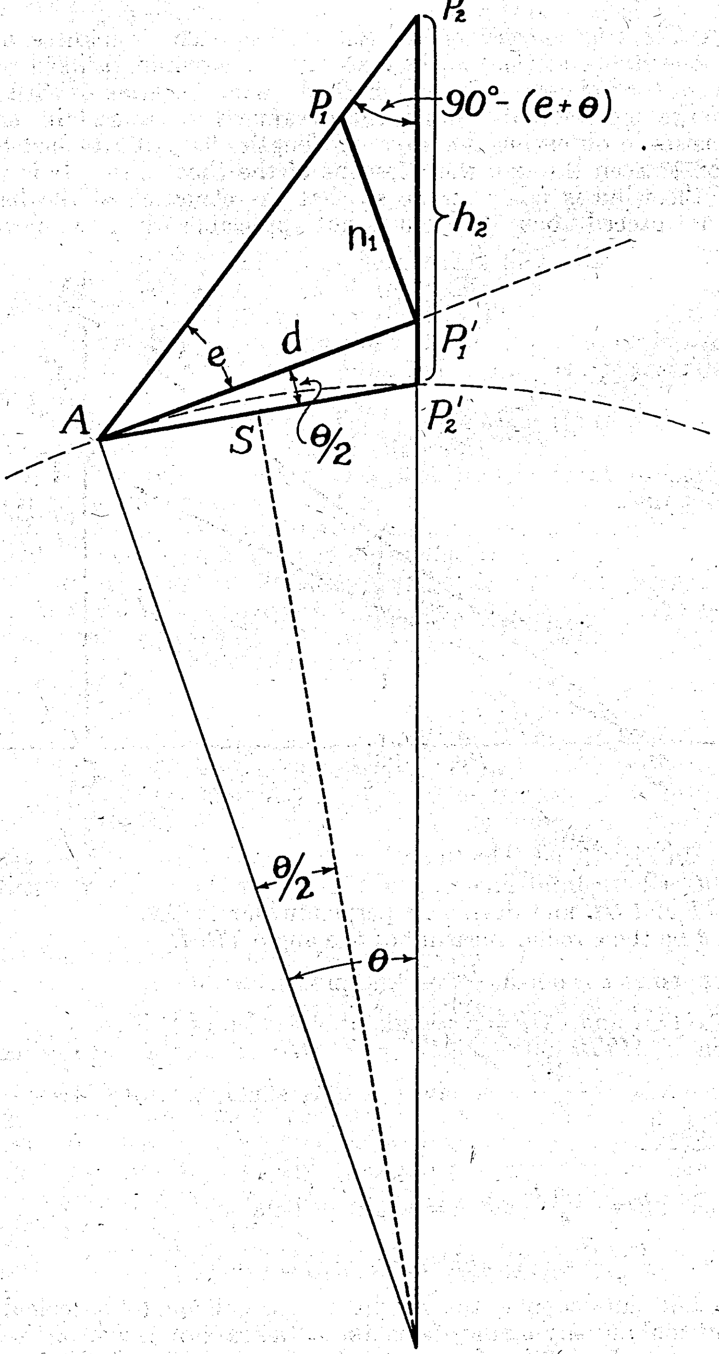

FIGURE 18.—Plan, showing correction to be applied to two-theodolite computations to allow for the earth's curvature.

VII. THE TAIL METHOD

181. *The trigonometry of the tail method.*—The weakness of the single-theodolite method is the necessity for assuming a fixed rate of ascent of the balloon. The tail method—a modification of the single-theodolite method—overcomes this weakness to a certain extent. It consists in observing the apparent length of a tail attached to the balloon as seen through the telescope of the theodolite. It is useful when the wind is fairly strong so that the elevation of the balloon does not exceed about 40°, but is not applicable when the elevation is large.

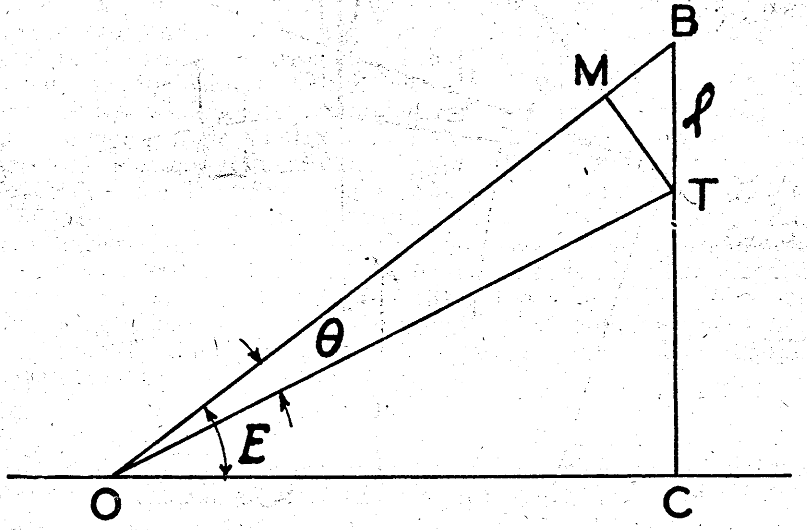

FIG. 19.

182. In Fig. 19, let O be the observer, B the balloon, BC the vertical line, OC a horizontal line, and T the end of the tail of the balloon. Join OT and OB and draw TM perpendicular to OB.

Let θ be the circular measure of the angle TOM.

Then, since θ is small, $\frac{TM}{OM}=\theta$ (approx.).

Let $BT=l$ and $COB=E=$angle of elevation of balloon.

Then $\angle\ MTB=90°-\angle MTB=\angle COB=E$, so that $MT=l\cos E$.

Hence $OM=\frac{l\cos E}{\theta}$, or since MB is small, we may write

$$OB=\frac{l\cos E}{\theta}.$$

Hence $CB=\frac{l\cos E}{\theta}\sin E=$height of balloon,

and $OC=\frac{l\cos E}{\theta}\cos \mathrm{E}=$horizontal displacement.

The tail thus enables the height of the balloon to be calculated without making any assumptions about the rate of ascent of the balloon. The computation for wind velocity and direction follows as in the foregoing method.

183. The angle θ in the foregoing discussion is measured by a graticule, which gives the apparent length of the tail as seen in the telescope. The unit of the graticule is equal to some fraction $1/k$ of a radian, the radian being the unit angle in a circular measure. Hence, if the apparent length of the tail is m graticule units, the angle is equal to m $(1/k)$ radians and hence

$$CB=\frac{Kl}{m}\cos E \sin E \text{ and } OC=\frac{Kl}{m}\cos E \cos E.$$

184. *The graticule.*—The graticule consists of a glass scale placed in the focus of the telescope or of an auxiliary horizontal cross hair operated by means of a micrometer drum. Thus, the tail of the balloon is seen moving among the lines of the graticule or is brought between the fixed and movable cross hairs, and its apparent length can be estimated.

185. To obtain the value of the graticule scale (k) of a theodolite, the following procedure should be adopted:

Set up a foot rule vertically at a measured horizontal distance of 100 feet from the object glass of the theodolite. The center of the rule should be in the same horizontal plane as the eyepiece of the theodolite. Focus carefully and determine as accurately as possible the number of graticule divisions (n) corresponding with the foot length, as seen in the telescope. Since the angle subtended by the rule is 0.01 radian, the value of k will be $100\times n$. It should be noticed that k may differ for different theodolites.

186. *Length and form of tail.*—It is advisable to adopt a standard length of tail for each theodolite so that the value of "kl," used in the computations, will always be uniform. The standard length should be between 25 and 35 meters. This, however, will usually be too long to appear in the field of view of the telescope during the first few minutes of the ascension. A subsidiary pendant should then be used until the full length comes within the field of view. This subsidiary pendant should be placed at a quarter or a fifth of the total distance of the full tail from the balloon, to simplify the mental calculations.

187. The tail consists of a double length of ordinary thread or silk. The end of the tail is marked by a pendant consisting of a foolscap sheet of very thin paper having a strip of very fine aluminum wire gummed along one of the shorter edges, while the opposite edge of the paper is folded over and gummed to assist in keeping the paper fairly rigid. The end of the thread is tied around the aluminum wire through a small hole in the paper. The visibility of the pendant is often improved by the use of colored paper, selected according to the appearance of the sky. Silvered paper is rather better than white paper with a clear, blue sky; red is suitable for a hazy or cloudy sky; and black, for an overcast sky.

A form of tail which spins is to be avoided, because it causes the thread to shorten and gives values of heights and velocities which are all too high.

188. In determining the free lift of the balloon the weight of the tail is to be corrected for in exactly the same manner as is the weight of a lantern or electric-lighting unit.

189. *The observations.*—After a little practice, it is found that the three readings—azimuth, elevation, and graticule—can all be taken at each minute. It is best to read the graticule first. Alternatively, the graticule can be read at the half minute between each minute reading of the azimuth and elevation, afterward deducing the minute readings of the graticule by interpolation. The upper pendant should only be used while the lower one is outside the field of view. When the reading of the graticule for the full tail has fallen to 5.0 no further minute readings should be taken, but the time should be noted when the remaining division of the graticule is passed as a check on the assumption of a uniform rate of ascent. After the limit of 5.0 has been passed, the balloon should be assumed to rise at 180 meters per minute; or, at the discretion of the observer, the vertical velocity may be assumed at some other rate, based on his experience during the initial stages of the ascent.

190. Owing to the swinging of the tail, a single observation, however accurate it may be, will not afford a reliable value of the angle subtended by the tail at the observer, especially if the angle of elevation is large. Oscillations in the vertical plane through the line of sight affect the accuracy of the results more than oscillations in the plane perpendicular to the line of sight. If the angle of elevation is small, the errors will, in general, be small; but the error produced in the micrometer reading by the swinging of the tail is a systematic error, and since this is, in general, too low, the computed heights and velocities are correspondingly exaggerated. When the balloon is at a fair height the values deduced from consecutive readings of the micrometer become rather irregular, and it then becomes necessary to smooth them out. The exact point at which the smoothing process should be adopted must be left to the discretion of the observer. Smoothing should not be employed indiscriminately, especially in the lower layers of the atmosphere, because by so doing the irregularities which represent actual irregularities or discontinuities in the atmosphere will thus be lost. In the higher levels, although consecutive tail readings may be irregular, they can still be used (by smoothing) to check the rate of ascent of the balloon, although they can no longer be used to define actual irregularities or discontinuities existing in the atmosphere. Smoothing is done by plotting the tail readings on squared paper with time as abscissa and drawing a smooth curve among the points so obtained.

TABLE 1.—*Pilot-balloon ascension report*

Station, Arlington, Virginia.
Starting time, 10:00 p. m., 75th meridian

Date, January 28, 1938
Ascension number, 18333

Observation point A

Minute	Elevation angle	Horizontal angle	Distance from observation point, m.	Altitude, m.	Wind dir. (360°=N., 90°=E., etc.)	Wind velocity, m. p. s.
Surface wind: direction, 214-SW Velocity 1.3						
1	69.7	266.3	80	216	287	2.0
2	60.4	287.4	235	414	264	3.4
3	51.0	264.1	495	612	238	6.2
4	41.4	249.3	910	801	234	8.6
5	33.8	243.4	1,480	990	240	10.3
6	28.6	243.9	2,145	1,170	249	11.3
7	25.3	245.9	2,855	1,350	259	10.4
8	24.4	249.6	3,375	1,530	274	9.3
9	23.7	253.7	3,895	1,710	285	10.3
10	23.0	259.1	4,455	1,890	299	11.6
11	22.6	265.1	4,975	2,070	306	12.8
12	21.8	270.7	5,625	2,250	307	14.3
13	20.9	275.4	6,365	2,430	307	16.2
14	19.7	279.8	7,290	2,610	307	17.7
15	18.7	283.3	8,245	2,790	308	17.4
16	17.9	286.0	9,195	2,970	307	19.6
17	16.8	288.4	10,430	3,150	306	21.6
18	--------	--------	--------	3,330	--------	--------
19	--------	--------	--------	3,510	--------	--------

Altitude 10 m.

Minute	Elevation angle	Horizontal angle	Distance from observation point, m.	Altitude, m.	Wind dir. (360°=N., 90°=E., etc.)	Wind velocity, m. p. s.
47	--------	--------	--------	8,550	--------	--------
48	--------	--------	--------	8,730	--------	--------
49	--------	--------	--------	8,910	--------	--------
50	--------	--------	--------	9,090	--------	--------
51	--------	--------	--------	9,270	--------	--------

Theodolite number, 361416.
Observer, M. S. Main.
Recorder, M. J. Chambers.
Disappearance due to distance.
Temperature (dry), −6.7° C.; (wet), −8.1° C.
Pressure (station), 1030.1 mb. (s. l.) 1030.8 mb.
Humidity, 63%.

Clouds and sky

	Form (0-9)	Dir.
High	5	NW
Middle	------	------
Low	------	------

Type of balloon, 30-gram, Red.
Weight of balloon, 29 ----gm.
Weight of lantern, 21 ----gm.
Total weight, 50 ----gm.
Visibility, 7.

NOTES

TABLE 2.—*Pilot-balloon ascension report*

Station, Washington, D. C.
Starting time, 9:41 a. m., 75th meridian

Date, July 1, 1937
Number of theodolites used, 2.

Observation point A, altitude 10 m.							Observation point B, altitude 50 m.					
Minute	Elevation angle	Azimuth angle	Distance, m.	Altitude, m.	Wind dir. (360°=N., 90°=E., etc.)	Wind velocity, m. p. s.	Minute	Elevation angle	Azimuth angle	Distance, m.	Altitude, m.	Angle C
	e	a	d	h				e′	a′	d′	h′	
0	Zero° setting on station B						0	180° setting on station A				
1	48.40	169.90	--------	--------	314	5.4	1	3.35	179.49	5,209	305	9.59
2	44.10	167.15	648	627	310	5.0	2	6.19	178.52	5,580	605	11.37
3	43.78	165.52	885	850	310	5.3	3	8.38	177.82	5,790	855	12.30
4	42.37	165.33	1,283	1,170	307	6.1	4	10.49	177.00	--------	--------	11.67
5	41.88	163.58	1,618	1,450	287	5.5	5	12.40	175.98	--------	--------	12.40
6	42.88	157.11	1,903	1,767	257	6.9	6	14.40	173.70	--------	--------	16.59
7	43.40	147.85	2,218	2,095	249	7.6	7	16.31	170.28	--------	--------	22.43
8	42.30	139.95	2,550	2,320	254	8.1	8	17.85	166.62	--------	--------	26.67
9	40.50	134.29	3,045	2,608	256	9.8	9	19.11	162.89	--------	--------	28.60
10	38.60	129.22	3,615	2,875	251	11.4	10	20.09	158.80	7,730	2,825	29.68
11	36.35	125.18	4,285	3,160	248	13.4	11	20.72	154.73	--------	--------	29.55
12	34.02	121.30	5,080	3,435	246	14.9	12	21.11	150.22	--------	--------	28.92
13	32.02	117.52	5,950	3,725	244	17.2	13	21.47	145.52	--------	--------	28.00
14	30.00	113.17	7,020	4,055	243	18.4	14	21.69	140.02	--------	--------	26.85
15	28.30	111.86	8,040	4,335	247	19.0	15	21.50	136.78	--------	--------	24.92
16	26.55	110.94	9,245	4,620	248	20.2	16	20.96	133.70	--------	--------	22.76
17	25.02	109.31	10,420	4,868	243	19.4	17	20.43	130.50	--------	--------	21.19
18	23.98	107.93	11,510	5,118	242	20.0	18	20.10	127.80	--------	--------	19.87
19	23.02	106.68	12,730	5,405	240	20.8	19	19.77	125.20	--------	--------	18.52
20	22.15	105.42	13,910	5,655	238	21.9	20	19.38	122.82	15,960	5,610	17.40
21	21.18	104.09	15,250	5,902	238	24.1	21	18.88	120.38	--------	--------	16.29
22	20.28	102.93	16,680	6,150	236	27.3	22	18.39	118.08	--------	--------	15.15
23	19.35	101.60	18,420	6,470	235	30.0	23	17.79	115.61	--------	--------	14.01
24	18.45	100.26	20,250	6,760	233	32.1	24	17.12	113.22	--------	--------	12.96
25	17.65	98.97	22,120	7,045	232	34.4	25	16.58	111.03	--------	--------	12.06
26	16.80	97.82	24,240	7,315	229	38.3	26	15.98	108.98	--------	--------	11.16
27	15.95	96.21	26,500	7,580	226	40.0	27	15.31	106.52	27,420	7,520	10.31

Theodolite number, 361415.
Observer, W. C. Haines.
Recorder, W. A. Wood.
Disappearance due to distance.
Surface wind: direction 325° (NW.), velocity, 2.8 m. p. s.
Temperature, dry, 20.0°, wet, 15.6° C.
Pressure, station 1019.1, sea level 1019.6 mb.
Relative humidity, 62 percent.

Theodolite number, 361419.
Observer, Carl Russo
Recorder, B. F. Dashiell.
Disappearance due to distance.

Clouds	Amount	Kind	Direction
Upper	1	Ci	SW.
Inter.		None	
Lower		None	

Type of balloon, 16″ (100-gram) pure gum.
Weight, 101 gm. Free lift, 450 gm. Total lift, 551 gm.
Baseline, A–B, length, 4,949 m. Azimuth 326.8°.
Rate of ascent from time-altitude curve, 281 m. p. s.

TABLE 3.—*Rate of ascent, in meters per minute, for given weight (w) and free lift (l)*

l.	w.																				
	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
75	159.0	157.7	156.4	155.1	153.8	152.6	151.5	150.3	149.2	148.1	147.1	146.0	145.0	144.0	143.1	142.1	141.2	140.3	139.4	138.6
80	162.1	160.8	159.5	158.3	157.1	155.9	154.8	153.6	152.6	151.5	150.5	149.5	148.5	147.5	146.5	145.6	144.7	143.8	142.9	142.1
85	165.1	163.8	162.6	161.3	160.2	159.0	157.9	156.9	155.8	154.7	153.7	152.7	151.7	150.8	149.8	148.9	148.0	147.1	146.3	145.4
90	167.8	166.6	165.4	164.2	163.1	162.0	160.9	159.8	158.8	157.7	156.7	155.8	154.8	153.9	152.9	152.0	151.2	150.3	149.4	148.6
95	170.5	169.2	168.1	167.0	165.8	164.8	163.7	162.6	161.6	160.6	159.6	158.7	157.7	156.8	155.9	155.0	154.1	153.3	152.4	151.6
100	173.0	171.8	170.7	169.6	168.5	167.4	166.4	165.3	164.3	163.3	162.4	161.4	160.5	159.6	158.7	157.8	157.0	156.1	155.3	154.5
105	175.4	174.2	173.1	172.0	171.0	169.9	168.9	167.9	166.9	166.0	165.0	164.1	163.2	162.3	161.4	160.6	159.7	158.9	158.1	157.3
110	177.7	176.6	175.5	174.4	173.4	172.3	171.3	170.4	169.4	168.5	167.5	166.6	165.7	164.8	164.0	163.1	162.3	161.5	160.7	159.9
115	179.9	178.8	177.7	176.7	175.7	174.7	173.7	172.7	171.8	170.9	169.9	169.0	168.2	167.3	166.5	165.6	164.8	164.0	163.2	162.4
120	182.0	180.9	179.9	178.9	177.9	176.9	175.9	175.0	174.1	173.2	172.3	171.4	170.5	169.7	168.8	168.0	167.2	166.4	165.6	164.9
125	184.0	183.0	182.0	181.0	180.0	179.1	178.2	177.3	176.4	175.4	174.5	173.6	172.8	171.9	171.1	170.3	169.5	168.7	168.0	167.2
130	186.0	185.0	184.0	183.0	182.0	181.1	180.2	179.3	178.4	177.5	176.6	175.8	174.9	174.1	173.3	172.5	171.7	171.0	170.2	169.5
135	187.9	186.9	185.9	185.0	184.1	183.2	182.2	181.3	180.4	179.6	178.7	177.9	177.0	176.2	175.4	174.7	173.9	173.1	172.4	171.6
140	189.7	188.7	187.8	186.8	185.9	185.0	184.1	183.2	182.4	181.5	180.7	179.9	179.1	178.3	177.5	176.7	176.0	175.2	174.5	173.7
145	191.5	190.6	189.5	188.6	187.8	186.9	186.0	185.2	184.3	183.5	182.6	181.8	181.0	180.2	179.5	178.7	178.0	177.2	176.5	175.8
150	193.2	192.2	191.3	190.4	189.5	188.6	187.8	187.0	186.1	185.3	184.5	183.7	182.9	182.2	181.4	180.6	179.9	179.2	178.5	177.7
155	194.8	193.9	193.0	192.1	191.3	190.4	189.6	188.7	187.9	187.1	186.3	185.5	184.8	184.0	183.3	182.5	181.8	181.1	180.4	179.6
160	196.4	195.5	194.7	193.8	193.0	192.1	191.3	190.5	189.7	188.9	188.1	187.3	186.5	185.8	185.1	184.3	183.6	182.9	182.2	181.5
165	198.0	197.1	196.3	195.4	194.6	193.7	192.9	192.1	191.3	190.6	189.8	189.0	188.3	187.5	186.8	186.1	185.4	184.7	184.0	183.3
170	199.5	198.7	197.8	197.0	196.2	195.3	194.5	193.8	193.0	192.2	191.4	190.7	190.0	189.2	188.5	187.8	187.1	186.4	185.7	185.1
175	201.0	200.2	199.3	198.5	197.7	196.9	196.1	195.3	194.6	193.8	193.1	192.3	191.6	190.9	190.2	189.5	188.8	188.1	187.4	186.8
180	202.4	201.6	200.8	200.0	199.2	198.4	197.6	196.8	196.1	195.4	194.6	193.9	193.2	192.5	191.8	191.1	190.4	189.7	189.1	188.4
185	203.9	203.0	202.2	201.4	200.7	199.9	199.1	198.4	197.6	196.9	196.2	195.5	194.7	194.0	193.4	192.7	192.0	191.3	190.7	190.0
190	205.2	204.4	203.6	202.9	202.1	201.3	200.6	199.8	199.1	198.4	197.7	197.0	196.3	195.6	194.9	194.2	193.6	192.9	192.2	191.6
195	206.6	205.8	205.0	201.2	203.5	202.7	202.0	201.3	200.6	199.9	199.1	198.4	197.7	197.1	196.4	195.7	195.1	194.4	193.8	193.1

TABLE 4.—*Degrees Fahrenheit into degrees centigrade*

°F.	°C.	°F.	°F.	°C.	°F.	P.	P.
31	—0.56	33	66	18.89	—2	0.1	0.06
32	.00	32	67	19.44	—3	.2	.11
33	.56	31	68	20.00	—4	.3	.17
34	1.11	30	69	20.56	—5	.4	.22
35	1.67	29	70	21.11	—6	.5	.28
36	2.22	28	71	21.67	—7	.6	.33
37	2.78	27	72	22.22	—8	.7	.39
38	3.33	26	73	22.78	—9	.8	.44
39	3.89	25	74	23.33	—10	.9	.50
40	4.44	24	75	23.89	—11	1.0	.56
41	5.00	23	76	24.44	—12	1.1	.61
42	5.56	22	77	25.00	—13	1.2	.67
43	6.11	21	78	25.56	—14	1.3	.72
44	6.67	20	79	26.11	—15	1.4	.78
45	7.22	19	80	26.67	—16	1.5	.83
46	7.78	18	81	27.22	—17	1.6	.89
47	8.33	17	82	27.78	—18	1.7	.94
48	8.89	16	83	28.33	—19	1.8	1.00
49	9.44	15	84	28.89	—20		
50	10.00	14	85	29.44	—21		
51	10.56	13	86	30.00	—22		
52	11.11	12	87	30.56	—23		
53	11.67	11	88	31.11	—24		
54	12.22	10	89	31.67	—25		
55	12.78	9	90	32.22	—26		
56	13.33	8	91	32.78	—27		
57	13.89	7	92	33.33	—28		
58	14.44	6	93	33.89	—29		
59	15.00	5	94	34.44	—30		
60	15.56	4	95	35.00	—31		
61	16.11	3	96	35.56	—32		
62	16.67	2	97	36.11	—33		
63	17.22	1	98	36.67	—34		
64	17.78	0	99	37.22	—35		
65	18.33	—1	100	37.78	—36		

TABLE 5.—*Miles per hour into meters per second*

m. p. h.	m. p. s.	m. p. h.	m. p. s.	m. p. h.	m. p. s.	m. p. h.	m. p. s.
1	.45	19	8.5	37	16.5	55	24.6
2	.89	20	8.9	38	17.0	56	25.0
3	1.3	21	9.4	39	17.4	57	25.5
4	1.8	22	9.8	40	17.9	58	25.9
5	2.2	23	10.3	41	18.3	59	26.4
6	2.7	24	10.7	42	18.8	60	26.8
7	3.1	25	11.2	43	19.2	61	27.3
8	3.6	26	11.6	44	19.7	62	27.7
9	4.0	27	12.1	45	20.1	63	28.2
10	4.5	28	12.5	46	20.6	64	28.6
11	4.9	29	13.0	47	21.0	65	29.1
12	5.4	30	13.4	48	21.5	66	29.5
13	5.8	31	13.9	49	21.9	67	30.0
14	6.3	32	14.3	50	22.4	68	30.4
15	6.7	33	14.8	51	22.8	69	30.8
16	7.2	34	15.2	52	23.2	70	31.3
17	7.6	35	15.6	53	23.7		
18	8.0	36	16.1	54	24.1		

TABLE 6.—*Inches into millibars*

Inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
29.0	982.1	982.4	982.7	983.1	983.4	983.7	984.1	984.4	984.8	985.1
29.1	85.4	85.8	86.1	86.5	86.8	87.1	87.5	87.8	88.2	88.5
29.2	88.8	89.2	89.5	89.8	90.2	90.5	90.9	91.2	91.5	91.9
29.3	92.2	92.6	92.9	93.2	93.6	93.9	94.2	94.6	94.9	95.3
29.4	95.6	95.9	96.3	96.6	97.0	97.3	97.6	98.0	98.3	98.6
29.5	999.0	999.3	999.7	1,000.0	1,000.4	1,000.7	1,001.0	1,001.4	1,001.7	1,002.0
29.6	1,002.4	1,002.7	1,003.1	03.4	03.7	04.1	04.4	04.7	05.1	05.4
29.7	05.8	06.1	06.4	06.8	07.1	07.5	07.8	08.1	08.5	08.8
29.8	09.1	09.5	09.8	10.2	10.5	10.8	11.2	11.5	11.9	12.2
29.9	12.5	12.9	13.2	13.5	13.9	14.2	14.6	14.9	15.2	15.6
30.0	1,015.9	1,016.3	1,016.6	1,016.9	1,017.3	1,017.6	1,018.0	1,018.3	1,018.6	1,019.0
30.1	19.3	19.6	20.0	20.3	20.7	21.0	21.3	21.7	22.0	22.4
30.2	22.7	23.0	23.4	23.7	24.0	24.4	24.7	25.1	25.4	25.7
30.3	26.1	26.4	26.8	27.1	27.4	27.8	28.1	28.4	28.8	29.1
30.4	29.5	29.8	30.1	30.5	30.8	31.2	31.5	31.8	32.2	32.5
30.5	1,032.9	1,033.2	1,033.5	1,033.9	1,034.2	1,034.5	1,034.9	1,035.2	1,035.6	1,035.9
30.6	36.2	36.6	36.9	37.3	37.6	37.9	38.3	38.6	38.9	39.3
30.7	39.6	40.0	40.3	40.6	41.0	41.3	41.7	42.0	42.3	42.7
30.8	43.0	43.3	43.7	44.0	44.4	44.7	45.0	45.4	45.7	46.1
30.9	46.4	46.7	47.1	47.4	47.8	48.1	48.4	48.8	49.1	49.5

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