W. B. No. 472

U. S. DEPARTMENT OF AGRICULTURE
WEATHER BUREAU
CHARLES F. MARVIN, Chief

# BAROMETERS AND THE MEASUREMENT OF ATMOSPHERIC PRESSURE

A PAMPHLET OF INFORMATION RESPECTING THE THEORY AND CONSTRUCTION OF BAROMETERS IN GENERAL, WITH SUMMARY OF INSTRUCTIONS FOR THE CARE AND USE OF THE STANDARD WEATHER BUREAU INSTRUMENTS

CIRCULAR F, INSTRUMENT DIVISION

FIFTH EDITION

*By*

C. F. MARVIN



WASHINGTON
GOVERNMENT PRINTING OFFICE

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# BAROMETERS AND THE MEASUREMENT OF ATMOSPHERIC PRESSURE.

## INTRODUCTORY.

### THE BAROMETER.

1. The hydrostatic principle, by virtue of which the pressure of the air is measured by the ordinary barometer, was first formulated at Florence in 1643 by Torricelli, whose famous experiments demonstrated, not only that the air exerted a very great pressure, but that this pressure changed slightly from day to day.

2. *Torricelli's barometer.*—To repeat Torricelli's experiment, fill a clean, dry, preferably warm, glass tube, closed at one end, with pure, dry mercury, using care to exclude all air. The length of the tube must, in general, exceed 30 inches. Close the open end of the tube firmly with the finger tip, and submerge it in an open cup of mercury. Upon removing the finger and causing the tube to stand vertically, a portion of the mercury will pass from the tube into the cup, leaving a vacuous space, known as Torricelli's vacuum, in the top of the tube. The column of mercury remaining in the tube will, at sea-level stations, be about 30 inches high. The weight of this mercury is sustained by and exactly balances the downward pressure of the air upon the surface of the mercury in the cup. The height of such a mercurial column, therefore, becomes a measure of the pressure of the air, and Torricelli seems to have been the first to discover that the height of such a column varied from day to day.

3. *Siphon barometer.*—Instead of constructing the barometer in the manner just described, where the cistern and tube are in separate parts, the tube may be made longer and turned up at the bottom so as to resemble the letter J, forming what is commonly called a siphon barometer, the long arm of which is closed at the top.

4. *Pressure of one atmosphere.*—Suppose the area of the inside of the barometer tube to be just 1 square inch, then a 30-inch barometric column will contain just 30 cubic inches of mercury. Now, 1 cubic inch of mercury weighs 0.4906 pound, which, multiplied by 30, gives the ordinary sea-level pressure of the air to be 14.718 pounds per square inch. This quantity is frequently used by engineers, and is called a pressure of one atmosphere.

5. This pressure of 14.7 pounds per square inch is, in the main, nothing more than the weight of an air column having a sectional area of 1 square inch and extending vertically to the upper limits of the atmosphere. In addition to the weight, pure and simple, however, such influences as the wind, the rapid heating and cooling in confined layers of air, and other causes modify by small amounts the elastic pressure of the air.

6. *Other forms of barometers.*—Within the past 50 or 60 years a form of barometer, made entirely of metal, has been devised, and is widely used at sea and by tourists and others on account of its convenience and portability. This form is commonly designated the aneroid, a word which signifies "containing no liquid." The instrument is also often called the holosteric barometer, meaning "wholly of solids." Aneroids, though often highly sensitive, are, at best, much less accurate than properly constructed mercurial barometers, as will be explained later.

## I.—MERCURIAL BAROMETERS.

7. *Fortin barometers, Weather Bureau pattern.*—In order that the height of the mercurial column may represent accurately the true pressure of the air, and in order to detect the comparatively small changes of pressure from day to day, many refinements are necessary in the construction of the instrument and great precision of measurement is required. An excellent form of the mercurial barometer, satisfying the requirements just stated, was devised by Fortin, and is now very widely used the world over. The particular pattern used by the Weather Bureau, sometimes called the Green barometer, is figured on page 11.

8. The barometer consists of a glass tube, about $\frac{1}{4}$-inch inside diameter, closed at the top and inclosed in a thin metal tube, through which large openings are cut on opposite sides, exposing to view the glass tube and mercurial column. The graduated scale is formed at one side of this opening, and a short tube or sleeve, also graduated (shown at *C*, figs. 1 and 2), encircles the barometer tube and slides smoothly within the metal part, motion being given to it by means of the milled head, *D*, and a small rack and pinion inside.

At *E*, figure 2, is shown what is called the attached thermometer. The bulb of this is entirely concealed within the metal tube, and is between it and the glass barometer tube, so as to show as nearly as possible the mean temperature of both the brass tube and the mercury.

9. *Cistern.*—The special feature of the barometer is a cistern so constructed that the level of the mercury within may be changed greatly and adjusted to a fixed index point.

The topmost portion of the cistern consists of a small boxwood piece, *G*, figure 3. The glass tube *t*, passes through the central portion of this, to which it is secured by a piece of soft kid leather folded in a peculiar manner and securely wrapped to both the glass tube and the boxwood cap, *G*. The flexible joint thus formed will not allow the mercury to escape, but permits the passage of air to and from the cistern.

The remaining portions of the cistern are the short glass cylinder *F*, figure 3, the two curved boxwood pieces, *i* and *j*, and the kid leather bag, *N*, with adjusting screw, *O*, clamps, etc.

It is plainly seen that on turning the screw, *O*, the leather bag may be folded up into or withdrawn from the curved boxwood chamber, *j*, in a manner to cause any desired change in the level of the mercurial surface.

10. *Ivory point.*—At *h*, figure 3, is shown what is technically called the "ivory point," which projects downward from the top of the cistern and forms a fixed and definite point, to which the level of the mercury in the cistern can be adjusted in taking readings of the barometer, as will be described hereafter.

The ivory point is, therefore, the zero end of the scale, from which all the measurements of the height of the column are made.

11. *Scale of barometer.*—The scale of the barometer is seen on the left of the opening, at the top. It is most conveniently made of a separate strip of metal, although sometimes it is engraved directly on the metal tube itself. The length varies from about 4 inches, for use at stations of only moderate elevation above sea level, to from 10 to 15 inches, or more, for barometers intended to be used in balloons or on lofty mountain summits. The graduations on the scale also vary, being only 10 spaces to the inch in many instances and 20 in others; the latter graduation is to be preferred on account of the greater accuracy attainable in readings.

The scale of the barometer when engraved on a separate strip is attached to the metal tube by small screws in such a manner that it may be adjusted slightly up and down, so that the 30-inch mark, for example, of the graduations can be placed at exactly the right ditance from the ivory point. This adjustment being made, the scale should not be moved afterwards.

12. *Vernier.*—A vernier is a device by which one is able to ascertain accurately much smaller fractional subdivisions of a graduated scale than could otherwise be observed by the eye without the aid of a microscope. For example, with a scale having only 20 subdivisions to the inch a vernier enables us to ascertain accurately the one-thousandth part of an inch. The name of the device is derived from its inventor, Pierre Vernier. This portion of the barometer is the little graduated scale, *C*, figures 1 and 2.

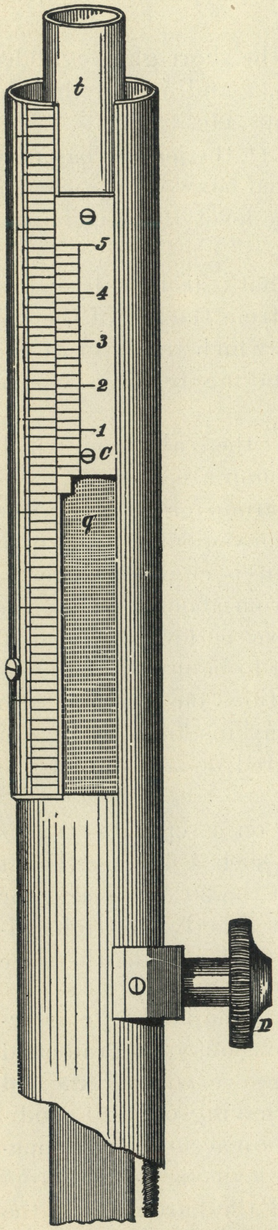



Fig. 1.

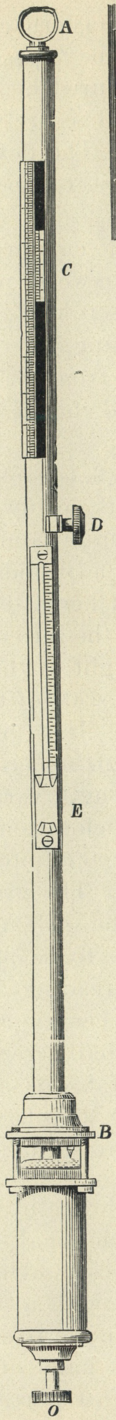



Fig. 2.

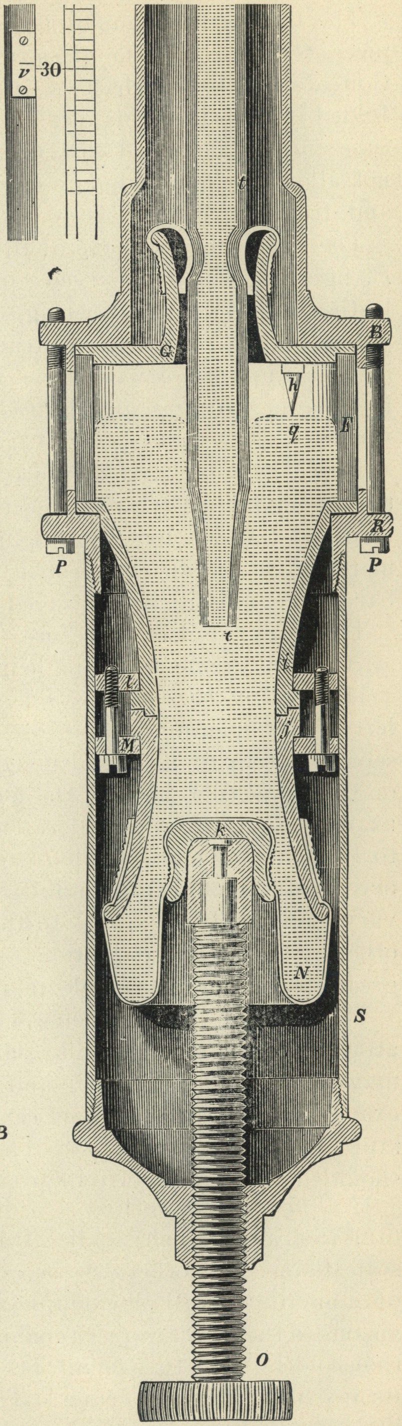
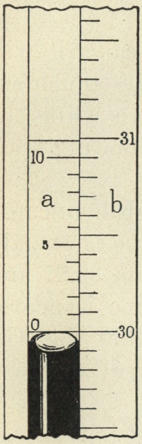


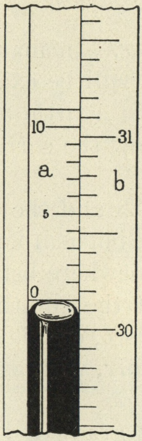

Fig. 3.

Mercurial barometer, with Fortin cistern.

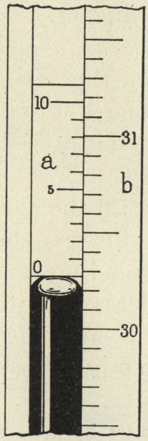
A vernier consists, essentially, of a small graduated scale, the spaces upon which are just a certain amount smaller or larger than those on the main scale. When two such scales are placed together some particular line of the one will always be coincident, or very nearly so, with a line on the other, and from this circumstance the position of the zero line of the vernier in reference to the scale can be very accurately determined, as will be readily understood from a study of the following figures and explanation:



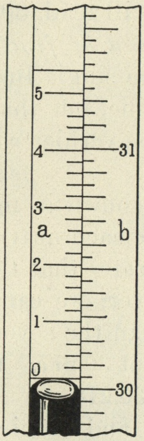

30.00
FIG. 4.



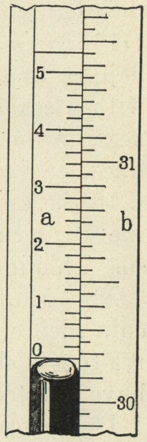

30.15
FIG. 5.




30.277
FIG. 6.




30.034
FIG. 7.




30.177
FIG. 8.

Verniers.

Figure 4 exhibits the manner of graduating a vernier so as to subdivide the spaces upon the scale into tenths. In the figure, *b* is the scale and *a* is the vernier. The lower edge of the vernier, which in this case is also zero line, is exactly opposite or coincident with 30 on the scale. The tenth line on the vernier is coincident with the ninth line above 30—that is, a space of 9 divisions on the scale is divided into 10 spaces on the vernier, so that each space on the latter is one-tenth part shorter than a space on the scale. In the present case the spaces on the scale represent inches and tenths; hence the difference between the length of a space on the vernier and one on the scale is $\frac{1}{10}$ of $\frac{1}{10} = \frac{1}{100}$ of an inch. This principle of matching two scales having spaces of slightly different magnitude is always followed in the construction of veniers, though, of course, the number of spaces embraced by the vernier is varied to suit the circumstances and the degree of minuteness desired. Moreover, in some instances, the vernier embraces one more space on the scale, instead of one less, than the number of its own subdivisions—that is, 10 spaces on the vernier may be made to correspond to 11 spaces on the scale.

If, as we have seen, the spaces on the vernier are one-tenth smaller than on the scale, then, in the adjustment shown in figure 4, the first line above the zero on the vernier is one-tenth part of the space, the next line two-tenths, the next three-tenths, etc., distant from the line next above on the scale. When, therefore, we find the vernier in such a position as shown in figure 5, where the fifth line on the vernier is coincident with a scale line, it is very clear that the zero line of the vernier must be just five-tenths above the scale line next below. Now, since we imagine these scales to represent inches and tenths, then figure 5 will read, 30.15 inches.

13. *Estimation of fractions on a vernier.*—In many cases it will happen that no single line on the vernier will be exactly coincident with a scale line, but that one line will be a little above while the next line on the vernier will be a little below the corresponding scale lines.

In the case shown in figure 6 the seventh and the eighth lines on the vernier are each nearly in coincidence, but neither one is exactly so. This indicates that the reading is somewhere between 30.27 and 30.28. Moreover, we can clearly see that the eighth line is nearer coincidence than the seventh. We, therefore, estimate that the true reading is about 30.277. We might, probably, with as great accuracy have selected 30.278.

If the scale and vernier are accurately graduated, such readings by a practiced observer will rarely be in error by more than 0.002 inch. It is important in estimating the fractions that the eye be exactly in front of the lines being studied.

14. In figures 7 and 8 are shown verniers applied to a barometer scale having 20 parts to the inch. In this case 24 parts on the scale are divided into 25 parts on the vernier. By the principle already explained in paragraph 12, the value of the subdivisions effected by such a vernier, or, as it is most frequently expressed, the least count of the vernier, will be $\frac{1}{25}$ of $\frac{1}{20} = \frac{1}{500}$ of an inch. In reading the vernier, therefore, each line will represent 0.002 inch, so that the fifth, tenth, fifteenth, twentieth, and twenty-fifth lines will represent one, two, three, four, and five hundredths of an inch, respectively, and are so numbered.

As described in paragraph 13, the lines in this kind of vernier also may not be exactly in coincidence; but in such a case, owing to the smallness of the spaces, it is not of any special advantage in making our estimate to consider whether coincidence is nearer one line than the other. In ordinary practice we simply take midway between. Thus in figure 8 the reading is between 30.176 and 30.178; we therefore adopt 30.177 as the proper reading.

15. *Caution against error.*—When the zero line of this style of vernier is next above one of the shortest lines on the scale, as was the

case in the example above, some attention is necessary in order to take off the correct reading. For example, in figure 8 we find that coincidence on the vernier is between lines designated 26 and 28, which corresponds to a reading of 0.026 or 0.028, or, taking midway between, 0.027. On the scale itself, however, we see the graduation next below the first line of the vernier is 30.150. The complete reading is found by adding the parts thus: 30.150+0.027=30.177. It frequently happens with beginners that the 0.050 represented by the short line on the scale is overlooked and omitted entirely—that is, the above reading might be called 30.127. Whenever readings are made with a scale and vernier of this character, special pains must be taken not to omit adding 0.050 to the vernier reading when the first line below the zero of the vernier is a short one.

16. *Strain on the cistern of a barometer.*—When the mercury is sent up to the top of the tube of a barometer by screwing up the cistern, an internal hydrostatic pressure is produced proportional to the amount by which the length of the column has been increased. This pressure tends to force the mercury through the joints of the cistern or the joints and pores of the leather bag. This is more particularly the case with a barometer at an elevated station, where, owing to the diminished air pressure, the column may need to be raised 10 or 15 inches in filling the tube, greatly endangering the cistern. For this reason the Fortin barometer cistern is not wholly satisfactory, as it is difficult to make and keep the joints so tight that the mercury will not be able to find its way through some very small crevices; such leakage soon impairs the barometer.

17. *Tuch cistern.*—Many of the barometers of the Weather Bureau are fitted with an improved form of cistern, devised by Mr. Charles B. Tuch, formerly of the Instrument Division. The construction of this is shown in figure 9.

The chamber for the mercury is formed of the iron cylinders, *c*, *k*, provided with windows at the top, and a small glass cylinder, *f*. The glass barometer tube is fastened into a metal piece, *b*, by means of several thicknesses of leather washers, held and clamped by a screw, *e*, above. The piston, *o*, fits the cylinder very snugly and can be moved up and down by means of the milled-head screw, *W*, thereby adjusting the mercury to any desired level.

18. *Fixed cistern barometers.*—It is very evident that as the column of mercury rises and falls in a barometer tube there is a corresponding change in the level of the surface in the cistern, and as long as the quantity of mercury in the whole barometer remains the same, it follows, except for slight temperature effects, that the true height of the column of mercury may always be found simply from readings at the top end, a due allowance being made for the slight rise and fall in the cistern.

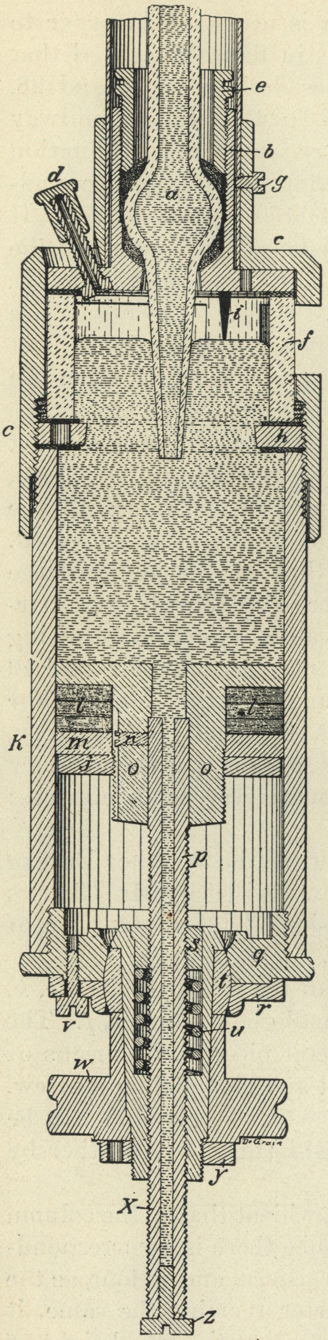


FIG. 9.—Tuch barometer cistern.

Adjustable cistern barometers, such as described in paragraphs 9 and 17, are, in general, the most accurate, as the correction for capillarity, paragraph 26, is usually more constant, and the accidental escape of a little mercury from the cistern does not matter. Still, very accurate results may be obtained by the use of well-made barometers with fixed cisterns, and this form is often adopted in the construction of barometers for use on shipboard.

The relation between the true length of the column and the observed position of its top depends upon the relation between the inside areas of the cistern and barometer tube. When this relation has been once worked out it is then necessary in reading the barometer to observe only the position of the top of the column and apply a "correction for capacity." (See paragraph 24.)

19. *Contracted barometer scale.*—As the correction for capacity in barometers with fixed cisterns remains the same so long as the quantity of mercury within the barometer and the inside area of tube and cistern are unchanged, it will not be necessary to apply a capacity correction to every reading made, provided we use on the barometer a scale having all its divisions shortened by just the proper amount to compensate for the capacity effect. To understand this more clearly, imagine a barometer with the top of the column just 30 inches above the surface of the mercury in the cistern. Suppose the sectional area of the barometer tube at the top is only one-fiftieth as great as that of the cistern (this is about the usual relation). Now if we imagine the column to rise a distance of 1 inch in the tube, it will then seem to become 31 inches high, but when the column rises 1 inch, the mercury in the cistern falls one-fiftieth of an inch, and, therefore, the real height of

the column must be $31\frac{1}{50}$ inches; that is, we may say, that each inch of a scale represents $1\frac{1}{50}$ inches of change in the real height of the mercurial column. If, therefore, a special scale be prepared having the spaces representing inches, each one fifty-first part of an inch shorter than a true inch, then readings of our imaginary barometer on such a scale will indicate the true height of the column, presupposing of course, that the sectional areas of the tube and cistern are uniform, and that the scale is adjusted to a proper distance from the cistern.

20. By methods of calibration manufacturers are able to construct scales and barometers of great accuracy in accordance with the above principles, and they are very convenient to use.

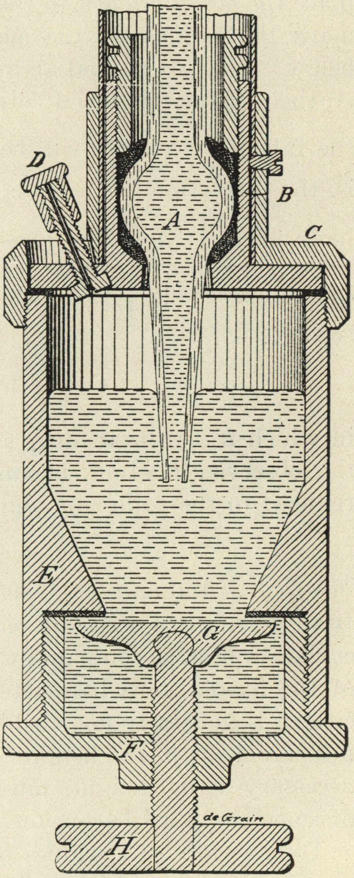


Fig. 10.—Fixed cistern barometer.

21. It is obvious that if a barometer tube in such an instrument is broken it will be difficult to find another so nearly the same size that it could be used with the old scale; generally a new scale is also required.

22. In figure 10 is shown a cut of an excellent barometer of the fixed-cistern type, devised by Schneider Bros., of Jersey City, N. J. One of the special features of the barometer is the means provided for filling the cistern and tube with mercury so that the barometer can be shipped safely from place to place.

To fill the cistern with mercury, the barometer is first very carefully and gradually inclined and inverted. When fully inverted the mercury suffices to fill up the cistern just to the throat of the contracted portion at *G*. By screwing up the milled head, *H*, the plate, *G*, closes against the bottom of the cistern and completely imprisons the mercury with only a little free space for expansion. If the barometer is now turned erect the mercurial column can not descend unless the screw, *H*, is loosened, whereupon the mercury flows into the previously unoccupied space below the plate, *G*, and permits the column to resume its normal level.

23. The capacity correction required for a barometer with fixed cistern and true scale graduated in standard units, and not contracted, as explained in paragraph 19, can be determined from careful measurements of the internal diameters of the tube and cistern made before the barometer is filled, but the accuracy of this correction should always be checked by subsequent comparisons, as indicated below.

24. *Capacity correction, how found.*—It is evident that by sliding the scale of a fixed-cistern barometer up or down it can be so adjusted that a reading at some one point is just right; for example, we may place the 30-inch mark so that when the top of the column is at this mark the surface of the mercury in the cistern is just 30 inches below. If the sectional area of the tube is $a$, and that of the cistern $A$, then, if the mercurial column in the tube rises one scale division, the fall in the cistern will be only the $\frac{a}{A}$ part of one division. That is, the correction for a scale reading just one division above the 30-inch mark is: $+\frac{a}{A}$ divisions; for a reading two divisions above the correction is: $+2\frac{a}{A}$, etc. This, expressed in a mathematical formula, becomes—

$$\text{Correction} = C = (h - R_o)\ \frac{a}{A};$$

in which $R_o$ is the reading at which the correction is zero and $h$ is the observed reading, uncorrected for temperature. This may be reduced to the following simpler form—

$$C = nh - m;$$

in which $m$ and $n$ are two quantities whose values are best determined from a complete series of readings of the actual height of the mercurial column, as compared with the reading of the top of the column of the fixed-cistern barometer. As the level of the mercury in the cistern is generally not visible in barometers of this type, the direct measurements of the heights of the column can not be made, and the necessary actual heights must, therefore, be obtained from readings of some standard barometer.

To determine the values of $m$ and $n$ accurately by comparisons, observations should be made over a greater range of pressures than ordinarily occur from day to day, and the best results will require observations under pressure artifically changed to suit.

25. Changes of temperature may cause the sectional areas of the tube and cistern to have a different relation than that assumed in the formula above, and may also change the value of $R_o$, but these effects are slight and are not considered here.

26. *Mercurial barometer for marine use.*—Mercurial barometers constructed upon the Fortin system and other forms such as described in the preceding paragraphs are almost universally used on land for the measurement of atmospheric pressure, and no other form of barometer affords as great accuracy in the measurement of that pressure. If, however, such an instrument were placed aboard ship at sea the column of mercury would surge up and down the tube more or less violently with every motion of the vessel, and readings would be rendered inaccurate or impossible.

27. This difficulty has been overcome in a form of instrument known as the Kew, or marine, barometer. Its distinguishing characteristics consist in substituting for the simple straight tube of uniform bore commonly employed in land barometers, a tube having a wide bore for 6 or 8 inches of the upper portion only. Below this the tube has thick walls with a small capillary bore only a few hundredths inch in diameter. Near the bottom end the bore of the tube is again enlarged to form an air trap, all as shown in figure 11. If small quantities of air chance to enter the open end of the tube they are not likely to enter the small point of the inner tube, but lodge instead in the surrounding space, as indicated, where the air must remain and does not affect the barometric readings. It may even be removed from the trap when the barometer is undergoing repairs.

28. The flow of mercury through the capillary bore takes place so slowly that the column can not surge up and down the tube seriously with the relatively quick motions of the ship. At the same time the height of the column adjusts itself to the slow changes of atmospheric pressure, and thus more or less perfectly answers the desired objects.

29. Figure 12 shows a high grade mercurial barometer adapted to all the requirements of marine use, together with a special gimbal supporting bracket and small wooden box, into which the barometer and bracket are folded and thoroughly protected and secured when not in use.

30. The glass tube and boxwood cistern, all as shown in figure 11, are secured inside the bronze-metal jacket provided at the top with a long, slotted opening through which the top of the glass tube and mercurial column can be seen. A scale of graduations is fixed beside the opening and a vernier of a form already described in paragraph 12 is arranged to slide up and down so as to enable accurate measurements of the height of the mercurial column to be made.

31. For marine use it is necessary that the barometer be free to hang in a vertical line despite the rolling and pitching of the vessel. For this purpose the well-known arrangement of gimbal rings is formed upon the outer extremity of a hinged bracket and secured to the barometer at a point some inches above the middle.

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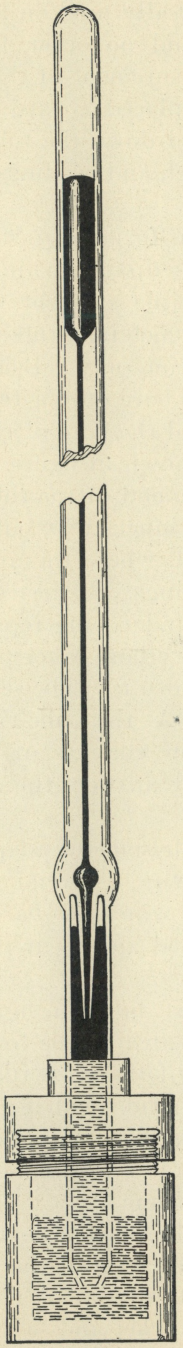

FIG. 11.—Tube and cistern of marine barometer.

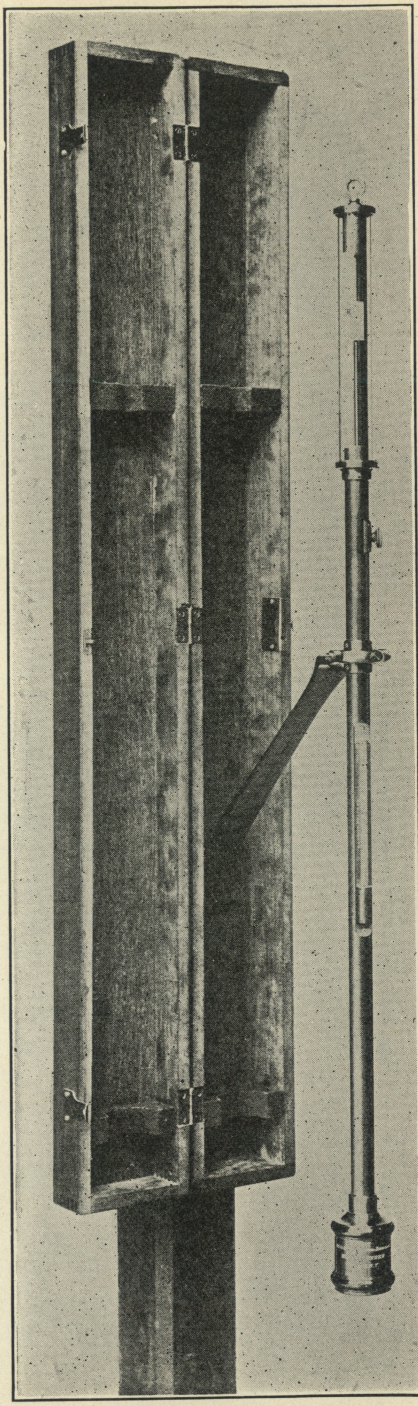

FIG. 12.—Marine barometer and box.

In the position shown in the picture the barometer is ready for reading, and the tube will swing on the gimbals so as to remain nearly or quite vertical. After a reading has been taken the barometer must not be left exposed, as it is very liable to injury by violent oscillations in heavy weather. In the equipment of the standard Weather Bureau design the whole bracket, barometer and all are arranged to fold up compactly within the small mahogany case, the lid of which closes with a spring clasp, and not only secures the barometer from accidental damage but from undue exposure to atmospheric influences as well.

32. *How barometer tubes may be filled.*—Processes that may be followed in filling barometer tubes for high-grade instruments are so rarely described and so little known that a short description of some methods frequently employed at the Weather Bureau with highly satisfactory results will doubtless be of interest to a number of readers.

The object of any filling process is simply to introduce pure mercury and totally exclude all air, moisture, or other foreign matter especially of a gaseous nature, that may possibly later occupy the barometric vacuum and cause errors by the pressure it exerts upon the top of the mercurial column.

33. *Funnel method.*—It may seem that the desired result could be obtained by carefully introducing clean mercury through a long slender-stemmed funnel reaching quite to the closed end of the tube. (See fig. 13.) A suitable funnel may easily be made by drawing down the end of a short piece of rather wide glass tubing. Such a method is sometimes used and will, indeed, give approximate results, but it will be found upon investigation that while the mercury seems to drive out all the air, yet a good deal will still be found in the vacuum. Originally, this air mixed with water vapor is strongly adherent to the walls of the glass tube by reason of a peculiar property this character of glass is found to have. When the barometric vacuum is formed, some of the gaseous matter thus attached to the tube is liberated and by its pressure depresses the mercurial column several hundredths of an inch, as has been shown by careful experiments.

In all cases it is of great importance that the inside walls of barometer tubes be perfectly clean. New tubes are thoroughly cleaned with whiting or other suitable material while open at both ends, and while still warm and dry the top end is closed and the cistern end tapered and finally fused shut.

Small tubes (one-quarter inch and less) that have become soiled by use, exposure, etc., can not be easily cleaned properly, and such are never used a second time in the Weather Bureau work. The methods given in paragraph 35 for cleaning larger tubes may, however, be used even with these.

One very simple and excellent method of driving off nearly all the air and moisture condensed on the glass walls is given in the next paragraph.

34. *The boiling method.*—This is a simple method commonly employed with all small tubes, say, one-fourth inch diameter, more or less; such, for example, as is required in the several types of barometers that have been heretofore described. Much larger tubes are frequently boiled, but these when full of hot mercury are difficult to handle, a strong heat is required, and the danger of serious accidents is considerable.

It is well at first to warm more or less the whole tube, and the cup of clean filtered mercury[1] from which the supply is drawn should also be gently warmed.

Sufficient mercury to fill the tube 3 or 4 inches is introduced by the aid of a funnel such as shown in figure 13, except that the slender stem need be only 2 or 3 inches lond. In the absence of such a funnel it is quite as well to employ a small paper cone of the kind commonly used in filtering mercury. The mercury in the tube is then boiled carefully over a good Bunsen burner flame. (See fig. 14.) For this purpose the tube is held easily in the hands and moved continuously through the flame and rotated so as to avoid undue local heating of the tube. As the heating proceeds the air and moisture vapor first form in minute silvery-white bubbles, giving the tube a frosted appearance. These enlarge, and after actually boiling the mercury for a while all evidence of formation of bubbles on the walls disappears, and further boiling of the mercury takes place with sudden bursts and with sharp metallic clicks as the portions of the boiling mercury strike each other or the walls of the tube. When it is apparent that the gases on the walls of the tube have been driven off sufficiently, a fresh quantity—3 or 4 inches—of warm mercury is added, and this portion then heated and boiled. The line of separation between the new and the old mercury is rendered plainly conspicuous by the frosted appearance previously mentioned.

These operations are repeated until the mercury reaches 3 or 4 inches from the tip of the tube, the latter portion being filled by the careful use of the funnel without boiling. If the walls of the tube are clean and dry the boiling method is easy to employ and gives very high vacua.

35. *Cleaning large tubes.*—Tubes that have contained mercury of which oxidized and impure portions may still adhere more or less closely to the wall should first be treated with dilute nitric acid (1 part in 20), and then thoroughly rinsed with plenty of water.

[1] For notes and remarks on testing and filtering mercury, see pars. 137 and 138.

Ammonia or some other alkali may be added, if desired, after which the operations described below should be followed.

Introduce several inches of soapy water and whiting with tissue-paper pulp. It is often easiest to put into the tube several small sheets of cheap straw or manila tissue paper, and add the water and whiting afterwards.

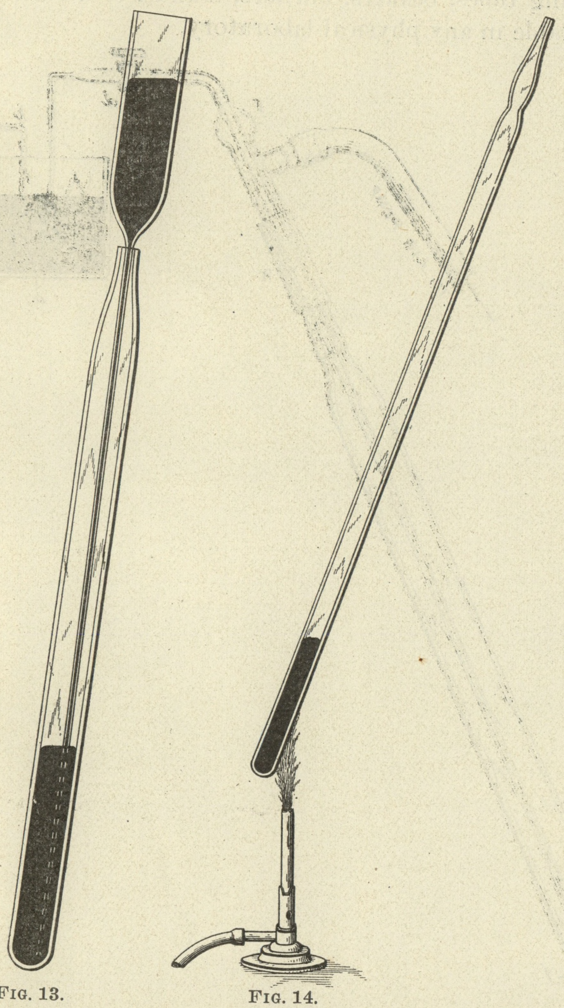

FIG. 13. FIG. 14.

Funnel tube and boiling method of filling barometer tubes.

This creamy mass can be strongly shaken about inside the tube and serves to scour and clean the walls in a very satisfactory manner. It is then removed by copious rinsing with clean water and afterwards with distilled water. After draining some minutes, strong alcohol in moderate quantities is several times introduced and successively drained out and the tube given a final draining for half an hour or so, if convenient, after which it is ready for drying and filling.

36. *Air-pump method of filling.*—This method, with numerous modifications, has been employed by the writer in a large number of cases with very satisfactory results. The method requires a good air pump, drying tubes, beakers, burners, stands, etc., such as are generally available in any physical laboratory.

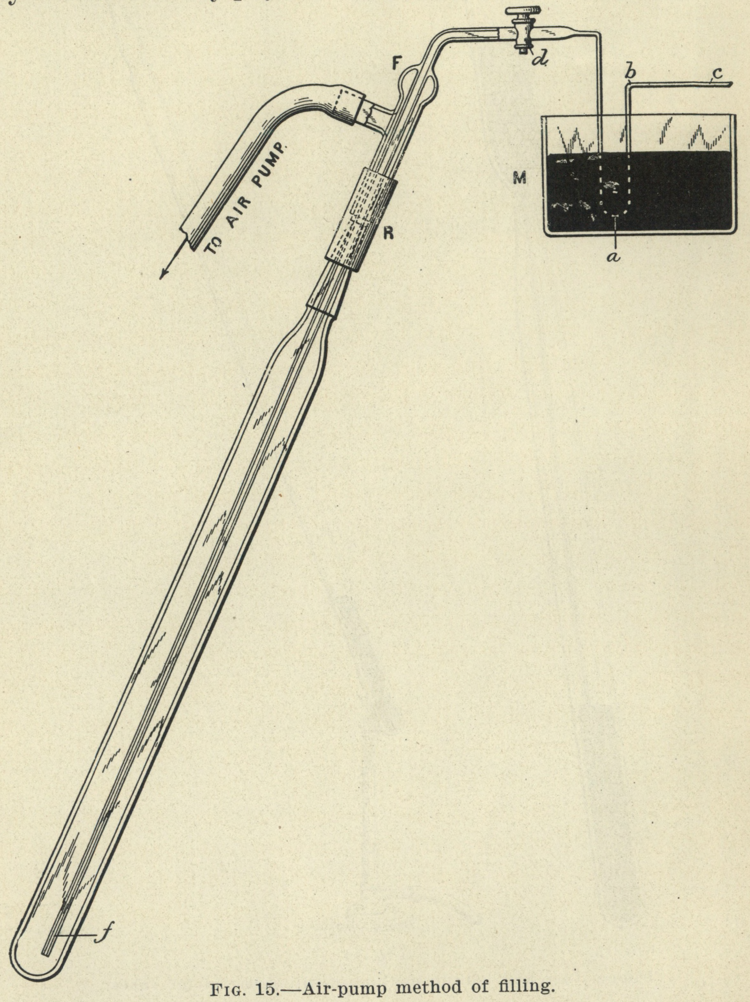


FIG. 15.—Air-pump method of filling.

The apparatus is arranged as shown in figure 15. The exhaustion and funnel tube *Ff* will probably require to be made up to suit requirements by some one a little familiar with simple glass-blowing operations. For most purposes this may be attached to the barometer tube by a short piece of soft pure rubber tubing. The outside end of the funnel is drawn down into a long capillary extension which is bent several times, as shown, so as to dip into the cup of mercury, *M*. Too fine a capillary should be avoided, and it is generally necessary and easy to weaken the capillary, as at *a*, by heating it a little, so that later the tube will break off at this point when a torsional strain is put upon it by twisting the bent extremity, *a b c*. The point at *c* is closed by fusion, to begin with. A stopcock may be employed, as at *d*, and in this case the breaking of the tube is not required, but if the stopcock leaks even a little, the result may be defective and the arrangement first described is often best.

37. *Drying and filling the tube.*—In order to dry the tube it is alternately nearly exhausted and dry air admitted while the walls are more or less continuously heated by playing over the tube with the flame from a Bunsen burner. These operations must be repeated 10 or more times and the tube kept hot. Throughout these operations the mercury is excluded and the funnel tube partakes at least partly in the drying influences. While the tube is kept quite warm and the vacuum maintained at a high point the capillary is broken at *a* and the mercury in *M*, which has been heated in the meantime, is permitted to flow. *M* need not be large enough to contain all the mercury required, but additions may be frequently made and the whole kept quite warm. The filling will take place slowly, depending upon the size of the bore of the inlet tube. The vacuum must be maintained at a high point until the mercury fills the barometer tube, when the flow may be stopped by admitting air to the pump. The vessel *M* must also be removed if there is any tendency of the mercury to flow one way or the other by gravitation.

For the very finest effects the barometer tube can be exhausted by a Sprengel or other high vacuum pump, but in this case the rubber tube connections must be replaced by glass and fused joints.

38. It may be remarked here that the very high vacua with which we are familiar nowadays, in X ray and other such tubes, are by no means essential, except in the highest grade of "normal" barometers (see paragraph 45), where results depend upon the absolute height of the mercurial column. In the case of instruments in which a correction is found by comparison with a normal, and especially in barographs where the results depend entirely upon differences in the position of the mercurial column, simple methods of filling give entirely satisfactory results. In these cases the gaseous pressure in the vacuum is so nearly constant that no serious error is involved.

Suppose, for example, that the residual air in a barograph tube exerts a pressure of 0.1 inch, which would be inexcusably bad filling. Now, since we set the pen of the barograph to agree, from time to time, with a standard barometer, the only effect the air can have is such as results from changes in pressure due either to changes in temperature or changes in the volume of the vacuum chamber.

A 20° change of temperature between settings of the pen is not usual but would introduce an error in this case of only about 0.003 inch, whence, with reasonably good filling, the errors from imperfect vacua are entirely insignificant.

39. *Errors of barometers.*—No matter how carefully a barometer may be made, certain errors due to various causes can hardly be eliminated. In the first place, if any residual air or vapor or any kind of gaseous matter remains in the top of the barometer tube, the column of mercury will not rise as high as it should. We know, likewise, from physical laws, that the capillary forces acting between the free surface of mercury and the glass walls at the top of the column also operate to prevent the mercury from rising as high as it should in the tube. Still other errors arise from faults in the graduation of the scale and from failure to place it and the vernier at exactly the positions they should occupy.

It is not practicable, or necessary, as a rule, to determine these errors separately. When an instrument is completed, its readings are carefully compared with those of a standard barometer. The differences found in this way represent the outstanding effect of the several sources of error mentioned above and are commonly called the "correction for instrumental error and capillarity."

40. There is still another source of considerable variation in the readings of mercurial barometers, namely, the influence of temperature, a rise of temperature expanding both the metal scale and the mercurial column. If both mercury and scale expanded equally no correction would be necessary, but the mercury expands much more than the scale, so that a large correction is required for temperature.

41. The following detailed discussion of the several errors mentioned above will make the matter more clear.

(1) *Corrections for capillarity.*—In all barometers having comparatively small tubes, that is, of less diameter than from 0.7 to 1 inch, the top of the mercurial column, or the meniscus, as the rounded surface is generally called, will nearly always be quite convex on account of the capillary action between the mercury and the glass. In consequence of this the mercury column is actually depressed a slight amount and never indicates the true barometric height. This source of error is one of the most troublesome to which barometers are subject, as the capillarity is never quite constant and there is no practicable method by which its changing value can be accurately determined in the daily use of an instrument.

The error due to capillarity is nearly always eliminated as far as possible from the scale reading by adjusting the scale so that allowance will be made for the average capillary depression. If an ordinary barometer be carefully examined it will be found that the 30-inch mark on the scale is appreciably less than 30 inches from the ivory point. In general, the difference represents the amount the mercurial column is depressed by capillarity. A portion of a barometer scale is shown enlarged at *v*, figure 2 (at the top and at the right). The index line at *v* is made accurately 30 inches from the ivory point, but the 30-inch line on the scale is shown set slightly below to offset the capillary depression.

(2) *Correction for imperfect vacuum.*—It is generally assumed that the space in a barometer tube above the mercurial column is a perfect vacuum, and that there is no downward pressure upon the top of the column of mercury. This, however, is not strictly the case in any instance, and often an appreciable quantity of air or water vapor is present. Any vapor that the mercury may give off is, of course, always present. This latter, however, is very small and is never considered except in the most refined investigations. If, therefore, any such pressures exist upon the top of the column it will be depressed, and a correction, which may be properly called correction for imperfect vacuum or reduction to perfect vacuum, should be applied. Such a correction will vary with both the temperature and the volume of the space. If the trace of air present is slight, as is nearly always the case in any good barometer, the correction for vacuum will be nearly constant, provided the volume is not changed much by great changes of pressure, as the changes corresponding to ordinary changes in temperature are comparatively small. Therefore, in ordinary observatory barometers this correction, like the one for capillarity, is included in the correction for instrumental error. When, however, a barometer is used at both high and low pressures, the volume of the vacuum space may change many fold, and in such a case any error due to imperfect vacuum is far from being constant.

(3) *Correction for instrumental or scale error.*—Errors arising from several independent sources are embraced under this designation, as, for example: (*a*) The graduated scale may not be adjusted so perfectly that its divisions are at exactly the right distance from the ivory point; (*b*) the sighting edge of the vernier may not be true or in proper correspondence with its zero graduation line; (*c*) the unavoidable errors and irregularities in the graduations of the barometer scale itself also introduce different errors from point to point along the scale. Nevertheless, sufficient precision in scale graduation is easily attainable even in a scale that is only fairly good, and such errors are generally so small as to be unimportant in ordinary barometeric observations and are seldom considered.

As stated in a previous paragraph, the combined effect of such sources of error as those just mentioned gives rise to what is generally called the correction for instrumental or scale error.

The manufacturer, in adjusting a good barometer, endeavors to eliminate as completely as possible, or at least to reduce to a very small quantity, the several corrections mentioned above; viz., correction for capillarity, for imperfect vacuum, and for instrumental error. This he can do by sliding the scale up or down a small fraction of an inch until he finds by repeated trials and comparative readings with a standard instrument that the new barometer, when corrected for temperature, as described below, gives the same or nearly the same readings as the standard. Any slight outstanding difference that may finally remain then becomes the "correction for instrumental error, including capillarity," or briefly, "correction for scale errors and capillarity."

By comparing a barometer in a partial vacuum, so as to ascertain the "correction for scale errors and capillarity" at several pressures, such, for example, as at each inch between 20 and 30 inches of pressure, it has been learned in a few interesting cases that very great differences in the correction may be found at different points of the scale. These differences amounted in one case to eighty-three thousandths of an inch between 25 and 30 inches, and could not be explained by any error of the scale or by any influence other than that of the irregular capillary action at different points of the tube. These investigations demonstrated the necessity of ascertaining the correction for scale errors and capillarity of each instrument for the particular pressure at which that instrument is to be used.

(4) *Correction for temperature.*—The temperature of a barometer affects the accuracy of its readings in two ways. First, the metal scale expands and contracts with changing temperatures, and is, therefore, continually changing its length. Second, the mercury itself expands and contracts much more than the scale. The 30 cubic inches of warm mercury in a barometer tube at, say, a temperature of 80° F., will be more than 1 ounce lighter than the same volume of mercury at the freezing temperature.

The true pressure of the air, therefore, is not shown by the observed height of the mercurial column until we take into account both the temperature of the scale and the density of the mercury.

For this reason barometric readings require to be reduced to a reading which would have been obtained had the mercury and scale been at certain standard temperatures.

The standard temperature adopted for the mercury is always that of melting ice—that is, 0° C., or 32° F.

When the readings of the scale are taken in inches, the standard temperature for the scale reduction is then 62° F. If, however, the metric unit of length is used, the standard temperature is then 0° C. In the latter case the same temperature serves for both the scale and the mercury.

There is thus a disparity between the temperatures at which English and metric scales are of standard length; moreover, tables of barometric corrections for temperature usually give the reduction for both the scale and the mercury in one correction, whence it follows from these two circumstances that the corrections in English and in metric tables are not mutually convertable. An error is therefore introduced if the uncorrected reading of a mercurial barometer expressed in metric units is converted into English units, or vice versa, and a temperature correction afterwards applied to the result. The conversion of barometer readings from English to metric or from metric to English units can only be made correctly after each reading has been fully corrected for temperature. A further discussion of this point will be found in the Monthly Weather Review for July, 1898, page 302.

42. *Barometer correction cards.*—Each barometer of the Weather Bureau, when sent out, is accompanied by a correction card (Form No. 1059–Met'l) showing the correction for instrumental error, *and also the corrections of the attached thermometer.* If these latter corrections are as large as half a degree, which is, however, rarely the case, they should be applied to the reading of the attached thermometer *before taking the correction for temperature from the table.*

43. *Tables of temperature corrections.*—Tables of correction for temperature are computed by simple formulæ taking into account the known coefficients of expansion of the mercury and of the metal or material of which the scale is made. The scale in this sense includes all the metal parts between the ivory point and the top of the column of mercury. It is generally assumed that the temperatures of the scale and mercury are the same, and that the temperature is given by the indications of the attached thermometer.

For barometers with brass scales the following formula is used for computing corrections:

$$\text{Correction} := C = -h\frac{t-28.630}{1.1123\ t+10{,}978}$$

in which $h$ is the observed reading of the barometer *in inches*, and $t$ is the temperature of the mercury and scale in degrees Fahrenheit.

The numerical factors in this equation are obtained by using the following values for the expansion of mercury and brass, viz:

Cubical expansion of mercury, 0.0001010 per degree Fahrenheit.

Linear expansion of brass, 0.0000102 per degree Fahrendeit.

In Section VIII are given full tables of corrections computed by the above formula.

44. *Correction for density of mercury.*—If the density of the mercury is not the same in two barometers that are exactly alike in every other respect, the heights of the mercurial columns will not be the same for the same pressure. In such a case a reduction to mercury of a standard density will be required. The presence of 1 per cent of lead with mercury causes a change in density that would require a cor-

rection of about 0.051 of an inch. On the other hand, mercury containing even so little as one one-hundredth of 1 per cent of lead is rendered so exceedingly foul that it could not be used for barometric purposes. It is therefore easily seen that a correction for standard density is a refinement which need not ordinarily be considered.

NORMAL BAROMETER—STANDARD BAROMETER.

45. It is easily understood, after what has been said above about errors of graduation, errors due to capillarity, to imperfect vacuum, to instrumental imperfection, etc., that even the best of ordinary barometers is liable to be quite incorrect until corrections for these errors have been determined. Moreover, from the nature of things we can not determine these corrections except by comparison with a standard barometer, and the question might properly be asked, How do we know the standard barometer is right? We will answer this by saying that the standard barometer ought to be a normal barometer. So few understand clearly the distinction between these words "standard" and "normal" in the present connection that some explanation is necessary. In the first place, the expression "normal barometer" is used a great deal by the Weather Bureau and meteorologists in general when, strictly speaking, the expression should be normal barometric pressure; by which is meant the average of a great many years' observations of atmospheric pressure at a single station. In the present case the word "normal" has an entirely different meaning.

A standard barometer need not necessarily be anything more than an instrument which has been pronounced to be correct by some special authority. For instance, the Congress of the United States might say that the indications of such and such an instrument represents the true atmospheric pressure and that the particular barometer in question is the standard of the nation. Such an instrument, although formally pronounced to be a standard, might, nevertheless, possess little more than the average accuracy and its indications still be more or less erroneous. Since the several errors to which barometers are subject can not, in the majority of cases, be determined except by comparison with an instrument whose errors are all known, a standard based only on the dictum of some authority can not necessarily be regarded as giving true indications. A normal barometer, however, is one the construction of which is such that the instrument, fundamentally and independent of all other similar instruments, gives a true measure of the pressure of the air.

Standard barometers should therefore generally be also normal barometers. It must not be understood that a normal barometer is absolutely without any error. The construction, however, is such that those errors which can not be wholly eliminated can yet be ascertained from the indications of the instrument itself. The error for capillary action, for example, is wholly eliminated by employing a tube of very large diameter. On the other hand, if the vacuum is not sufficiently perfect, the error from this cause can still be ascertained, for the barometer will be constructed so that readings can be made when the vacuum chamber is large, and again when it is many times smaller and the pressure of the remnant of air therein proportionately increased; from such readings the desired corrections can be computed. So, also, other errors are either eliminated or are ascertained by special investigations, and the reading of the barometer after all known corrections are made is regarded as fundamentally correct.

Barometers of this type are generally elaborate of construction and will not be described here. Several of the European normals are fully described by Prof. Abbe in the Annual Report of the Chief Signal Officer, 1887, Part II.

### II.—ANEROID BAROMETERS.

46. Figures 16 and 17 represent two of the more important types of aneroid or holosteric barometers, showing, principally, the internal mechanisms. The first is a more common form, but the second is, in general, somewhat better. The essential feature is the same in both instruments and consists of the small metallic box or cell, *M*, the upper and lower walls of which are made of very thin circular sheets of corrugated German silver, which are soldered together on their outer edges, forming a very short cylinder. The air is thoroughly exhausted from this cell through a tube at one side, which, when the vacuum is as perfect as desired, is pinched tightly together, cut off, and hermetically sealed with solder producing the projection seen at *c*. The flexible corrugated surfaces, which tend to be collapsed by the pressure of the outside air, are forcibly held apart by the action of a strong steel spring, *R*. As the pressure of the air increases the spring is compressed and the corrugated surfaces approach each other slightly, returning again or separating still farther with diminution of pressure. To measure the changes in atmospheric pressure, it is only necessary to measure the minute movements of this flexible cell.

The two forms of aneroid figured herein differ simply in the manner by which the minute alterations in the elastic yielding of the spring are magnified and rendered measureable.

47. In the common aneroid a lever, *l*, attached directly to the spring connects by a link, *m*, with a very short arm of a sort of bell-crank lever, *r*, *t*, having a horizontal axis on pivots at each end.

The longer arm, *t*, of this bell-crank lever is connected by means of a wire, *s*, with a very fine chain, the other end of which winds around a small wheel or drum on the axis, *a*, upon which is mounted the hand as seen. At *b* is shown a small spiral steel spring, like the hair-spring of a watch, which serves to take up the slack in the loose connections of the numerous joints, levers, and links.

At *r* is shown, also, a small counterpoise weight attached to the bell-crank lever to aid in securing a more stable position of the index when the barometer is placed in different positions; that is, whether the dial is horizontal, or vertical, or turned to one side or the other.

The point of attachment of the link, *m*, to the bell-crank lever is sometimes adjustable so that the movements of the hand can be made to correspond to the value of the scale graduations.

The steel spring, *R*, is also slightly adjustable by means of a screw from the underside threaded into the part, *N*. This permits adjusting the hand to any particular point of the scale to give correct readings.

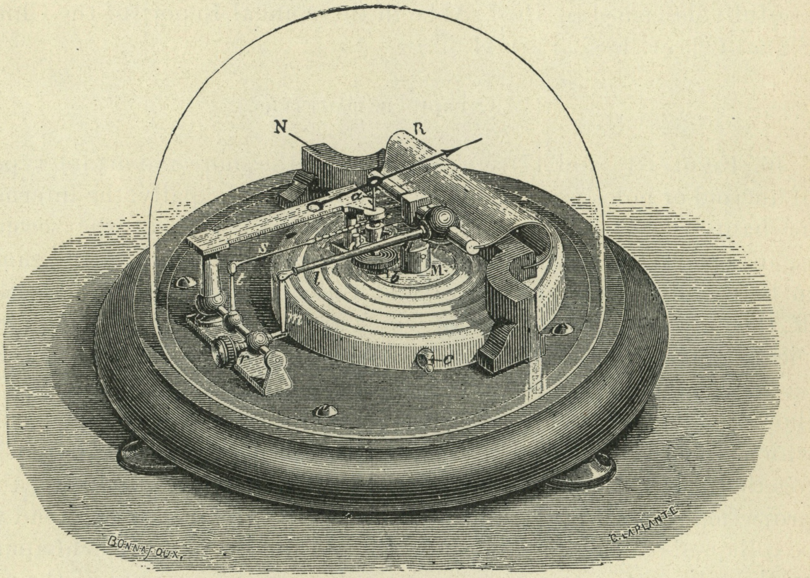


FIG. 16.—Aneroid barometer.

48. *Effects of temperature.*—The steel spring and the feebler elastic reaction of the composition metal of the vacuum chamber are appreciably weakened by increase of temperature, so that in some cases a rise of the pressure may seem to occur which is really caused by the weakening of the spring. In some cases efforts are made to compensate for this by leaving a small quantity of air in the vacuum chamber, which when heated increases its pressure upward and tends to offset the weakening effect upon the springs. A better plan is to make the lever, *l*, of two different metals; viz., brass and iron, firmly brazed together. The differential expansion of these two metals with temperature changes produces flexure in the lever. By filing and adjusting the bimetallic bar, the flexure due to temperature can be made very nearly to balance the effect of temperature on the spring.

The aneroid is then said to be "compensated" and this word is often found on the dial. In many cases this word is there when the compensation is very imperfect.

49. *Defects.*—The friction and looseness in the joints of the links and the lack of perfect balance in the various parts give rise to continually changing errors in the reading of the aneroids. This will be shown by tapping the aneroid from different sides and holding it in a variety of positions; a different reading will be given for each condition.

50. *Goldschmidt's aneroid.*—The numerous levers and links in the common aneroid are dispensed with in this form, and the minute movements of the cell and spring are measured directly by means of a micrometer screw.

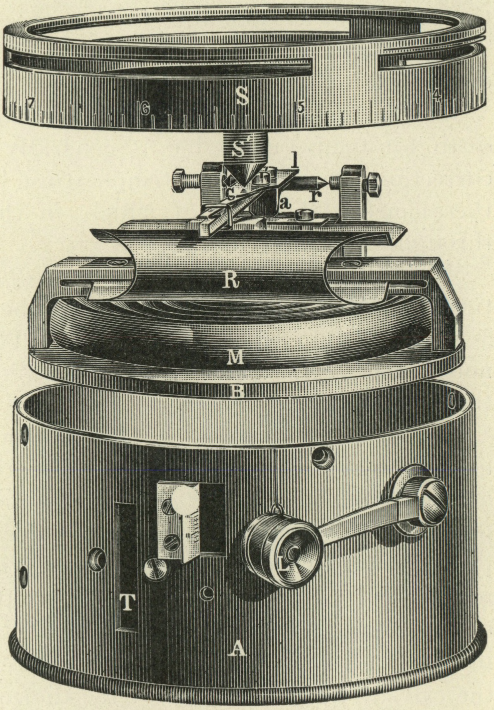

FIG. 17.—Goldschmidt's aneroid.

This is accomplished in several different ways by manufacturers, a common form of instrument being shown in figure 17, where the parts have been separated for a better view. The plate, *B*, with its attached mechanisms, is secured in the bottom of the box, *A*. The micrometer screw, *S′*, works through the cover of the box. The corrugated aneroid vacuum chamber, *M*, is held distended in the usual manner by the steel spring, *R*. A sharp knife-edge projection, *a*, of a double-formed lever, *l*, rests upon a smooth polished spot near the outer end of the spring. This spot is sometimes a bit of glass or agate. The lever, *l*, is pivoted delicately upon an axis at *r* and is formed of two parts joined near the axis. The upper piece of this lever is a very delicate steel spring, with a flat polished surface at *o*, which by the springiness of the arm presses against the point of the micrometer screw, *S′*. At the ends the spring and lever are formed with little flat surfaces, each having a fine line engraved across the middle. This construction is not clearly seen in the drawing. To observe the air pressure the aneroid must be "set" by bringing the above-mentioned lines into coincidence. For this purpose, and at the same time to measure the movement necessary to bring about such a coincidence, the finely cut micrometer screw, $S'$, is provided. The large head, $S$, having a scale of graduations engraved upon its outer rim, being turned, the point of the screw presses against the spring at $o$, deflects it so that the lines upon the ends of the spring and lever may be placed in exact coincidence. To facilitate making this adjustment accurately, a small magnifying glass, $L$, is generally provided. A small scale is opposite the ends of the lever, $l$, when the mechanisms are in their normal position and indicates the whole number of turns made by the screw, or, what is the same thing and more convenient, shows the pressure corresponding to the successive positions of the screw. The fractions of a turn are indicated accurately by the graduations on the head of the screw.

51. *Temperature effects.*—The Goldschmidt aneroid is not compensated for temperature, but is generally accompanied by a table of corrections therefor, the temperature being indicated by a small thermometer, the scale of which, in the aneroid shown, is visible through an opening at $T$.

52. *Reading, how made.*—Aneroids of this pattern are read by first turning the micrometer screw until the lines upon the spring and lever come into exact coincidence. The reading on the scale is noted, and to this is added the part taken from the graduations on the head.

53. Consult paragraphs 104 to 106 for information respecting the use of the aneroid in determining elevations.

54. *How adjusted to standard pressures.*—The aneroid barometer, no matter how perfectly constructed, does not indicate any particular pressure until by careful comparison with a standard barometer its index is adjusted to give as nearly as possible the same reading as the standard. This adjustment is made by means of the screw, which in nearly all aneroids is seen just within a small hole in the back of the case. The graduations of the dial must of course be such as to show changes of pressure on a scale of millimeters or inches.

The Goldschmidt aneroid is similarly adjusted in a variety of ways, of which a common one is to shift the zero or index line at which the reading of the micrometer screw is made.

55. *Errors and defects of aneroids in general.*—After being once adjusted to give accurate pressures, as already described, the aneroid should be handled with great care. Violent knocks and shaking will, especially with the common aneroid, almost certainly change or shift the various links and levers in their joints and change, more or less permanently, the position of the index. For such reasons aneroids are very liable to acquire unknown and often large acci-

dental errors, and can not, therefore, be regarded as very satisfactory instruments.

56. *Errors due to very slow changes, "creeping."*—If an aneroid adjusted to read correctly under ordinary air pressures is placed within the receiver of an air pump, the index will quickly fall to a lower pressure when a partial vacuum is formed. If, however, the vacuum be maintained constantly at the same pressure for many days in succession, the reading of the aneroid will be found gradually to become lower and lower, but after three or four weeks further changes cease or are very small. The amount of this slow change differs greatly and may be from one-half inch or less to over an inch, according to the diminution of pressure and other circumstances. Again, when the barometer is removed from the air pump it does not immediately return to its original correct reading, but its indications will be found to be too low, several weeks being again consumed in a slow return to approximately its former correct reading.

This "creeping" action depends, no doubt, upon some molecular changes, as yet not clearly understood, that take place within the materials of the aneroid box and steel springs. In any case the readings are liable to be very seriously in error, and tourists and others who carry with them aneroids for the purpose of ascertaining elevations should have means to determine and eliminate the very serious errors referred to above. A further discussion of these errors will be found in the Monthly Weather Review for September, 1898, page 410.

57. The aneroid barometer is a convenient instrument for showing more or less accurately *the character and the amount of barometric changes* going on from day to day, but the mercurial barometer is the only instrument that gives atmospheric pressures with that degree of precision required in simultaneous meteorological observations.

58. *Test of condition of aneroid.*—Aneroids, seemingly good, are often defective, because some of the joints of the levers and pivots are too tight, causing the hand to stick and not move with the perfect freedom it should. The condition of an aneroid can be quickly tested in this respect by tapping the instrument on the side or bottom with the fingers or knuckles, or perhaps better by lifting the instrument about one-fourth of an inch from a table or cane-seated chair and placing it back again somewhat sharply. Under this treatment, if the joints and levers are perfectly free, the hand will jump away and then return quickly with a vibratory movement to its original position. If the instrument is defective, the hand in some cases will not respond to the slight knocks, or will do so without exhibiting any vibratory movement, or upon being disturbed it may move a little, but will not return to its original position.

III.—MISCELLANEOUS BAROMETERS.

59. Many curious and interesting forms of barometers have been devised for the purpose of showing the changes of air pressure in a much more magnified manner than is possible with ordinary barometers, especially of the mercurial pattern. A few of these will be briefly mentioned. Many others equally curious and meritorious are necessarily omitted.

60. *Water barometer.*—This may be constructed in practically the same manner as the mercurial barometer, except that water is used instead of mercury. Now, as mercury is 13.6 times as heavy as water, it will result that the water column will be 13.6 times higher than the mercurial column, or about 34 feet hight; also a change of 1 inch in pressure by the mercurial barometer will appear as a change of 13.6 inches in the water barometer.

The great defect of the water barometer, aside from its inconvenient proportions, is the shortening of the column, due to the pressure of water vapor in the vacuum. This shortening amounts to about 10 inches at a temperature of 70° F., and if the temperature were to rise 10° the pressure would seem to fall nearly 4 inches, when really no change of pressure had occurred.

61. *Glycerin barometer.*—Glycerin, sulphuric acid, or nonvolatile oils may also be used in place of mercury, each affording a magnified indication of pressure changes, as in the case of the water barometer, and with the advantage that the errors due to vapor pressures are much less, or are quite inappreciable.

62. *Diagonal barometers.*—It is easily seen that if the top portion of a barometer tube be bent off at a small inclination upward from a horizontal position, the movement of the mercury along this diagonal portion will exhibit, in a magnified manner, the ordinary fluctuations of atmospheric pressure. The same result is secured by forming the top portion of a barometer tube into a helical coil having suitable graduations.

63. *Dial barometers.*—Probably the most practical expedient for magnifying the indications of an ordinary siphon mercurial barometer is the form known as the "dial barometer," shown in figure 18.

The action of the instrument will be readily understood from the diagram without further explanation.

64. *Sympiesometer.*—This is another form of sensitive barometer, in which the pressure of the air, acting through a short column of liquid of low specific gravity, is made to compress a portion of air confined within the instrument. In this case it is necessary to make allowance for the expansion and contraction of the confined air with changes of temperature. This is conveniently accomplished by providing the instrument with two scales, one of which, containing the readings of pressure, is set to a certain line on the other scale accord-

ing to the temperature indicated by the attached thermometer of the apparatus

65. *Howson's barometer.*—This ingenious and novel device is shown in section in figure 20. The barometer tube is large in diameter and longer than usual. The cistern is recurved and extends as a long core up inside the barometer tube, reaching within 3 or 4 inches of the top of the column of mercury. The proportions are arranged to be such that the upward pressure of the air on the under side of the cistern is sufficient to sustain the cistern and contents suspended from the end of the barometer tube.

When a change of pressure occurs the cistern is caused either to ascend upon a barometer tube or to move down to a new position of equilibrium, and, by selecting suitable proportions between the internal diameter of the barometer tube and the thickness of its walls in relation to the diameters of the core and cistern, the movement of the latter up and down the tube with changes of atmospheric pressure can be made to represent pressures upon a greatly magnified scale.

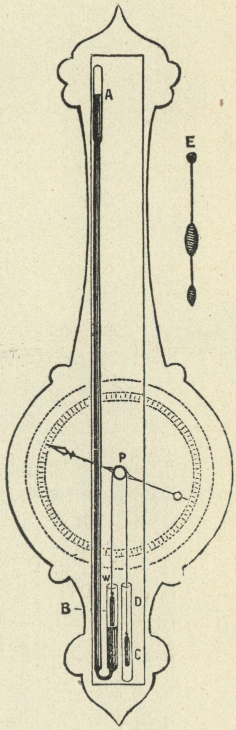

Fig. 18.—Dial barometer

66. *Magnifying siphon barometer.*—Figure 21 illustrates still another expedient by which the indications of a plain mercurial barometer may be greatly magnified. The short leg of a siphon barometer is extended upward, in the manner shown. The small-bore tube, *a*, is enlarged at the top to have the same diameter as the cistern portion. The portions, *a*, *b*, *c*, of the short leg are filled up to a point at about *h* with colored water, and then above this with kerosene or some other liquid of nearly the same density as water and with which it does not mix. It is plain that when the level of the mercury in the short leg changes, the meniscus separating the oil from the water in the small-bore tube will be seen to change its position by an amount enlarged in proportion to the relation between the areas of the cistern and the small tube.

67. *General comments on magnifying barometers.*—The special barometers described above are interesting and in many respects curious, but they can not be regarded as anything more than philosophical toys and curiosities. It is impracticable in any of the magnifying instruments to determine the absolute pressure with great precision, for the expedients of magnification introduce sources of both constant and accidental errors that affect the results to a magnified extent, so that even less precision generally results than is attained with well-made mercurial barometers of the simple pattern.

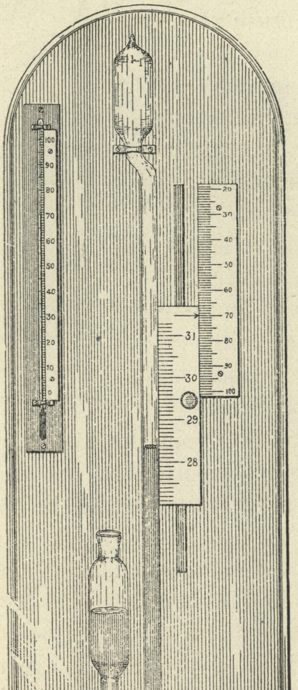


FIG. 19.—Sympiesometer.

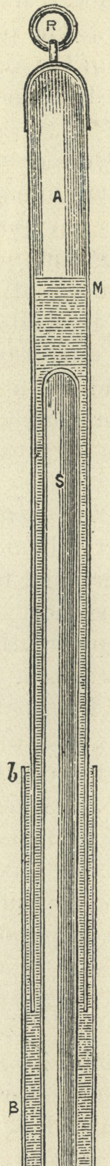


FIG. 20.—Howson's barometer.

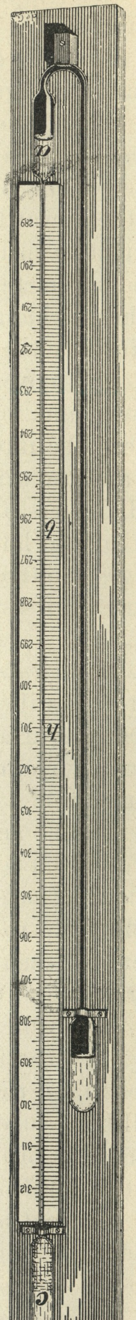


FIG. 21.—Three-liquid barometer.

### IV. BAROGRAPHS, OR CONTINUOUSLY RECORDING BAROMETERS.

68. The barograph is a form of barometer with the addition of parts by which a continuous record of the barometric oscillations is traced upon a sheet of moving paper or obtained by photographic processes upon sensitized plates. Many different forms of apparatus have been devised, nearly all of which are more or less elaborate, in general, but not correspondingly accurate. In most cases the changing temperature to which the instruments are subjected introduces small errors, and the mechanisms effecting continuous registration either obstruct the free action of the barometer proper or do not transmit to the record sheet a trace representing exactly the original fluctuations of pressure. The absolute value of the pressure indicated by the position of the tracing point is also subject to uncertainties, and while *changes* of pressure are shown with greater or less accuracy, it is impossible, even with the best instruments, to record the *absolute* pressure with a precision equal to that of an eye reading of a standard barometer. In general, therefore, the indications of automatic instruments are checked and corrected by reference to occasional eye readings of a standard barometer.

69. It hardly requires to be said that the mercurial barograph is more reliable and gives more accurate results than those of the aneroid type. Many ingenious mechanisms are employed to effect the continuous registration, thus:

(1) In some cases this is accomplished by directly photographing on a moving sheet of sensitized paper or a moving plate the changing positions of the summit of a barometric column, notably the case at the Kew Observatory, England.

(2) In other forms, a float resting upon the mercury in the open leg of a siphon barometer communicates the motion directly to a lever which carries the recording pen at its end and produces the record on a magnified scale. It is difficult to overcome the friction of the pen and magnifying levers sufficiently to obtain correct records; the construction in some forms is therefore modified and clock movements or electromagnets are caused to perform the real labor of producing the record. Under this category we have such cases as follow:

(3) The motion of the float is communicated to a very delicately poised lever, the slightest movement of which sends a current of electricity through properly disposed magnets, which either alone or acting in conjunction with clockwork perform the real labor of moving the pen mechanisms and preserving a proper condition in the equilibrium of the float.

(4) A distinct class of barographs is obtained by constructing mechanisms which measure and record the barometric oscillations by *weighing* the changing quantities of mercury within a poised barome-

ter tube or cistern. The weighing is effected by suspending the barometer tube or its cistern from the beam of a balance which is continuously preserved in a condition of equilibrium by the automatic movement of a counterpoise traveling along the beam of the balance. The movement of the counterpoise is effected either by clockwork, or by electromagnets, or by both.

(5) A modification of the weighing principle consists in substituting for the balance mechanisms coiled steel springs, by the deflection of which the changing weights are measured and recorded.

The following descriptions, given in some detail, of representative types of mercurial barographs that have been maintained in operation by the Weather Bureau will enable the student interested to understand more fully how such mechanisms operate:

70. *Foreman's barograph.*—This is shown in figure 22. It belongs to a class mentioned above under (3). Prof. G. W. Hough, director of Dudley Observatory, Albany, N. Y., about 1862, perfected barographs recording on this principle, the form here figured being designed by Mr. H. L. Foreman, who was at one time Prof. Hough's assistant. The glass siphon tube of the barograph is at the back at *B*, and is only partly visible, the bend being hidden behind the record cylinder, *A*. The open end of the siphon tube is seen at *C*; an iron float rests lightly upon the surface of the mercury within, being sustained by means of a fine wire, *t*, from the short end of the lever, *l*, which is delicately poised upon steel knife edges at *r*. The long end of this lever at *h* is tipped with platinum and placed between two platinum-pointed screws, both of which nearly, but not quite, touch the tip of the lever when the latter is poised in proper equilibrium. The upper screw is connected by the wire, *W*, with an electromagnet at the back of the instrument; a corresponding electromagnet, partly seen at *M*, is connected by the wire, *W′*, with the screw just beneath the tip of the lever. *P* is a strong clockwork driven by the cord, *T*, and permitted to run intermittently whenever released by the action of the electromagnets at *M*.

The clock movement, *D*, regulated by the pendulum, *F*, gives motion to the recording cylinders, *A*, *A′*. The cylinder, *A*, makes 1 revolution in 24 hours, whereas *A′* revolves at the much slower rate of about 1 revolution in 16 days.

The lever, *l*, together with the platinum-pointed screws and electrical connections, *W*, *W′*, are all mounted upon a carrier, *R*, which is moved by the fine-threaded screw, *S*, and guided by the columns *a*, *a*. The coarse-threaded screw, *S′*, is provided with the double-pen carrier *R′*, the screws, *S′* and *S*, being geared with each other by means of suitable wheels. We will suppose that the mechanisms have been properly set so that the iron float is normally sustained upon the surface of the mercury and the lever, *l*, poised in equilibrium, in which

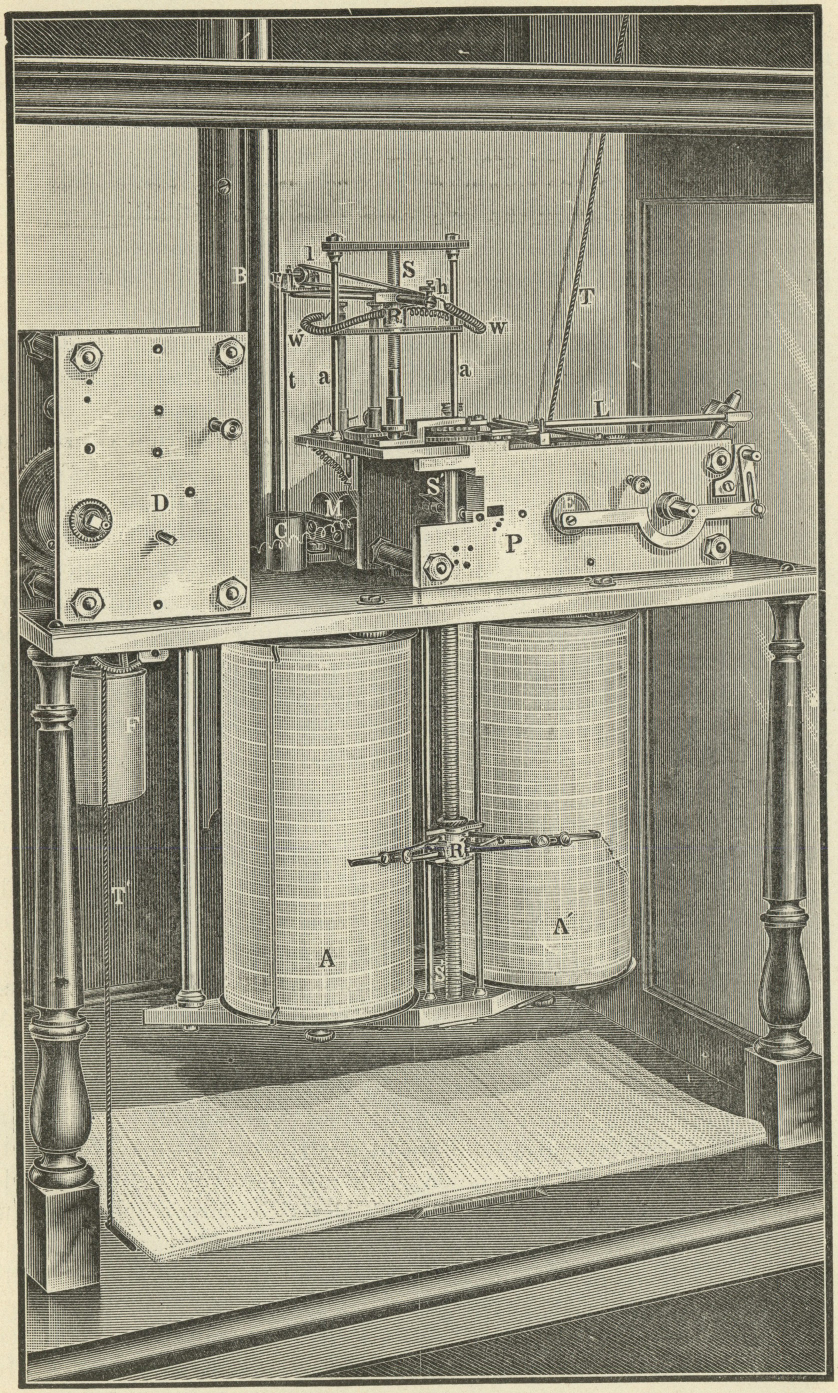


FIG. 22.--Foreman's barograph.

case the platinum tip, *h*, will stand about midway between the platinum-pointed screws above and below it, respectively. The pen carrier, *R′*, must also then occupy such a position on the screw that the tracing pens will indicate the true barometric pressure upon the rulings on the record sheet. Appropriate connections with an electric battery being made, the action of the mechanisms will be as follows:

Any minute change in the level of the mercury will alter the position of the iron float, in consequence of which the platinum tip of the lever, *l*, will move into contact with one or the other of the platinum-tipped screws, causing a current of electricity to be directed through the electromagent connected therewith. The action of either electromagnet releases the clockwork, *P*. In doing this, however, the one magnet shifts the lever, *L*, laterally toward the back of the instrument, while this lateral movement will be toward the front if brought about by the action of the other magnet. The movement of the clockwork causes the lever, *L*, to advance or recede so that a pawl upon the end, engaging a tooth of a ratchet wheel upon the end of the screw, *S′*, revolves the latter a fraction of a turn. This fractional turn will be in one direction if the lever, *L*, is drawn backward or in the opposite direction if *L* is pushed forward, according as the lever, *l*, has made contact with the upper or under screw. This movement of the screw, *S′*, shifts the pen carrier, *R′*, and the pens upon the record sheet, and, being communicated to the screw, *S*, causes a proportionate change to take place in the float-carrier, *R*. The clockwork automatically stops after one such cycle of actions. If after these movements the lever, *l*, is again poised in equilibrium no further action ensues until the contact of *h* with one or the other of the screws is again made, whereupon the cycle of actions will again be set up and, if necessary, repeated in quick succession until the equilibrium of the poised lever, *l*, is restored. The movement of the pen carrier, *R′*, corresponding to a change in the position of the float, is four times as great as the change in the height of the mercurial column. A change of 1 inch in pressure, therefore, is represented as a change of 4 inches on the sheet. Each closure of the circuit producing $\frac{1}{25}$ revolution of the screw, *S′*, or $\frac{1}{50}$ revolution of *S* represents a change in the height of the mercurial column of 0.001 inch, which is the nominal sensitiveness of the instrument. Owing, however, to unavoidable imperfections in screw threads and electric contacts and to the capillary action of the mercury in the barometer tube, the probable error of the instrument is much greater than this, no doubt amounting to at least 0.01 inch.

By selecting proper proportions for the long and short legs of a siphon barometer, the effects of temperature can be almost perfectly eliminated. This, however, appears not to have been considered when Foreman's barograph was designed, and the records are subject to small periodic errors due to temperature changes. For the further elucidation of the automatic compensation of siphon barographs for temperature see paragraph 80.

Owing to the presence of the float on the surface of the mercury in the short leg, and to other causes, it is practically impossible to make a direct measurement of the actual height of the column of mercury. When, therefore, it is desired to set the recording pens or check their positions in relation to the true air pressure, it is necessary to make a reading of the standard barometer. In the barograph next described the effect of temperature is inappreciable, and the actual height of the mercurial column may be directly measured at any time, thus dispensing with the extra barometer required with Foreman's barograph.

71. *Marvin's normal barograph.*—This instrument is shown in figures 23 and 24. It belongs to the class mentioned above under (4), wherein the mercurial column is directly weighed upon a balance.

The glass tube which, with the top portion of the mercurial column, may be seen at *B*, is freely suspended by the hook, *h*, from the balance, *A*. The point of the tube dips into the mercury contained in the cistern, *C*, which is suspended by a gimbal joint from the columns, *d*, *d*, by means of the metal tube, *B'*, which forms a sheath and protection for the glass barometer tube proper. The weight of the barometer tube on the short arm of the beam, *A*, is balanced by the rolling carriage, *W*, and a fixed weight (not shown) on the end of the long arm of *A*. Whenever a change occurs in the height of the mercurial column, the weight changes, and the carriage, *W*, must be moved to a new position if equilibrium is to be preserved. In order to make the motions of the carriage, *W*, automatic, a platinum-tipped contact spring is attached to the balance beam at the extreme end, *r*, of the long arm. The slightest displacement of the beam from its position of equilibrium causes the spring to move into contact with one or the other of two platinum-pointed screws, shown enlarged in figure 24 at *m*, *m'*. These are electrically connected, respectively, with the magnets, *M* and *M'*, so that when the spring, *r*, makes contact with *m* or *m'*, an electric battery being in proper connection, a current is caused to flow through the corresponding electromagnet, the action of which causes the pin, *N* or *N'*, to engage the teeth of the notched wheel, *D*, in such a manner as to revolve it tooth by tooth. The long screw, *S*, figure 23, carries the wheel, *D*, fixed at its end so as to be revolved thereby. The threaded carrier, *W'*, fitted to the screw, *S*, is connected by a double universal linkage to the rolling carriage, *W*. The electromagnets thus act very directly through the wheel, *D*, and the screw, *S*, to automatically move the carriage, *W*, into such positions as may be required to maintain the equilibrium of the balance; that is, to prevent the contact spring on the beam from remaining continuously in contact with either screw *m* or *m'*.

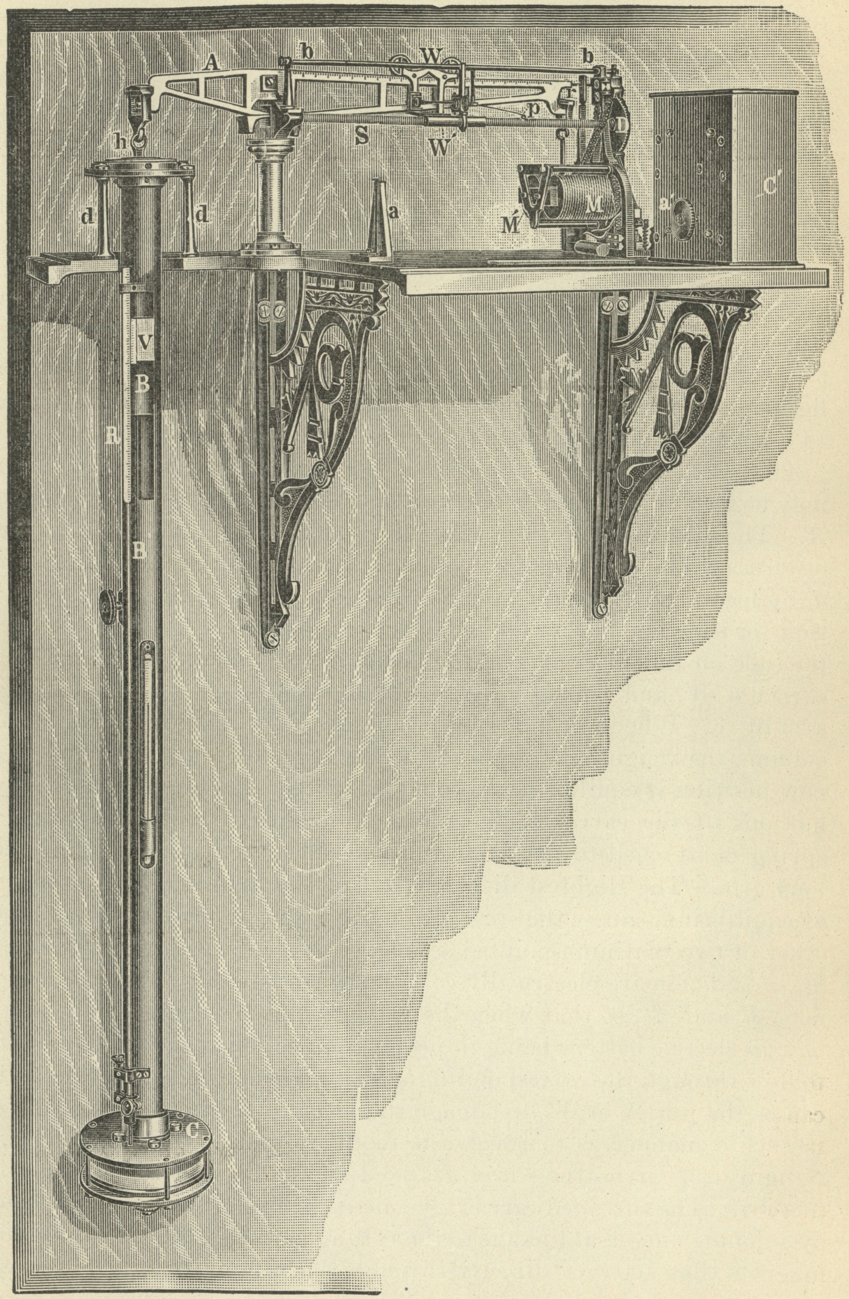


Fig. 23.—Marvin's normal barograph.

The motor mechanisms act in such a manner that, whenever the equilibrium is disturbed and the electric circuit closed, the armature of whichever electromagnet is affected makes stroke after stroke, revolving the wheel, *D*, until the equilibrium is restored. Generally one or two strokes only are necessary, representing a change in the

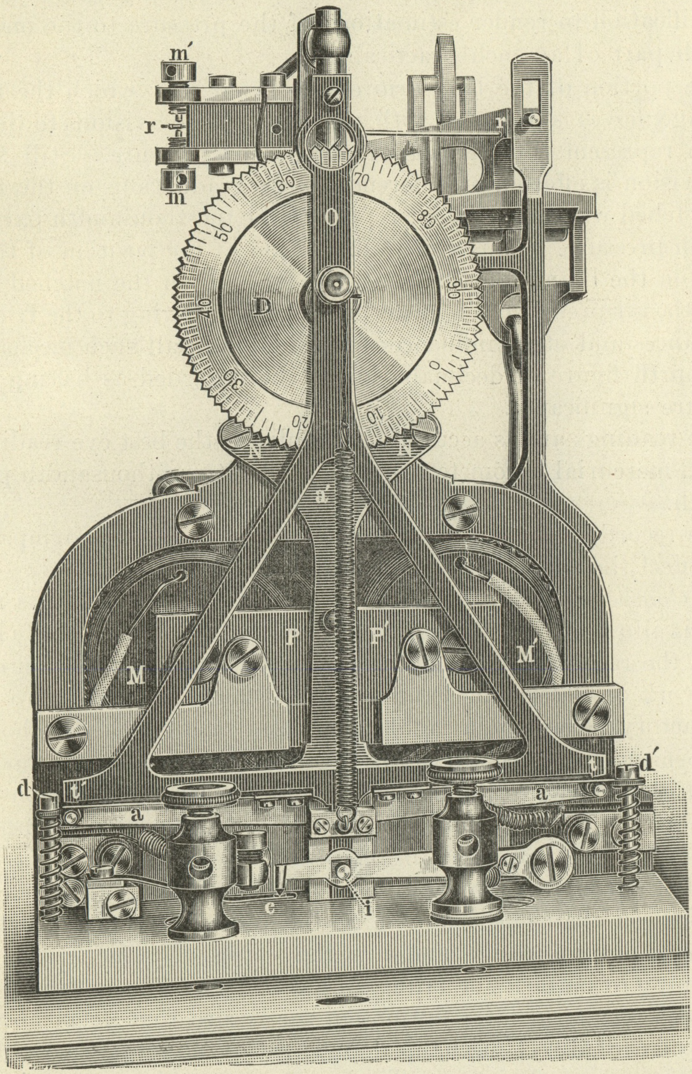


FIG. 24.—Electric-motor mechanisms.

carriage corresponding to only the ten-thousandth part of an inch of pressure, as explained below.

The continuous record of the pressure, as indicated by the successive positions of the rolling carriage, is obtained in a very direct and simple manner. A suitable spring, adjustably attached to the threaded carrier, $W'$, is fitted with a pen, $p$, figure 23, and traces the pressure curve upon a large cylinder, not shown in the figure, but mounted with its axis in the bearings $a$, $a'$. The cylinder is revolved regularly by the clock movement, $C'$.

If the height of the mercurial column changes 1 inch, the rolling carriage and recording pen will move 5 inches, thus giving a sufficient magnification to render estimations of the pressure to the one-thousandth part of an inch practicable.

The portion of the long arm of the beam over which the rolling carriage moves is provided with a scale of 20 subdivisions to the inch, which represents hundredths of an inch of pressure. Still further subdivision is effected by reference to the graduations on the face of the notched wheel, *D*. These represent the ten-thousandth part of an inch in pressure. Thus a mere inspection of the position of the carriage on the beam, together with the reading on the notched wheel, gives the air pressure to four decimal places. Owing to the frictional resistances and other influences unavoidable in all such mechanisms, the fourth figure of decimals can not be regarded as having a real pressure significance.

The readings are as accurate, probably, as the best eye readings of a good mercurial barometer, that is, to about one-thousandth part of an inch.

The record is not appreciably affected by changes of temperature that affect the whole instrument uniformly.

72. *Compensated siphon barograph, Marvin system.*—This instrument is illustrated in figures 25 and 26 and belongs to that class in which the record is made mechanically without interposition of any clockwork or electric mechanism to overcome friction, etc. To secure satisfactory records on a highly magnified scale by this method it is indispensable that the friction involved in writing the magnfied record be removed to the last degree. Experience has demonstrated that this has been accomplished in the arrangement described, and this instrument proves to be exceedingly accurate and far more reliable than any of the types heretofore employed. The clock and electrical mechanisms required in the older instruments act in a certain sense indirectly and are the cause of some errors. The weakening of batteries or failure of electric mechanisms from time to time also results in interruptions in the record that do not occur in the system of direct mechanical registration now to be described.

73. *Compensated siphon.*—The barometer of this instrument is a special form of siphon clearly shown in figure 25 and with dimensions marked in figure 26. The long and short branches consist of simple, straight tubes. These are narrowed down at the lower ends where they are fitted into the upturned branches of the bend, or **U**. The tubes, in fact, form hollow stoppers carefully fitted and ground

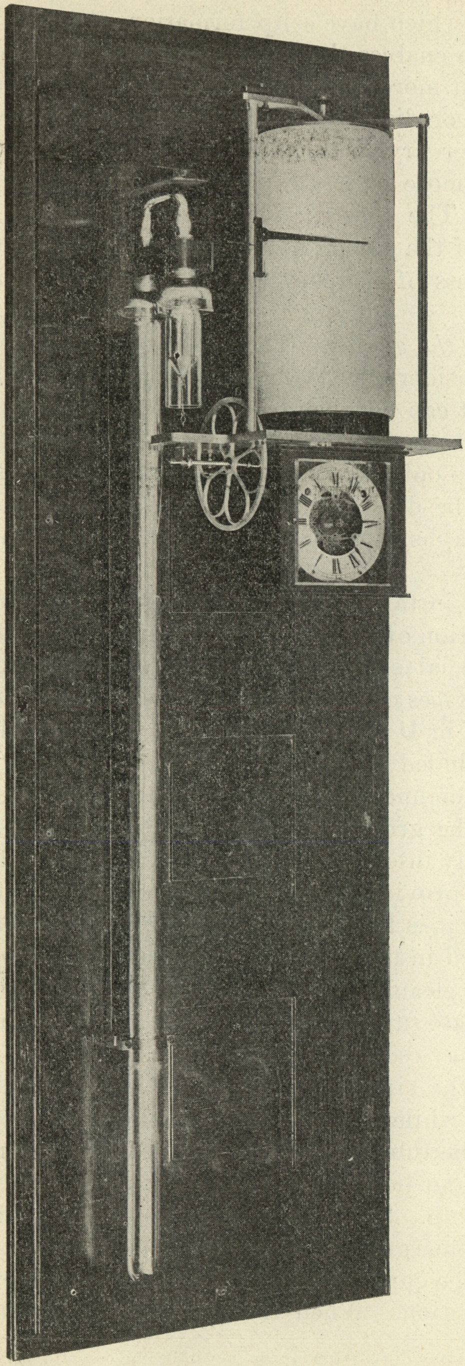

FIG. 25.—Compensated siphon barograph, Marvin system. Glass cover case removed.

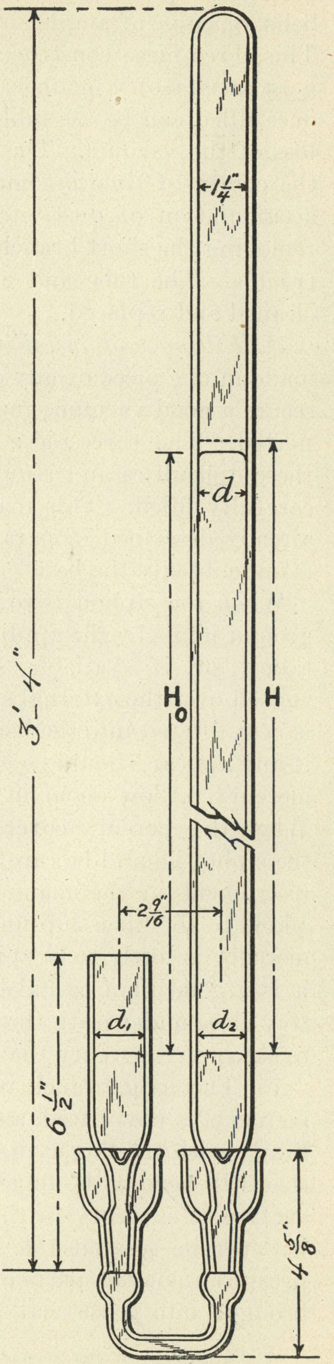


FIG. 26.—Siphon tube.

in. The top of the U above the ground joints are provided with bells, or cups, of ample size, which have a lip formation on one side. This three-piece construction enables the barometer to be filled in a most satisfactory manner, but more especially the siphon after being once filled can be assembled or dismantled and transported without loss of the vacuum. The mercury in the open leg of the siphon in the course of time becomes more or less fouled with oxidation, the accumulation of dust, etc. The construction described permits of removing the short branch of the siphon at any time with very little trouble. The tube and excess of mercury can then be thoroughly cleaned and replaced.

74. *Filling and installing the siphon.*—The ordinary siphon tube made in one piece of any considerable size is very difficult to fill and secure a good vacuum, and it can not then be easily cleaned or transported. The three-piece construction already described overcomes these difficulties and requires only that the long, straight branch be carefully filled. This may be done by almost any of the methods already described in paragraphs 33 to 38, but the air-pump method is undoubtedly the best.

When the siphon is to be installed it will be well to prepare the ground joints by the application of a little lubricant, such as vaseline, tallow, or, if available, special stopcock lubricant, very sparingly rubbed over the external surfaces of the tubes. A little pure mercury is next filtered into the bend, or U-shaped section. Small air bubbles, if any appear, should be excluded by tilting the tube and causing the mercury to flow about in a manner that will accomplish this result. When the mercury covers the ground surfaces the short branch of the siphon should be carefully inserted [1] and the whole secured to the instrument in the manner provided. More pure mercury is now added to the open cup until it is filled nearly to the brim. As some mercury is likely to be spilled in the course of subsequent operations, it is a good plan to have a clean porcelain or glass photographer's tray close underneath the plate supporting the bend. This will serve to catch any mercury that may escape.

75. The long branch of the siphon, completely filled with clean mercury, is now lifted, and, while the open end is temporarily closed firmly with the finger tip, the tube is carefully inclined in a manner that will permit the finger and point to to be dipped below the free surface of mercury in the cup. Still supporting the weight of the heavy tube so that the submerged end does not bear with undue pressure upon the parts of the cup, the whole is carefully and slowly brought into a vertical position. When the elevation of the tube

[1] The alignment of the ground joints of the siphon can never be made quite perfect, and the two branches are marked with a side that when faced to the front gives the best results. In seating the tubes they should be faced in this position.

has reached the point at which the mercury begins to leave the top of the tube, an assistant should be ready to catch in a suitable vessel (a dry, clean, drinking glass will answer very well), the excess of mercury that overflows from the open cup.

The heavy tube must be fully supported until quite vertical, and the end only then inserted into the ground joint and rotated a little as it is faced to the front.

76. Certain precautions must be observed throughout the operations we have just described. (1) The tip end of the tube must not, under any circumstances, be lifted out of the mercury after the finger is removed. (2) After the flow of mercury has started the elevation of the tube must be made gradually; otherwise the column of mercury will tend to oscillate or surge up and down and may uncover the point of the tube in the cup. (3) Any lowering of the tube causes the mercury to recede into the vacuum, and will empty the cup unless the supply is kept up by pouring back some of the excess that has already overflowed.

77. Having finally seated the long branch, some of the excess of mercury must be restored to the siphon and the level brought up to the proper point in the open leg. At the completion of these operations one of the cups of the bend is full to overflowing with mercury, and the other is nearly or quite empty. Some of the mercury in the full cup can easily be removed by splashing it out into a cup held to receive it, using a piece of card or ivory paper folder for the purpose. A little mercury may be added to the empty cup.

78. *To clean the mercury.*—When the glass and mercury in the open leg become soiled through prolonged use, all that is necessary after removing the float is to loosen carefully the short branch of the siphon and permit the excess of mercury to overflow into a clean glass. When thus emptied the open branch may be removed, thoroughly cleaned, and replaced. Most of the dirt will come away with the glass tube, but the mercury may easily be filtered and replaced clean and bright.

79. *To dismantle the siphon.*—If it is desired to take down the siphon, it is first necessary to remove the short branch, carefully collecting the excess of mercury, and then, after separating the ground joint of the long arm, the latter is slowly inclined, while an assistant steadily pours mercury into the open cups to replace what flows into the vacuum. When the tube is entirely filled, the finger may be slipped over the open end while submerged in the mercury and the whole tube removed.

80. *Temperature compensation of siphon.*—It has already been mentioned that by giving the siphon barometer proper dimensions the influence of temperature can be eliminated for all practical pur-

poses. The compensation operates so that changes of temperature affecting the whole instrument uniformly produce no sensible change in the level of the mercury in the short or open branch of the siphon. The actual difference of level of mercury in the two branches will, of course, be affected by temperature in the usual way, but not the absolute position of the surface in the open leg. Since all measurements are made only on this surface in many forms of mercurial barograph, it is very desirable to realize in the design of such instruments this condition of automatic compensation for temperature.

The physical principle utilized for this purpose is found in the different rates of expansion of mercury and glass or whatever material is used for the tube or envelope for the mercury. If the coefficient of expansion of the envelope were zero, the mercury would rise slightly in the open leg with rise of temperature, and vice versa. As the theory of this temperature compensation is not stated in the ordinary textbooks of physics and meteorology, and, in, fact, does not appear to be widely known, it seems worth while to present it here briefly. The theory was developed by Prof. G. W. Hough[1] in 1862, and later by Goulier:[2]

Let $m$ =Cubical expansion of mercury per unit temperature.
Let $g$ =Cubical expansion of glass per unit temperature.
Let $V_0$ =Volume of mercury in instrument at temperature $t_0$.
Let $d$ =Diameter of tube at top of column in vacuum.
Let $H_0$ =Height of column, at temperature $t_0$.
Let $H$ =Height of column, at temperature $t$.
$d_1$, $d_2$=Diameter of the two branches of the siphon at the level of the top of the column in the open branch.

We assume that the pressure remains constant. Therefore the barometric column for a change of temperature must change its length by an amount represented by the expression

$$m(t-t_0)H_0;$$

otherwise its hydrostatic pressure will be altered; that is,

$$H-H_0=m(t-t_0)H_0.$$

Neglecting small quantities of a second order of magnitude, the volumetric increase in the barometric column will be the expression

$$\tfrac{1}{4}\pi d^2 m(t-t_0)H_0,$$

which is the change necessary to preserve hydrostatic equilibrium.

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[1] Hough, Prof. G. W. Annals of the Dudley Observatory, Albany, N. Y., Vol. I, 1866, p. 88.
[2] Goulier, C. M. Comptes-rendus, vol. 84, 1877, p. 1315.

Now, the apparent change in the volume of mercury in the tube will depend upon the differential expansion of mercury and glass, and is given by the expression

$$V_0(m-g)(t-t_0).$$

When this increase is just equal to that necessary to preserve hydrostatic equilibrium, all the expansion will seem to take place in the vacuum chamber and no change will occur in the level of the mercury in the open leg. To realize this condition we have

$$V_0(m-g)\ (t-t_0)=\tfrac{1}{4}\pi d^2 m\ (t-t_0)\ H_0,$$

or

$$V_0=\frac{\pi d^2 H_0}{4}\,\frac{m}{m-g}.$$

The expression

$$\frac{\pi d^2 H_0}{4}$$

is the volume of the barometric column, supposing the diameter to be the same throughout as at the top.

The cubical coefficient of expansion of mercury, $m$, is a very definite quantity and for barometric work may be taken to be 0.0001010 per degree Fahrenheit. The expansion of glass is much smaller and varies considerably, ranging, according to Regnault's measurements, from 0.0000145 for common white tubing to 0.0000118 for the hard French and crystal tubes. That is to say, the whole volume of mercury in a siphon to be compensated must be about

$$V_0 \doteq 1.168\frac{\pi d^2 H_0}{4}$$

if made of common tube,

or

$$V_0=1.132\frac{\pi d^2 H_0}{4}$$

if made of French crystal.

No great exactness is necessary in the volume of $V_0$. It will suffice to assume $H_0$=the mean barometric pressure at the place of observation, and the total volume of mercury should be about 17 per cent more than requisite to fill a column of height $H_0$ and diameter $d$.

If the bend of the siphon is of wide bore, the open leg and bend must be very short (for example: $30\times0.17=5.1$ inches); otherwise $V_0$ will be too large. For this reason, as well as for convenience of construction, the bend is best made of smaller diameter than the main tube, as shown in the illustration.

81. The theory given above takes account only of the influence of temperature on the mercury and glass tube. The effects that result from changes in the mechanisms described later for transmitting and

inscribing the record, and for holding the glass barometer tube itself, all require consideration, but fortunately these are in the main so small, especially when considered in relation to the highly magnified scale on which they record is inscribed, that they may be neglected. In any case they can be incorporated with the mercury effect so that by adding or removing small amounts a certain total volume, $V_0$, of mercury at temperature $t_0$ may be employed, and thus all uniform effects of temperature on the whole apparatus will be automatically compensated.

If the siphon is not compensated, then the volume of mercury at temperature $t_0 = V_1$, which in general will be greater than $V_0$, but may be less, and a small correction will be required, the amount of which will be simply the apparent expansion of the excess of mercury occupying the bend and short leg of the siphon. This expansion may be imagined simply to lift the whole column of mercury a small amount, $\Delta h$.

The volumetric expansion will be

$$(V_1 - V_0)\ (m - g)\ (t - t_0),$$

and the rise of mercury, $\Delta h$, is given by the expression

$$\frac{\pi}{4}(d_1^2 + e_2^2)\ \Delta h = (V_1 - V_0)\ (m-g)\ (t-t_0)$$

In general, $d_1$ and $d_2$, will be made sensibly equal, and, in fact, $=d$. Hence:

$$\Delta h = 2(V_1 - V_0)\frac{(m-g)\ (t-t_0)}{\pi d^2}.$$

Let $y$ = the amount by which the mercury in the open leg of the siphon stands higher than required for compensation. Then, since an equal excess of mercury occupies the opposite branch of the U, we have:

$$V_1 - V_0 = 2\frac{\pi d_2}{4} y.$$

$$\Delta h = y\ (m-g)\ (t-t_0),$$

or, for ordinary glass:

$$\Delta h = .0000865\ y\ (t - t_0).$$

That is, the temperature correction required is simply the apparent expansion of the short column $y$ of excess of mercury. Now, the temperature variations affecting a barograph throughout the period of a single record sheet, or rather during intervals when the record may be checked by eye observations of a standard barometer, will rarely exceed 10° or 20° F. If $y$ = 1 inch, for example, then $\Delta h$ for 20° = .00173, a quantity which, in general, may be neglected.

82. *Magnifying and recording mechanisms.*—In the barograph illustrated, the barometric changes are magnified five times and recorded on a vertical drum adapted to embrace a change of 2 inches of pressure and revolving once in three days, moving at the rate of nearly a quarter of an inch per hour. A long experience with a variety of scales indicates that records on time and pressure scales of about the above proportions give, on the whole, the most satisfactory and graphic picture of ordinary barometric oscillations. Even the sudden changes that sometimes occur with thunderstorms are very well brought out; but for the most detailed effects of this character a more rapid time scale is necessary. The magnification is sufficiently great to show clearly the small fluctuations of from a few thousandths to some hundredths of an inch that sometimes occur for hours at a time.

In the siphon form of barometer the change of level of the mercury in either leg is only half of the whole change, assuming both legs to have the same diameter, and, since we measure effects in the open leg only and desire a fivefold magnification, it follows that an actual tenfold magnification of the movements of the float is necessary. This is accomplished by a large and a small wheel operating on the principle of the wheel and axle, as may be clearly seen in figures 25 and 27. This construction provides a perfectly balanced system which is itself neutral in all positions and, at the same time, admits of a wide range of movement, results impossible to secure with lever systems commonly employed in cases of this kind.

In order to secure the strength of construction and at the same time reduce friction to a minimum, the multiplying wheel and axle are mounted on carefully designed and constructed ball bearings, each cell containing only six balls, each one-sixteenth inch in diameter. The ends of the axis entering the ball cups are 70° cones.

A conical steel float, with the base somewhat hollowed out so as to conform fairly well with the shape of the surface of mercury rests lightly upon the top of the column and is suspended from the small drum of the wheel-and-axle system by means of a narrow platinum ribbon about 0.001 inch thick. The pen carrier is suspended by a very fine copper wire running in a groove in the rim of the large wheel, the diameter of which is approximately 5 inches, while that of the drum is one-tenth as great. The exact ratio of these wheels is made so as to realize a fivefold magnification of pressure changes; due account being taken of any slight differences in the diameters of the open and closed chambers of the barometric column.

To realize a condition of minimum friction great attention is necessary in the design and arrangement of the pen carrier. First, the weight must be the least practicable, since the mass of the float must be somewhat in excess of 10 times that of the pen carrier, and any unnecessary weight in these parts introduces avoidable pressure and friction on the axle. Second, while the pen carrier is guided and constrained to move without sensible looseness in a definite vertical line by sliding along a fine, stretched wire, nevertheless the whole arrangement is so poised and balanced that if not disturbed by exterior influences the carrier will rise and fall in exactly the same vertical line, as nearly as may be, even when the wire is removed. This adjustment serves to eliminate any sliding friction experienced by the pen carrier not absolutely essential to constraining the pen to the desired vertical line. Finally, the contact pressure of the pen on the record sheet is no greater than essential, and results from a small residual gravitational tendency of the carrier to rotate the pen point against the record sheet with a very gentle pressure. The siphon tubes are about 1¼ inches in diameter and the float is only slightly smaller. This gives a moving force capable of overcoming the unavoidable friction in a highly satisfactory manner, and the absence of any complicated mechanisms renders false and interrupted records almost an impossibility.

83. *Time checks on record sheet.*—As thus far described the barograph is complete, and with the aid of the driving clock and drum, which require no further description, gives highly accurate and continuous records. The detailed analysis of barometric records generally requires hourly readings. When record sheets are employed with ruled scale for pressure and time, there is always a difficulty in setting the record so that the ruled hour lines on the sheet indicate the true time. A similar difficulty arises in setting the pen to the correct point on the pressure scale. This, however, is of slight consequence if sheets are properly printed and cut with uniform margins and carefully placed on the cylinder.

To secure easily an equally satisfactory result with the time record, the driving clock is provided with a dial and hands in the usual fashion. These moving continuously day after day enable the clock to be regulated to keep correct time, a result very hard to secure when the rating is done on record sheets that are frequently changed. More especially, however, the barograph is equipped with a special time-marking device which automatically operates once each hour at the instant the minute hand of the clock reaches XII, or the zero point of the hour. Nearly all the time lines are omitted from the printed rulings of the record sheet, and the marker operates so as to lift the float a few hundredths of an inch and immediately release it. This causes the recording pen to oscillate a few times up and down and to inscribe a short transverse line across the pressure record. These transverse strokes are, in fact, the hour lines for the entire record and are inscribed with all the accuracy required.

84. There is a further advantage from the action of the time marker. The float is raised from the mercury momentarily and subsequently oscillates slightly. This causes a general renewal of the forces of buoyancy and capillarity which determine the exact position of the float, and any failure of the pen at the end of the oscillations to return exactly to its original position is an index of the magnitude of errors that arise partly from friction and partly from variation in the capillary and buoyant forces.

Discontinuities of several thousandths of an inch, due to these causes, are sometimes found in the records, rendering apparent the existence of small errors which would otherwise be only conjectured.

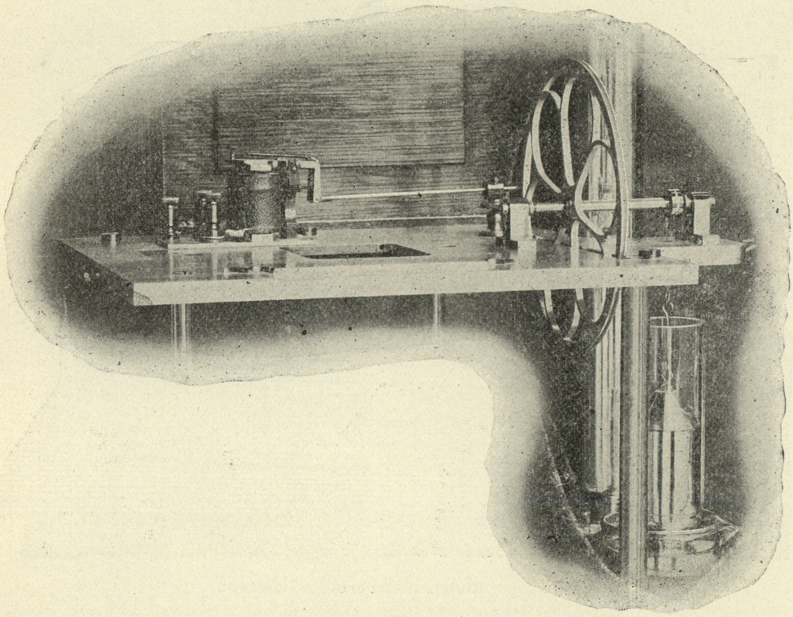

FIG. 27.—Time marker.

85. The time marker is shown in figure 27, and consists of an electromagnet, the circuit of which is momentarily closed by a spring contact operated by the minute hand of the clock as it passes the XII point of the dial.

The armature of the magnet is L-shaped, as seen in the picture. A long, light, horizontal rod is pivoted at the depressed end of the L-formed armature, and is also partly lifted by the pull of a spring carried wholly on the armature. The outer end of the long arm is tipped with a bit of soft rubber, and is further loaded with a small counterweight, which rests lightly on a small post or stop provided for that purpose.

86. The action of the marker is as follows: When the armature is suddenly pulled down upon the magnet the rubber-tipped rod is

thrust forward against the rim of the large wheel. The inertia of the counterweight suffices to overcome for an instant, but only for an instant, the pull of the spring previously mentioned. In this instant, however, the rubber-tipped end of the rod has engaged the rim of the wheel and the slower-acting pull of the spring then lifts the rod and thus turns the wheel a small distance (one to two tenths of an inch). As soon as the armature is released by the breaking of the contact in the clock, the wheel and float are released and oscillate freely for a moment, producing the results already fully explained.

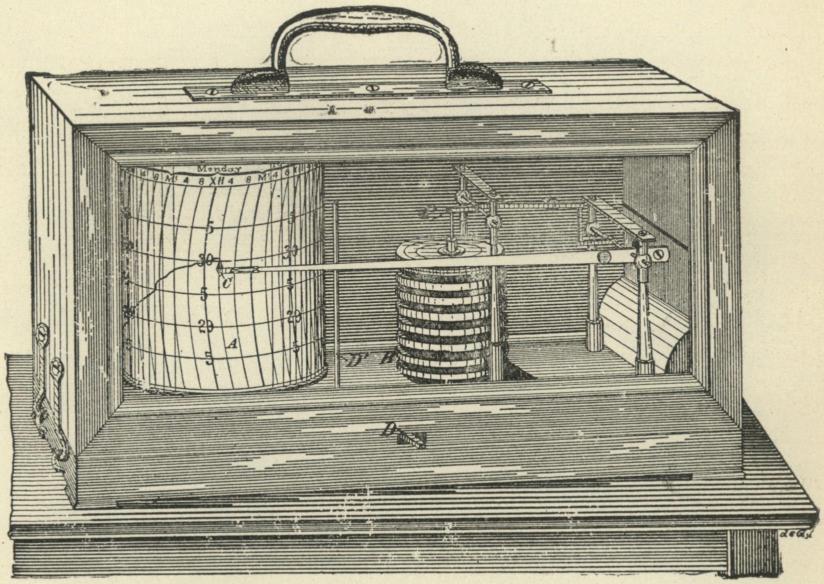


Fig. 28.—Richard's aneroid barograph.

87. The recording drum makes a complete rotation in 74 hours, i. e., 3 days and 2 hours. Sheets ordinarily are changed at any time between 11 a. m. and 12 noon, preferably shortly after 11 a. m. The new record is therefore fully started before noon, and a check reading of the standard barometer is made as nearly as possible at noon. This furnishes a check observation for determining the starting error of the barograph. Further checks may be obtained subsequently from the regular observations at 8 a. m. and 8 p. m.

88. *Aneroid barographs.*—Extremely simple and portable barographs are constructed upon the aneroid principle, of which that of Richard, being widely used, is fully described. (See fig. 28.)

It consists of a cylinder, *A*, on which the recording paper is wound, revolving once a week by means of a clockwork contained inside. A series of corrugated metallic shells, *B*, eight in number, joined one above the other and exhausted of air, forms an aneroid system eight times as sensitive as a single chamber. The movement of the shells is still further greatly magnified and is transmitted to the recording pen, *C*, by a series of connecting levers. The pen may be released from contact with the paper by pushing the lever, *D*, to the right.

The corrugated shells are the same as used in ordinary aneroids, as described in paragraph 46, the steel springs for distending the shells being placed inside. The shells are made into a vertical column by screwing the one on the other. The lower base of the column being fixed, the upper end rises and falls with every variation in the atmospheric pressure, by a quantity which is the sum of the displacements of the elementary shells.

The compensation for temperature is accomplished by leaving a sufficient quantity of air in one of the shells, ascertained by experiment when the instrument is made, so that with a rise of temperature the tendency of the barometer to register too low on account of the weakening of the springs, and the expansion of the levers and other parts, is counteracted by the increased pressure of the air in the shell. However, the instrument should be kept at a uniform temperature as far as possible.

## V.—GENERAL INSTRUCTIONS.

### (A) FOR CARE AND USE OF BAROMETERS.

89. *Exposure of barometers.*—The two important considerations in selecting a proper location for a barometer are (1) that the cistern and top of the mercurial column may be in a good light and (2) that the temperature may be as constant as possible. The best conditions for light are obtained when the barometer can be placed between the observer and a window, preferably a north one, covered either with tissue paper or fitted with ground glass. Very nearly as good results are obtained by a light from one side reflected from clean white paper or white glass immediately back of the barometer. The top of the column should be about the height of the observer's eye. The barometer should not be exposed either to the direct rays of the sun or to the air currents that are always found in the vicinity of cracks and crevices in windows.

In establishing stations, officials will use special care in selecting the exposure of the barometers and satisfy the conditions stated above as nearly as possible. In general, it will be necessary to avoid exposures near windows, as proper temperature conditions can not be found in such locations.

As houses, no matter how tightly built, always permit the free flow of air in and out through crevices, ventilators, chimneys, etc., it results that the air pressure within is exactly the same as without, except possibly for very slight differences of very short duration. If such were not the case it would be necessary to expose barometers out of doors to obtain the real air pressure.

89a. *Pumping of barometers.*—Notwithstanding what has just been said about the pressure indoors and out being the same during very windy, gusty, weather barometers within doors are often subjected to very rapid and irregular oscillations of pressure, caused by gusts of wind blowing into doorways, windows, or chimneys, and momentarily increasing the pressure, or by blowing across chimney tops and otherwise, so as to produce a sort of suction that momentarily diminishes the general pressure. In consequence of these effects the mercurial column of a barometer may be observed on such occasions to rise and fall irregularly within narrow limits, the motion in many cases being little more than changes in the curvature of the meniscus. This action is called the "pumping" of barometers, and, of course, interferes with accurate pressure observations.

The term "pumping" is also applied to much more violent oscillations of the mercurial column, such, for instance, as will occur when an ordinary barometer is exposed on a vessel at sea, or when carried in an upright position in the hand. In barometers for use on shipboard this action is prevented by making the lower portion of the glass tube of very fine bore, so that the movement of the mercury is necessarily too slow to follow sudden and irregular oscillations of pressure.

90. *Verticality of barometers.*—For accurate results it is necessary that barometers should be exactly vertical when the adjustments for reading are made. For this purpose the better forms of barometers are arranged to be suspended from rings at the top, so that the instrument itself acts as a plumb line and takes a vertical position with sufficient accuracy. It is desirable, however, for convenience in setting the barometer, as well as to insure the permanent verticality of the instrument, to steady it in supports which are first adjusted, once for all, so that the barometer is accurately vertical, as determined by a plumb line applied alternately at the front and one side.

91. *Improved barometer box.*—The standard pattern of barometer box now in use by the Weather Bureau is shown in figure 29.

This box must be securely attached to the wall in a location affording good light and not subject to sudden changes of temperature. In many cases it will first be necessary to fasten to the wall hard-wood strips, to which the top and bottom of the barometer box can be secured by screws passing through metal plates provided for this purpose. Place the screw for holding the top of the box in the

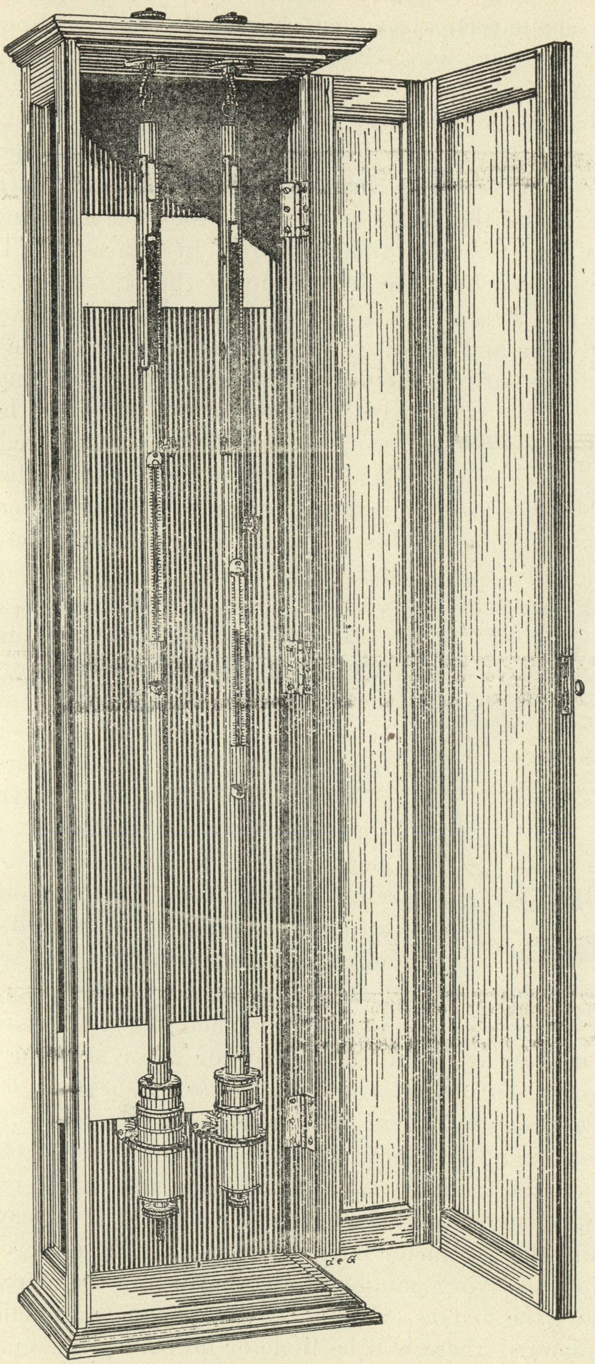

FIG. 29.—Improved barometer box.

center of the top strip and suspend the box thereon. When the box is set about vertical (as determined by a plumb line) secure it firmly at the bottom by a screw passing through the metal plate into the wooden strip.

The hooks in the top of the barometer box will, upon examination, be found to be adjustable in their positions. Place them in their central positions and hang thereon the "station" and "extra" barometers. Next, find the positions at the bottom for attaching the ring-shaped guides, one of which is shown in figure 30. These rings should be slipped over the lower end of the barometer, and placed about the mid height of the cylindrical part of the cistern. Mark the screw holes and fasten the rings to the back of the box. The barometer when at rest should hang freely within this ring, and may be adjusted to do so by the hook at the top. When the rings are fitted with centering screws these should be carefully screwed up until the barometer cistern is very gently clamped and held steadily, but not in the least deflected from its vertical position when free.

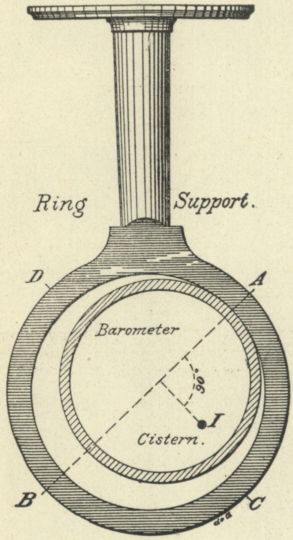


FIG. 30.—Barometer cistern and ring support.

Barometers that swing slightly free within the ring support should, in setting, be steadied against one side of the ring, as shown in figure 30. The following caution must, however, be observed.

92. *Caution against error.*—In adjusting the barometer for reading it is very important that it be steadied against the ring in the proper manner, otherwise an appreciable error is introduced, because of imperfect verticality.

If *I*, figure 30, is the position of the ivory point, then steady the cistern against the ring at *A* or at *B*, but never at *C* or *D*, or at other points. *A and B should always be in a line exactly at right angles to a line through the ivory point and the center of the cistern.*

A little thought will show the necessity for this. If, for illustration, we imagine the ivory point at one side and just in contact with the mercurial surface and the barometer vertical, it is very clear that if we swing the barometer out of vertical a little either to one side or the other, the ivory point will either dip into the mercury a little or rise above the surface, whereas, if the barometer be deflected backward or forward, there will be little or no perceptible change in the level of the mercury at the ivory point.

93. *Old-style barometer boxes.*—The simplest form of box used by this bureau is shown in an improved form in figure 31. The top end of the box is made of thick material, which is recessed to receive the top portion of the barometer when suspended upon the long hook, *H*, screwed into the top. For reading, the barometer is drawn out upon the hook, as shown in the figure, and returned to the box after the observation. The lid of the box is fitted to close under the hook so that the whole barometer is thoroughly encased and well protected. Except that the barometer must be shifted out of and into the box every time readings are made, and the further disadvantage that the cistern necessarily swings free, this style of box answers the purpose in a very satisfactory manner.

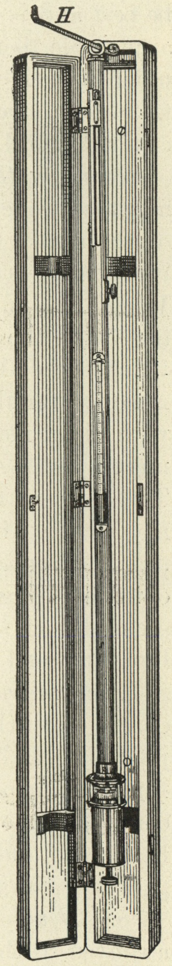

FIG. 31.—Barometer box.

94. The barometer should be carefully lifted along the book and not made to slide roughly or permitted to knock against the guides in the box.

95. When boxes such as described in the preceding paragraphs are not furnished the barometer may be suspended from almost any suitable hook securely fastened to the wall in such location as will satisfy, as far as possible, the conditions of paragraph 89.

96. *Marine barometer box.*—This has already been described in previous paragraphs 26 to 31. We need only add that in attaching this box to the wall the height must be regulated so that the scale comes at the level of the eye when the hinged bracket is lowered with the barometer in the reading position. The barometer will be several inches too high to read conveniently when folded into the box.

97. *How to set and observe the barometer.*—Having in mind the various sources of error affecting barometers, and other peculiarities of the instrument, we may next consider how best to secure accurate readings. The presence of the observer's body near the barometer tends to increase its temperature. The scale and outer parts are affected first, then the thermometer, and much more slowly the mercurial column. Generally, however, this effect is slight, as only a few minutes are required in making a reading. It is best to read the attached thermometer first. Next, if the barometer is freely suspended, jostle the cistern a little, so that the mercurial surfaces may be detached if they tend to cling to the glass walls. To "set" the cistern of the barometer, the level of the mercury should be lowered a little by turning the milled head, *O*, figure 3, and raised again until

it is just in contact with the ivory point. To make this adjustment of the mercury to the ivory point accurately requires care and sharp scrutiny.

*Adjustment of cistern, first method.*—One way is to sight between the point and the mercury and watch for the slightest thread of light that can be detected. The screw should be turned very carefully until this thread of light just disappears. This method is believed to be best and is uniformly practiced at the central office. It is equally applicable to new barometers with bright mercurial surfaces and to older ones the mercury of which is more or less oxidized. The light should be strong from behind the barometer and the front of the cistern should be in shadow.

*Second method.*—The adjustment of the mercury to the ivory point may also be determined by watching the formation and disappearance of the small, dimplelike depression made in the mercury when the ivory point is pressed into the mercury a little and again withdrawn. When the dimple just disappears the surface may be supposed in contact with the ivory point. The mercury often clings to the ivory point, especially when the ivory is newly cut. This method, however, is not so reliable and accurate, and, in general, can be followed only with clean mercury. Moreover, it is not good practice to lower the mercury any slight amount after it is once raised to the ivory point. The effect of this generally is to change simply the convexity of the meniscus at the top of the column, and this gives rise to a new and unknown correction for capillarity. The most uniform results are obtained by gradually raising the mercury until precise contact is secured. If it is imagined the mercury has been raised too much, lower it until entirely free from the point and adjust again.

*Third method.*—Another method that is often given is to watch closely until the reflected image of the ivory point coincides with the point itself. This also requires clean, bright mercury and is therefore not a general method. Great precision in the adjustment of the contact of the ivory point with the mercury may be attained with a little care and practice, and observers may scarcely be conscious of precisely the manner of making the adjustment.

98. *Adjustment of the vernier.*—The level of the mercury being adjusted to the ivory point, the vernier must next be brought to the top of the column. Greater uniformity and accuracy are insured if the fingers be now tapped smartly against the side of the metal barometer tube. This aids the mercury in detaching itself from the glass and forming into a normal meniscus. The proper setting of the vernier is made when the light is just cut off from across the extreme summit of the meniscus. The figures on page 11 indicate how the vernier should be set to the mercurial meniscus. The lower edge of the vernier must be brought just to the level of the *extreme summit* of

the meniscus. The eye must be held so that *both front and back edges of the vernier are in the line of vision.*

99. It is needless to say that throughout the setting of the barometer, as described above, the column must be maintained vertical, either by means of the fixed supports or by the skillful handling of the freely suspended barometer, so that at the critical moments when contacts are judged to be made the instrument is truly vertical.

100. After the cistern and vernier are adjusted in the manner described above it remains only to read the scale and vernier in accordance with the instructions in paragraphs 13, 14, and 15.

101. This reading may next be corrected for temperature by applying the proper correction taken from Table I, corresponding to the temperature shown by the attached thermometer, and further corrected, if necessary, by the addition or subtraction, as the case may be, of all other corrections known for the instrument, such as correction for capillarity, instrumental error, imperfect vacuum, gravity, etc.

102. *Reduction to standard gravity.*—The following will elucidate the nature of the gravity correction as applied to barometric observations—an important matter that is often but indifferently considered in the ordinary textbooks of meteorology:

By the well-known principle of hydrostatics on which the action of the mercurial barometer is based the pressure of the atmosphere is equal to the pressure of the column of mercury that it will support. But this latter pressure is only another name for the weight of the mercury, and for columns of equal section the weight varies both with the height of the column and with the force of gravity.

The force of gravity varies with latitude and altitude; therefore the height of the barometer, even when corrected for temperature and instrumental error, does not give us a true measure of the atmospheric pressure unless we first eliminate the small variations that are due to gravity; that is, observations taken over a widely extended region to be strictly comparable must be reduced to a standard force of gravity.

The standard gravity adopted by physicists is that at the level of the sea in latitude 45°.

Tables of corrections for gravity are given in Section VIII.[1]

103. *Reduction to sea level.*—It was mentioned in paragraph 5 that the atmospheric pressure was in the main nothing more than the weight of a vertical column of air extending to the limits of the at-

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[1] According to the formula for the force of gravity adopted by the International Bureau of Weights and Measures we have for the variations in gravity due to the latitude

$$G = g_{45} \, (1 - 0.00259 \cos 2\,\theta)$$

The variation in the force of gravity for different altitudes is small, and is given by the formula

$$G_h = g_o \, (1 - 0.0000000597\, h)$$

h being the elevation in feet.

Neglecting this latter factor, the application of the gravity correction is equivalent to multiplying the height of the barometer by the factor

$$(1 - 0.00259 \cos \theta)$$

mosphere. It naturally follows that as we go above the general surface of the earth, whether in balloons or by ascending mountains, the atmospheric pressure becomes less and less as we leave more and more of the air beneath us. When it is desired to chart and compare simultaneous observations of atmospheric pressure over extended areas, and at various elevations above sea level, no inference can easily be drawn from the actual pressures themselves, but each must be reduced to some standard level. The sea level plane is most generally adopted, but the selection of a plane 2,000 to 5,000 feet above the sea offers more rational conditions in certain respects and is sometimes advocated. For comparative purposes, therefore, barometric observations from different stations requires a "reduction for elevation."

We can form a clear idea of what is wanted by confining our attention to the case of a barometer in a balloon at an elevated point above the sea. The reduction for elevation is simply a measure, expressed in inches of the mercurial column, of the weight of the column of air between the balloon—that is, the barometer cistern—and sea level. This weight evidently depends not only upon the elevation above sea, but also upon the mean temperature of the air below the balloon and the amount of moisture it contains.

The temperature and moisture conditions are easily conceived of in the case of a barometer in a balloon with a great ocean of air directly beneath, but when we consider the reduction for elevation of barometric observations taken over extended plateaus and at great distances from sea level, such, for example, as the reduction of observations at Denver, Colo., no clear meaning attaches to the temperature and density of the air column; in fact, the air column can not have any real existence, and this constitutes a considerable difficulty in computing satisfactory values for the reductions for elevations. Approximate values only, therefore, are possible. Considerations such as these lead us to see the advantage of making all reductions to a plane, say, 5,000 feet above sea level, in which case an air column actually exists, and has a definite mean temperature, humidity, etc.

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NOTE.—The diminution of gravity as we go from latitude 45° to the Equator causes the mercury in the barometer to weigh less, and hence for a given pressure in the atmosphere the mercury in the barometer stands higher than it would if the force of gravity preserved the uniform standard value. Therefore, the farther a barometer is removed from latitude 45° the greater its correction becomes, so that at the Equator a pressure that appears to be 30 inches (at sea level) is really about 29.92 inches.

It should be noticed that when the barometer is thus corrected for its peculiar error due to the influence on it of variations of gravity the pressure that it then gives is the actual pressure of the air at each latitude expressed in terms of an absolute and not a variable standard.

It is important to remember that the barometric pressure is due not only to the weight of the air, but also to the prevailing winds, the rapid heating or cooling and consequent expansion or contraction of low layers of air, and to other causes.

In the mercurial barometer we balance this elastic pressure by weight of quiescent mercury; a change of the force of gravity will change the weight of the column of mercury without necessarily changing the atmospheric pressure.

Various more or less arbitrary computations of the temperature to be used in finding the reduction for elevation have been tried from time to time. At present the temperature selected for the reduction of the observations of the Weather Bureau is the mean of the current air temperature and that of the preceding 8 a. m. or 8 p. m. observation.

104. *Determination of height by barometric readings.*—The calculation of elevation above sea level by barometric readings involves all the principles and encounters all the difficulties of the "reduction to sea level" described above. This method, therefore, of measuring heights is to be used only when others are not possible, and numerous observations should be made to eliminate the very large accidental errors to which the method is subject.

As the aneroid barometer is used by tourists and others so largely in connection with determination of elevation, some further discussion of the subject is here given.

105. *Determination of heights by the aneroid.*—A reading of a barometer at a single station, without reference to the air temperature and corresponding pressure at some adjacent points whose elevations are known, gives only the crudest possible idea of the elevation of the station, and the neatly constructed little pocket aneroids in morocco cases on sale in the shops, having their dials graduated to feet of elevation above sea level, are to be regarded as extremely inaccurate, especially if the scale of altitudes is graduated upon the same metal plate as the scale of inches. In many aneroids the scale of feet is adjustable, and on this account may serve to some advantage for showing small differences of elevation, but at the best all direct indications of elevation from readings on the dial of the aneroid are only roughly approximate.

106. *Adjustable scale of elevations, how used.*—If the scale of feet is adjustable on an aneroid for moderate changes of elevation, it may be conveniently used as follows: If a tourist is about to set out on a short expedition to an elevated point, starting at a station of which the elevation is known, let him set the movable scale of the aneroid so that the proper graduation, marking the known elevation, stands opposite the index hand. On reaching the elevated point the position of the hand on the scale of feet will now indicate approximately the new elevation, provided, of course, the scale has not been shifted, and provided further that the real air pressure was uniform throughout the vicinity and did not change at all during the time occupied in the expedition. If this time was several hours or the distance considerable, the result may be very greatly in error. Suppose we know our elevation to be 500 feet and we set the scale to this point. To-morrow the aneroid may indicate only 200 or even 800 feet, the new value being a direct result simply of the changes in air pressure.

A variation of one-tenth of an inch in the barometric pressure affects an observation of altitude by from nearly 100 to nearly 150 feet, according (1) to the elevation itself and (2) the temperature at the time. On this account and because of the large accidental errors to which aneroids are subject, as described above, they are unreliable in the determination of elevations.

107. To determine heights as well as can be done by pressure measurements, it is necessary that simultaneous observations, not only of the barometer but of the temperature and humidity of the air, be made at one or more adjacent stations of which the elevations are known. These observations, by means of suitable tables, will give the difference in elevation of the stations, and the mean result from a large number of such simultaneous readings will give a fairly accurate value for the desired elevation, especially if the differences of elevation and the distances between the stations are not very great.

108. *The care and preservation of barometers.*—A barometer is a very delicate instrument, and in general must be handled with great care; therefore observers in handling a barometer should first inform themselves as to the best methods to follow and the various precautions to observe, as embodied in the instructions given below.

109. When a new barometer is received, in unpacking it should be lifted cistern uppermost from the box and all wrappings removed after placing the barometer in a horizontal position. When moved about, the cistern end should be carried uppermost.

110. To turn the barometer tube end up, bring it first gradually to a horizontal position, watching for a small bubble at the cistern. This should never be very large, nor should it be absent, in which case there may be serious pressure from within, tending to force the mercury out through joints of the cistern, etc. If necessary, the adjusting screw should be turned so that the bubble is not larger than a space within which a 10-cent coin could be placed. The tube may then be gradually elevated to an upright position. The mercurial column should not be lowered until the instrument is safely suspended from a hook.

111. Never remove a good barometer from its supports while the mercurial column is at or near its normal height. Always screw up the cistern until the top of the column is just visible at the *top of the opening in the brass case.* Do not subject the barometer to quick movements or sudden changes in its position; always move it about slowly and regularly and change its position gradually. Do not handle or carry the barometer in an upright position. Handle it horizontally, or upside down as far as possible, preferably the latter. The proper procedure to invert a barometer is as follows:

Examine the cistern to see if there is any special air vent as at *d*, figure 9, in the Tuch cistern. Screw up the mercury until it reaches the top of the cistern. *Then close tightly the air vent*, and continue screwing up the cistern until the top of the mercurial column reaches the summit of the opening in the metal tube. Always avoid screwing up the cistern until the tube is entirely filled with mercury. It is impossible to tell exactly when the tube is full, and a turn too much of the screw is almost sure to force the mercury through the joints of the cistern or even the pores of the leather bag and lead to very serious injury of the barometer. Do not strain the screw if it goes hard. Mercury may have leaked from the cistern, and what remains be insufficient to fill the tube. A barometer can be safely inverted even if there is quite a deficient supply of mercury in the cistern.

When the mercury is near the top of the tube, remove the barometer from its supports and incline slowly, listening, meanwhile, for any slight sound or "click" that may be emitted from the top of the barometer. When the tube is nearly horizontal, watch for the appearance of an air bubble at the cistern end showing there is still a small free space within. From the horizontal position the instrument may be turned cistern end up without any special precautions and may then be handled and carried with ease and safety. It is even advisable now to *loosen the cistern screw a turn or so*, that there may be plenty of free space in the cistern.

112. *Special instructions for handling marine barometers.*—It will be readily understood from the description of the marine barometer and its cistern that special care must be employed in inverting such a barometer. In this case the cistern is not and can not be filled with mercury. Moreover, the constriction of the tube prevents the vacuum from filling quickly, so that to invert a barometer of this kind the tube must be inclinded 30° or 40° from the vertical and held in such a position, and farther inclined, if necessary, until the vacuum chamber is completely filled with mercury, whereupon the instrument may be fully inverted and handled without danger, cistern uppermost.

Since the cistern is only partly full ordinarily, the marine barometer is more liable to injury in shipment than other barometers and, in fact, is best transported by hand.

113. *The "metallic click."*—The so-called "metallic click" is best produced while the barometer is inclined at about 45°, or possibly still more nearly horizontal at high-level stations. The cistern must not be screwed up too much. The "click" occurs just as the mercury moving up the tube reaches the top and completely fills it. If the barometer is quickly inclined, the violent shock of the mercury against the top of the tube is sometimes sufficient to crack the tube. Hence, sudden movements of this sort are always attended with danger to the barometer.

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Many think they can judge of the excellence of the vacuum in a barometer by the character of the "metallic click." It is exceedingly deceptive, however, and even experts are able to draw only approximately correct conclusions from its character. The greatest caution should be exercised in producing the click, as, if the vacuum is first class, it tends to injure the barometer. A good plan is to incline the barometer, as described above, until the mercury almost reaches the top of the tube; then, holding it in this position, move it somewhat quickly, but very slightly and regularly, back and forth three or four times exactly in the direction of its length, and, if necessary, changing the angle of inclination and increasing, very cautiously, the intensity of the shaking motion until two or three gentle clicks may be heard. Too great care can not be exercised in this respect, and only the most gentle clicks should be produced. Even then, with very perfect vacua, the internal stress is very great, and barometer tubes that have been subjected to boiling in the process of filling and are not thoroughly annealed are sometimes in such a state of internal stress as to be very easily cracked and injured.

114. *Handling barometers at elevated stations.*—In the case of stations from 3,000 to 10,000 feet or more above sea level the top of the mercurial column, in extreme cases, is a long distance from the top of the tube. It is not advisable, therefore, when it is desired to invert such a barometer, to screw up the cistern immediately until the column reaches nearly the top of the tube. A better plan is to raise the column only 2 or 3 inches, then, while gradually inclining the instrument, continue to screw up the cistern until the column is about to disappear from view at the top. The object of this is to avoid subjecting the cistern to the considerable hydrostatic pressure that occurs if the column is raised several inches above that which the air pressure itself is capable of supporting.

At an elevated station the barometer must be in a much more nearly horizontal position to produce the "metallic click" than at sea level.

115. The best possible care a barometer can receive is to be protected from accumulations of dust, etc., and left quite alone. When readings must be taken, and the barometer is suspended from a hoop upon which it is drawn out to a position convenient for reading, the rough sliding of the barometer along the hook, together with the springing movement up and down, and finally the knocks the cistern is apt to receive when the instrument is returned to the box, are all very injurious to the condition of the barometer and are to be avoided by gentle and careful handling.

116. The results of comparative barometer readings conclusively show that in spite of every care a difference of several thousands of an inch in the indications of two or more instruments can not ordinarily be avoided. Any change of instruments at a station therefore

is apt to make a more or less objectional break in the strict continuity of the pressure reports from that station and obviously such changes should be made only when absolutely necessary.

117. After continued use the mercury in the cistern of a barometer loses its brilliant surface and becomes coated with a slight film of oxide. This does not impair the barometer to any serious extent, and very accurate readings can yet be made. It is a bad practice to clean the mercury in barometers as soon as it becomes slightly dull and tarnished. Leaks are apt to be started in the joints of the cistern, and slight changes in the position of the ivory point give rise to new and unknown corrections for instrumental error. The mercury itself is apt to become contaminated with impurities and afterwards will remain bright only a very short time.

118. *Comparative barometer readings.*—Each regular Weather Bureau station is supplied with two good barometers to lessen the chances of a break in the record and to guard against erroneous reports from the use of imperfect instruments. Monthly, therefore, and on other special occasions, as further specified in paragraph 122, five comparative readings of all barometers on station should be made at uniform intervals of hours, half hours, or quarter hours, as may be most convenient to the observer.

119. As the object of the comparative readings is to ascertain accurately the amount of discordance between the barometers and enable the main office to replace defective instruments, it is important that the observer use more than ordinary care to read the barometers exactly as they are. He should not feel biased or disposed, in the slightest degree, to make the readings come out one way more than another. His whole endeavor should be to make the settings and readings as accurately as possible, without any regard as to how the readings may differ in the end. When the pressure is found to vary rapidly, make the readings of the two or more instruments as quickly as possible, and throughout the series endeavor to keep the temperature stationary.

120. Before each reading the cistern of the barometer should be unscrewed so as to lower the mercury one-sixteenth to one-eighth of an inch below the ivory point and the setting then carefully made.

121. An interval of two or three hours should intervene after barometers are unpacked, cleaned, or moved to a new office and hung in position before comparative readings are commenced.

122. Comparative readings should always be made with new barometers whenever received at a station, and also both before and after instruments are removed from one location to another or cleaned.

123. *Suggestions and instructions for cleaning barometers.*—In a few cases observers are authorized to clean cisterns of barometers that

are very dirty and can not easily be replaced. (See paragraph 187.) The following instructions will then guide in the proper performance of the work:

124. Take a series of five comparative readings before the work is begun.

125. Provide one or more very clean, *dry* porcelain or glass cups or saucers. Avoid the use of damp, unclean, or metal vessels. Cleanse the vessels by thorough washing in soap and water and wipe dry with a clean towel, finally polishing the vessel with tissue or similar soft paper. Provide, also, some pieces of clean cloth and sheets of tissue paper for cleansing the glass parts of the cistern, also a few small sheets of clean white paper about 4 by 6 inches for use in filtering the mercury. Calendered letter paper is not so good as the ordinary so-called book paper. A most convenient position for cleaning a barometer is to be seated in front of a desk with a drawer at the top and side partly opened. This affords convenient corners in which the barometer can be rested in upright positions during the process.

126. The barometer will be removed from its box or support and inverted, as described in paragraph 111.

Unscrew with one hand the portion of the cistern marked *S*, figure 3, grasping with the other hand *only the narrow flange R.*[1]

127. Next separate the two wooden portions of the cistern marked *i* and *j* by loosening the four screws uniting the split-ring clamp marked *l* and *M*, in figure 3. It is important that each screw be loosened a little in turn, otherwise an uneven strain may be thrown upon some portion of the fragile wooden flange and chip out a piece. After loosening each of the screws one may be taken out entirely, and the whole system of split rings still interlocked by the screws will generally unfold from around the cistern. Sometimes another screw must be taken out.

If the rings are separated, they should afterwards be united again precisely in the original relation. When removing the wooden piece *j*, to which the leather bag is attached, lift it cautiously directly up from the part *i* so as not to spill the mercury, which is thereby exposed and should just about fill *i*. Hold a clean, dry vessel close under the flange of *i* and pour out steadily from the cistern all or nearly all the mercury it contains. The mercury will not leave the open end of the barometer tube so long as the latter is not raised

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[1] If mercury has leaked out of the cistern this will generally be indicated by the presence of minute globules of mercury adhering to the threads of the screw *O*. In such a case the cap at the extreme bottom of the cistern should be unscrewed, instead of the portion marked *S*, thereby preventing the escape of the mercury which has leaked out. As this mercury, by reason of its contact with the metal parts of the cistern, is impure, it must be emptied separately, and *under no circumstances* afterwards used in the barometer or mixed with good mercury, as the whole will be rendered impure.

To empty this impure mercury from the cistern the finger must be used to force the kid-skin bag up into the cistern while the barometer is inclined and the impure mercury poured out.

much above a horizontal position, and generally not then unless the opening is large and the tube shaken or jerked a little. Care must be taken to prevent the mercury from passing out of the tube. The barometer is then returned to its inverted position and the remaining parts of the cistern removed by loosening the screws *P* and *P;* here again each screw must be loosened a little in turn to avoid clipping or cracking the glass cylinder. If a small globule of mercury remains in the glass cistern, allow the latter to rest in its position, while the boxwood piece, *i*, the metal flange, *R*, and the screws, *P*, are removed. Then holding the glass cylinder in position with the fingers, empty what remains of the mercury in the cistern. In handling the little leather washers taken from the parts of the cistern, avoid wrinkling or creasing them or otherwise changing their form, as any injury of this kind will probably result in leaks that can not be prevented except by new washers.

128. The barometer tube and attached wooden piece *G*, figure 3, may be next withdrawn from the metal sheath and all the parts thoroughly cleaned. Before removing the tube notice exactly the position of the ivory point in reference to the outside sheath so that it may be returned to this position, otherwise a change may be introduced in the correction for instrumental error. In all probability small quantities of mercury will be spilled into or remain in various little cracks and crevices while the cistern is being emptied. These, by all means, should be thoroughly dislodged, especially from about the metal parts. With the glass tube removed, the sheath should be tapped and shaken smartly to remove all small globules of mercury. It may then be wiped and cleaned thoroughly with cloths or chamois skin. In case the scale is somewhat dull and tarnished it may be brightened by suitable polishing, but this is a delicate operation and should be avoided rather than otherwise. The danger lies in shifting the position of the scale, and if polishing is absolutely necessary, it should, therefore, be done with very great care.

The upper portion of the glass tube should also be cleansed on the outside with the aid of a damp cloth if necessary.

129. *Air in barometer tubes.*—How air can gain entrance to the vacuum of a barometer otherwise in good condition, which is supposed to have been hanging quietly and undisturbed upon its supports, is a matter that is very difficult both to imagine and to explain. No case of this sort has ever occurred among the hundreds of barometers handled at this office, so that when such a defect is discovered in an instrument in use at a station the observer in investigating the cause and reporting the matter should make sure that the barometer has not been tampered with or roughly handled by unauthorized persons, as, if uninjured in other respects, misusage is the most probable explanation of the defect.

130. If an appreciable quantity of air is in the tube at the time of cleaning, it can be seen more or less conspicuously in the shape of a small bubble or bubbles adhering closely to the walls of the tube. If these bubbles appear no larger than good-sized pinheads, and especially if they are not more than halfway up the tube, then it is certain that the conditions of the vacuum is more likely to be greatly impaired than improved by attempts to remove them.

131. Sometimes the barometers that observers may be called upon by private parties or friends to inspect or repair, seem to have numerous rather flat-shaped air bubbles firmly lodged against the sides of the tube. Generally these are not air bubbles at all, but are particles of moisture, the presence of which is due to carelessness in the original preparation and filling of the tube. The edges of an air bubble are sharp and the mercury generally remains bright and makes well-defined contact at a steep angle with the glass. If some moisture is present, either alone or with the air, the edges are less clearly defined, the mercury is oxidized, and the angle of contact is less steep, the bubble itself being very flat.

It is impossible, without entire cleansing, drying, and refilling, to do anything with a barometer that contains moisture.

132. If a bubble or so of air is present in a tube, the plan that should first be tried to remove it is as follows:

*First method.*—Incline the tube 45° or thereabouts, with the open end up, and tap it gently in the vicinity of the bubble, revolving the tube a little at the same time so as to encourage the bubble to creep along the inclined surface of the glass. If the inclination is too great the bubble will be greatly compressed by the weight of mercury above it; if too small the bubble will not tend to move.

If the treatment is successful and the bubble is removed, the result will probably be beneficial; but at best the operation is generally very tedious, and often the bubble seems to grow smaller and finally disappears, being separated into almost imperceptible portions which remain distributed along the walls of the tube.

*Second method.*—The following plan is more frequently applied, especially when the quantity of air already in the tube is considerable, is lodged at the top, and must be partially removed at least:

Empty an inch or two of mercury from the tube. Close the open end tightly with the gloved finger and cause a large bubble of air to glide slowly and regularly along the tube until it unites with all the portions of air it is desired to remove. The large bubble is then as slowly and gradually worked to the open end of the tube again, using every possible precaution to prevent small portions of the bubble from separating and remaining behind. Such a bubble of air may sometimes be successfully passed once into and out of the tube, but even at the best the vacuum in a barometer that has been treated in this manner is very apt to be greatly impaired and can not be restored. The reason of this is that the glass walls of the tube have very strong hygroscopic properties, and while the air bubble is passing along the tube considerable portions of both moisture and air are invisibly retained upon the walls of the tube. While, therefore, a bubble of air may be successfully passed once into and out of the tube, a repetition will be attended with less good effect, as in the meantime the moisture and gases of the bubble will have acted upon the mercury to produce oxidized films that will probably adhere to the walls of the tube, so that when bubbles are again passed there will presently be a marked tendency to cling to the tube and leave small detached bubbles imprisoned against the walls. When, afterwards, the barometer is set up the walls in the upper portion and near the vacuum, being no longer subjected to the full air pressure as they were while the bubble was passing along the tube, now readily give off both air and moisture, and in many cases numerous little bubbles form against the walls even below the top of the column and probably later work their way into the vacuum.

133. The removal of air from a barometer tube, therefore, can not be perfectly effected in any such way, and should not be undertaken unless the defect is a very serious one. If the comparative readings taken before cleaning a barometer do not show serious errors, any air the tube may be thought to contain had best be allowed to remain.

134. One of the most difficult and delicate parts of the process of cleaning is that about the wooden piece, *G*, and ivory point. The deep and narrow annular space between the glass tube and the boxwood is generally covered with oxide of mercury, which should be thoroughly removed by repeated wiping with clean cloths applied upon the ends of slender sticks or by similar means. Tufts of raw cotton will adhere firmly to, and are readily wrapped about, rough sticks and may serve with advantage in wiping out the narrow spaces. Sometimes, however, the space is so small that it can not be properly cleaned. Care must be observed not only here but in subsequent operations, to blow away or otherwise remove every vestige of lint, dust, shreds of cotton, etc., as, if allowed to remain about the parts of the cistern, they will quickly find their way to the surface of the mercury, upon which they will float about to the detriment of accurate adjustments.

It is obvious that the delicate ivory point should be handled with great care.

135. The glass cylinder of the cistern should be washed in soap and water and thoroughly rinsed in copious applications of fresh water. After this *it should not be touched with unprotected hands, especially upon the inside.* Wipe it thoroughly dry with a clean, dry towel or handkerchief, and polish with clean tissue paper. The

remaining wooden portions of the cistern should also be wiped thoroughly clean and dry without touching the inside with the bare fingers. Shake out of the bag as far as possible every little particle of mercury that tends to remain in hidden corners and crevices. These little particles are very apt to be dirty and impure, and should, therefore, be removed.

136. The several parts of the barometer should be replaced in the following order:

First, return the glass tube to its sheath, *being careful to place the ivory point in the position in relation to the scale, or front of the barometer, formerly occupied;* also to avoid handling with the bare fingers the end portion of the barometer tube where it dips into the cistern, as a slight film of oil may be communicated to the mercury of the cistern by this means.

The glass cylinder, with its leather washers, one at each end, is next placed in position, followed by the wooden piece, *i*, and the metal flange ring, *R*. The three long screws, *P*, are next to be inserted and partially screwed up. While these various pieces are still loosely held by the screws, it is well to jostle the parts about a little and twist the ring and boxwood pieces upon each other and the glass cylinder. In other words, try to bring the surfaces in the several joints nicely and uniformly into contact with each other, and adjust the ring, *R*, so that the screws are not even imperceptibly askew, but, when properly drawn up, produce a direct, uniformly distributed pressure. When the parts are thus adjusted the screws, *P*, are to be tightened *little by little*, each one a little in turn after the others, until all are drawn down together equally tight. The observer must judge of this partly by the amount he has turned each screw and partly by the resistance it offers to further turning. It is not necessary that the screws be very tight. A judicious regard for these ideas constitutes in part the skill of the expert and is the secret of perfect joints. To disregard them produces leaky joints and unequal pressures that are apt to break the fragile boxwood flanges or crack the glass.

Before describing the filling of the cistern, some tests and experiments showing the purity and properties of mercury will be mentioned.

137. *Purity of mercury, how tested.*—Pure mercury is beautifully brilliant and mobile, and does not exhibit the slightest adhesion to clean, dry glass or porcelain surfaces, whereas the amalgamation of the mercury with the slightest perceptible traces of foreign substances, such as lead, tin, zinc, etc., changes completely the character of this peculiar substance. Each observer should try for himself the following instructive and simple experiment:

Prepare a small, shallow, flat-bottomed porcelain cup or white piece of chinaware, or glass vessel if the others are not to be had. Wash and dry thoroughly without touching the inside with the bare fingers. The vessel may be just a little warm with advantage. Filter into the vessel, through a paper funnel, such as described below, rather less than a teapoonful of pure mercury. If the mercury has been properly fitted and is of extreme purity, the brilliant globule will roll about the cup with the greatest activity, as the latter is moved a little, and will draw out momentarily into slender cylindrical portions which, if broken asunder, will quickly separate into smaller portions, which draw themselves up into beautiful little spheres or larger rounded buttons, none of which clings in the slightest degree to the clear surface of the vessel. Under favorable conditions and during the rapid movements of the mercury a scarcely audible but still a very characteristic crackling sound can be heard, due to the development of small sparks of electricity. Such is the characteristic behavior of clean, pure mercury in a clean porcelain dish. If, however, the mercury contains the most minute trace of lead, tin, zinc, etc., this fact will be shown by a more or less marked tendency of the little, slender portions of the mercury to draw out into sharply pointed, tapering "tails," the tip ends of which cling to the vessel and remain. If the observer is not in possession of the small quantity of extremely pure mercury needed in the above experiment, the most striking part of it will be lost. After watching the beautiful manner in which the pure mercury rolls about the dish, add to it a small flake of lead or solder. The flake should be very small shaving cut off with a penknife, and should contain not nearly so much material as in the head of the smallest pin. Place this upon the mercury and allow it to remain a moment. It will presently be wholly dissolved. Now repeat the rolling about of the mercury in the cup and observe the wonderful change.

The former brilliant globule has now a dull surface, with its edges clinging at many points to the surface of the dish. The clean white surface of the dish will now be soiled and discolored when the mercury is made to flow over it a few times. The presence of one part of lead in one hundred thousand parts of mercury is readily shown by this test.

Only one who has performed this experiment is prepared to appreciate fully the importance of absolute cleanliness in barometer cisterns and the necessity for the avoidance of the slightest metallic contamination of the mercury.

138. Of course, the mercury used in the above experiment can not be again used until purified. This can be done quite well by washing with dilute nitric acid, about one volume of acid in fifteen volumes of water. The mercury and acid may be placed in a bottle and vio-

lently shaken, or the acid may be poured over the mercury and allowed to remain several hours. When the acid has thoroughly cleansed the mercury, the latter, upon the contents of the bottle being violently shaken, will break up into very fine globules which, for a moment, do not coalesce. This formation of the mercury into minute globules in the presence of dilute acid will take place only with quite pure mercury.

139. Returning now to the process of restoring the barometer, the next step is to filter the mercury and fill up the cistern. Roll up a small sheet of clean paper into a sharp cone, looking through it to the light to see that the opening is very small. Holding the cone over a clean vessel, partly fill it with mercury. By twisting the folds of the cone in a manner that the observer must learn by trial, the opening at the point may be regulated to any size desired, even while the cone contains mercury. Keep the cone well filled with mercury until all has been added, and do not allow the very last portion to pass through the filter. If the observer has only the supply of pure mercury taken from the barometer, economy must be exercised, but there is no difficulty whatever in being able to filter and utilize the entire quantity of mercury originally in the barometer, and this is sufficient. The purity of some of the filtered mercury may be tested as described above. Another indication of the purity of the mercury is the character of the mark left on the paper cone after filtering. To be able to judge by this, observers must filter both pure and impure mercury and compare the marks.

140. The mercury for the cistern, having been filtered at least once, may next be filtered into the cistern, directing the little stream so as to strike against the glass cistern to avoid inclosing small air bubbles near or upon the barometer tube. The open end of the tube should, in the meantime, be completely filled, and the mercury heaped into a little button on the tip end. This button will unite with the mercury of the cistern as it rises around the tube, and the chances of inclosing air in the tip end of the tube are thus greatly lessened.

In general, the cistern should be filled to the brim of the piece, *i*. Before fitting the piece, *j*, the leather bag should be pushed out from the inside and every effort used to detach and remove all dust, shreds, little particles of leather, etc.

141. In securing the clamp rings the screws should be tightened a little at a time, and the precautions cited in paragraph 136 observed to insure a closely fitting and uniformly tight joint.

When the screws are all tightened, the leather bag should be thrust up into the wooden piece, *j*, and held there firmly by the finger while the barometer is gradually turned right side up, watching to see if any leaks show themselves at any of the joints. The mercurial column should not be lowered under any circumstances at this time.

If a leak occurs, it is probably due to uneven tightening of the joints, and in most cases it is better to loosen the whole joint and shift it a little before tightening again rather than to strain the screws that are already tight, in the hope of making closer contact.

142. From one to three or more hours after the cleaning operations are completed and the barometer is returned to its support a series of five comparative readings with its companion or standard instrument should be made.

143. *Additional suggestions for cleaning barometers with the Tuch cistern.*—The parts of the barometers with Tuch cisterns can be removed only by the aid of a special wrench, which will be furnished when any observer is authorized to clean such barometers.

The special points to be observed are as follows:

Before fully screwing up and inverting the barometer, close tightly the air vent, *d*, figure 9. Consult also paragraph 17.

When about to open the cistern, loosen the screw, *W*, figure 9, one or two turns. Then unscrew the piece, *q*, being very careful at this time not to unscrew the part, *K*. When completely unscrewed, the piece, *q*, with attached piston, *o*, may be wholly withdrawn, exposing the mercury. All or nearly all of this may be poured out in the manner described in paragraph 127 without danger of starting the mercury from the end of the barometer tube. The small portion of mercury that is apt to remain should be poured out afterwards, removing first the tube or barrel, *K*, then the clamp ring, *h*, holding the glass cistern in position by the hand until the last portion of mercury is emptied.

To remove the barometer tube from the sheath, the cap of the air vent must be first removed.

It is always best not to disturb any more than necessary the various leather washers and fittings.

144. In replacing the parts *be sure the cap of the air vent is screwed up* before introducing the mercury.

After inserting the glass cistern and washers screw down upon it the ring clamp, *h*. Then filter in as much mercury as practicable, observing the precautions mentioned in paragraph 140. Next screw down snugly the tube or barrel, *K*, and add the remaining mercury. Finally, replace the piston and cap, *q*.

If the piston does not fit the barrel snugly enough, the washers should be tightened by turning up the screw, *j*, using the special wrench. The parts of the piston should not be taken apart nor the washers disturbed, except possibly to tighten the screw mentioned above.

During the operation of replacing the piston it should not close down upon the mercury, which would be subjected to severe pressure thereby. At last, tighten the screw *Z*.

Before the instrument is placed erect the piston should be screwed up close to the mercury, still leaving a small space, as shown by the air bubble, visible in the cistern when the barometer is held nearly horizontal.

145. *Suggestions about moving and packing barometers.*—Preparatory to moving invert the barometer as described in paragraph 111.

The most approved methods of packing barometers for transportation are to be learned by carefully observing the manner followed in packing instruments sent out by this office. The instrument should be shipped in a horizontal position. The air-bubble space in the cistern should be small, but still sufficient to admit of expansion with temperature changes.

When carried about by hand, the cistern should be uppermost.

The barometer should be first wrapped in soft paper, then with a thick layer of cotton sheeting and an outer wrapping of heavy paper. Thus prepared, it is then placed in the middle of a strong wooden box and completely and closely surrounded with good excelsior or cotton or similar elastic packing material. The lid of the box must be *screwed* down, not nailed, and a strong handle attached to the middle, so that the box may be carried by one hand in a horizontal position.

146. *Leather carrying cases.*—In using the leather carrying case, supplied when barometers are to be transported by hand, secure the barometer in the hinged wooden sheath, being careful to observe that the latter closes tightly without straining either the milled head for regulating the vernier or the attached thermometer. The wood should be neatly cut away, if necessary, but only sufficiently to receive these projecting parts. Insert the barometer, *cistern uppermost*, into the leather case.

147. On steamboats or railroads the barometer, if hung up in any manner, should be secured against striking or pounding the side of the room or car. In wheeled vehicles the barometer should be carried by hand, supported by a strap over the shoulder, or held upright between the legs. It should not be allowed to rest on the floor, as a severe jolt may break the tube. On stage routes, when impracticable to carry it by hand, hang the barometer on a hook inside the stage and securely fasten the lower end, so that it will not swing when being thus transported. If carried on horseback, it should be strapped over the shoulders of the rider, where it is not likely to be injured.

148. *Change of location.*—It sometimes becomes necessary to change the location of instruments from one office room to another or to a different point in the same room and making little or no change of elevation. In such cases the barometer box can be moved bodily with the instruments in place. The first step is to prepare the wall

at the new location by setting up the necessary wood strips and the screw at the top on which the hook of the barometer box can be hung. If no change is to be made in the elevation this screw must be at exactly the same height as the corresponding screw at the old location. After the usual comparative readings have been made and all is prepared the barometer cisterns will be screwed up until *full* of mercury and the box moved bodily in an upright position and secured at the new location. Comparative readings should not be made after the removal until an interval of two or three hours has elapsed, unless the temperature is practically the same in the two locations.

149. *Shipment of serviceable barometers.*—Every possible care is taken at the central office to secure the highest attainable precision in the pressure observations at stations and to ascertain the amount of abnormal errors that sometimes develop in the use of instruments. To this end defective instruments are called in to the central office for recomparison, and obviously it is of the highest importance that every precaution be taken in packing such instruments to insure their safe arrival at destination.

150. In reporting on defective or unserviceable barometers, observers should state clearly the condition of the instrument, and whether or not the mercury can be screwed up to such an extent as to permit of forwarding the instrument "mercury filled." Such barometers are called in by the official in charge, division of supplies, central office, *by express*, and observers should keep on hand constantly a small supply of the special "Notice," "Glass," and "Very fragile" labels, two or three of which should be tacked or pasted on outside cover of box in a conspicuous manner.

151. *Shipment of empty instruments.*—When barometers are so seriously defective that check comparisons can not be made or are valueless, observers will be authorized to forward the barometer to Washington, first carefully emptying all the mercury, which will be preserved in a clean bottle and packed in the box with the barometer.

### (B) CARE AND USE OF BAROGRAPHS.

152. *Exposure of barographs.*—The general principles of the exposure of barometers given in paragraph 89 apply to barographs also, except that the matter of light is not so essential. Every precaution, however, must be observed to prevent the instrument from being exposed to great changes of temperature and to direct influence of sunshine, etc.

The instructions following apply particularly to the Richard barograph.

153. *Adjustment to standard pressure.*—When the instrument is first set up at a place, the pen should be made to mark, as nearly as possi-

ble, the corrected pressure (see paragraph 172) given by a standard mercurial barometer at the same place. This adjustment is made by raising or lowering the whole series of aneroid shells by means of a screw reached through a hole in the base of the instrument just under the aneroid shells. This screw is turned by one end of the key supplied for winding the clockwork. The adjustment of the barograph to agree with a standard barometer will rarely prove permanent and will require a little alteration from time to time, there being a slight tendency for an aneroid barometer to read too high with age. It is generally necessary to set the barograph to standard at the time a new sheet is put on, but if the error is small it is better to allow for it than to readjust.

154. *Special Adjustment for high elevations.*—The adjustment afforded by the screw underneath the base of the instrument is not sufficient to bring the pen to the proper pressure at stations four thousand feet or more above sea level. In this case, and also to prevent injury to the barograph while in transit over lofty mountain passes, it is sometimes necessary at this office to disconnect the system of levers from the aneroid shells and to provide one or more extra holes in the stem projecting at the top. Barographs found disconnected in this manner upon arrival at stations need simply that the links be united again, placing the small pin in whichever hole will bring the pen nearest the middle of the record sheet. When shipping barographs, if the instrument has to pass over a greater elevation than 3,000 feet, the system of levers should be disconnected, as above.

155. When the pressure at any particular station is such as not to be included in the rulings on the record sheets furnished with the instrument, observers will change the numbering of the lines by some convenient whole number and adjust the pen of the instrument accordingly.

156. The sheets should be changed at about noon on the 1st, 8th, 15th, 22d, and 29th of each month.

When a barograph is first put in operation the trace on the sheet should start at the proper date and hour, even if near the end of the sheet. The roman numeral, XII, at the top of the sheet indicates noon, and the letter "M.," midnight.

If not already done, the lower edge of the sheet should be trimmed accurately parallel to the longitudinal lines and should rest closely against the flange at the bottom of the cylinder and the pen be adjusted to the proper pressure, in accordance with instructions in paragraph 153.

157. *Barograph clocks.*—Every effort should be made to regulate the barograph clock to keep correct time, winding once a week, or oftener if found to give better results. The instrument should be inspected each day by the observer in charge and properly adjusted

by him when necessary. Whenever a clock is adjusted, a marginal note stating the fact should be connected with the proper hour. If the clockwork goes too fast or slow, it can be regulated in the same manner as the movement of a watch, through an opening in the cylinder marked *A* (to "accelerate") and *R* (to "retard"), corresponding to the letters "F" and "S" near the ends of the regulator itself.

158. *Time error of barograph.*—The clock movements of these barographs often keep but imperfect time, and it is important that the record be checked in this respect, so that proper correction may be made in compiling the records of hourly readings. This result is secured by gently touching the lever of the recording pen, so as to deflect it and cause a slight lateral mark to be made on the record sheet across the barometric trace. A mark of this character will be made each day at noon, seventy-fifth meridian time; the record sheet will thus always show how much the barograph clock may be in error.

In producing these marks great care must be exercised not to strain the lever mechanism in any way; the weight of any ordinary lead pencil is amply sufficient to make the mark, *which should not be more than one-eighth inch in length.*

159. *Pens.*—Pens should be kept clean. Only the standard register ink should be used. Care must be observed in cleaning a pen not to bend or deform the points and render it unserviceable. (See Circular A, Instrument Division.)

160. *Corrections.*—Owing to imperfections in barographs, more or less frequent comparisons should be made with standard instruments, and corrections applied according to the scheme fully described in Circular A, Instrument Division.

## VI.—CONCERNING THE ELEVATION OF STATIONS.

161. In the system of the Weather Bureau the elevation of a station is the height above mean sea level of the zero point—that is, the "ivory point"—of the barometer scale, and all measurements and levelings for elevations must be made in reference thereto.

162. *Elevation determined by spirit level.*—Whenever a station is established or an office moved and the elevation of the barometers changed, observers will secure the services of a competent surveyor or city engineer, who will run a line of levels to determine accurately the elevation of the station above or below the "plane of reference." In many instances this survey can be secured without expense through the courtesy of the Government or of the city engineers. In the remaining cases the cost will be included with other items of

expense incident to the establishment or removal of the office, authority for the expenditure being procured in the usual manner.

All heights will be given in feet and hundredths or thousandths of a foot.

163. *Fixed point.*—The engineer will establish a so-called "fixed point" or bench mark in a permanent manner on the outer stonework of the building, from which direct measurements of the height of the barometers can readily be made, or a line of levels conveniently run to the "plane of reference" at any time.

164. *Plane of reference.*—The "plane of reference" should, in general, be the top of rail at depot. In case, however, a bench mark of a permanent characted and of high precision, such as erected by the United States Coast Survey, the Lake Survey, the Mississippi River Commission, or the Engineer Corps, has been established, this will be used as "plane of reference." The same plane should be used, as a rule, in all measurements within the same town, and will not be changed except for good reason.

165. All levelings must be run by a competent person and the line will be run over a closed circuit which, in the case of a new station, will be from the plane of reference through the "fixed point" to the barometer, and back through the "fixed point" to the plane of reference. In the case of the removal of an office the line will be run from the barometer in the old office to the barometer in the new office, passing through the "fixed points" at both the old and the new office, thence through the "fixed point" at the new office to the "plane of reference," and thence to the point of starting.

A copy of the field notes, certified to by the surveyor running the levels, will be filed with the report of elevation which will be rendered on Form No. 1058–Met'l.

The observer will fully inform the surveyor concerning the foregoing provisions for running the levels.

166. When, for any reason, it is impossible to run the levels provided for in paragraphs 162 to 165, the observer will, in case of the change of location of the barometers, or removal of the office, make a special set of comparative barometer readings; that is to say, the comparative barometer readings always required on changing the location of instruments will in case levels can not be run be made in three sets, as follows:

First. Set before removal. Second. Set during removal; that is, station barometer in new office, extra barometer in old office. This set of readings will be recorded as usual on Form No. 1027–Met'l, and will be accompanied by two readings of the exposed thermometer, to be noted on the margin, the first taken immediately before and the second immediately after the set of barometer readings. Third. Set after removal; that is, both barometers in new location.

When there is an assistant on station the five readings of the second set must be synchronous, but in case there is no assistant at station, eight readings in all will be made alternately in the two offices, in the following order: No. 1 in new office; Nos. 2 and 3 in old office; Nos. 4 and 5 in the new office; Nos. 6 and 7 in the old office, after which the extra barometer will be carried to the new office and the eighth reading made on the station barometer. Finally, the third set of comparative readings will be made.

The interval between readings should be as nearly uniform as possible, and is left to the convenience of the observer, depending upon the distance between stations, etc.

167. When changes in the location of the barometers that do not alter the elevation are authorized, a line of levels need not be run, and only the usual comparative barometer readings before and after removal will be made.

168. *Reduction of observations to a " station elevation."*—On January 1, 1900, a specific elevation above sea level was adopted for each Weather Bureau station, and for purposes of record and publication all barometric observations will be correlated to this "adopted or station elevation." In case, therefore, an office is moved to new quarters and the elevation of the barometer is thereby changed, a proper correction will be applied to the barometric readings in the new location that will reduce the observed readings to the pressure appropriate to the " station elevation," notwithstanding changes and removals. The pressure thus ascertained will be designated " station pressure."

169. The " station elevation " for a station in operation January 1, 1900, is its elevation above sea level on that date. For stations closed before 1900, or subsequently established, the elevation will be, in general, the elevation above sea level of the zero point of the barometer at the date of closing or opening the respective stations.

170. Reduction of current observations to a " station elevation " in accordance with the foregoing plan will, therefore, be required only when changes are made in the elevations of the barometers. In all such cases the Instrument Division of the central office will furnish a new copy of the barometer correction card (Form No. 1059–Met'l), in which a " removal correction," based on the change made in the elevation of the barometers, will be combined with the corrections for local gravity, scale errors, etc. The " sum of corrections " thus determined, together with the " correction for temperature," will be applied to all recorded readings of barometric pressure, and the result will be regarded as the pressure of the air appropriate to the station in question.

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171. The following example will elucidate the complete correction of observed barometer readings:

| | | |
|---|---|---|
| Observed barometer reading (attached thermometer, 76.5°) | | 30.287 |
| Correction for temperature (Table I) | −0.131 | |
| Sum of corrections, Form No. 1059–Met'l | +0.032 | |
| Total correction | | −0.099 |
| Station pressure | | 30.188 |

The "total correction," as shown above, will be entered on Form No. 1001–Met'l, and applied to the "observed" reading, deriving thereby the pressure of the air appropriate to the adopted elevation of the station; this result wil be recorded on Form No. 1001–Met'l, in the columns for "station pressure."

172. The barograph will be adjusted and corrected to correspond with the "station pressure" ascertained as shown in the above example. See also paragraph 153.

173. All pressure observations made at a station and reduced according to the foregoing plan as therefore strictly comparable with each other, all being reduced to the adopted elevation. Furthermore, a change of elevation or removal of office does not necessitate a new table of reductions to sea level; that is, all observations will be reduced to sea level, when required, by one and the same table of reduction, namely, that based on the adopted elevation of the station.

174. *Nomenclature.*—The following nomenclature, embracing barometric terms, will be used, as far as practicable, in the correspondence, records, and publications of the Weather Bureau:

*Actual elevation.*—The height of the zero points of the barometers of a station above sea level.

*Station elevation.*—The elevation above sea level adopted for a station as the basis to which all pressure observations at the station are correlated.

*Observed reading.*—The direct result of the reading of an instrument, uncorrected for any errors.

*Actual pressure.*—Meaning the actual pressure of the air at a barometer, as obtained from the observed reading after applying the necessary corrections for temperature, gravity, and instrumental errors.

*Station pressure.*—A pressure corresponding to an "adopted or station elevation" which may differ slightly from the actual elevation of the barometer. When the "actual" and "station" elevations are the same at any particular station, the removal correction will be zero and the actual pressure and the station pressure are then numerically equal.

*Reduced pressure.*—The actual or station pressure reduced to sea level, or to some other specified plane.

*Correction for scale errors, capillarity, etc.*—A mean difference between the readings of a given instrument and those of the standard barometer duly corrected. This quantity embraces all outstanding errors in the subdivision of the scale, or its total length; errors in the adjustment of the sighting edge to the zero line of the vernier; errors of capillarity, imperfect vacuum, etc.

*Correction for temperature.*—The correction depending on the temperature of the mercury and the metallic scale.

*Correction for local gravity:*

(*a*) *Latitude term.*—The correction based on the variation of the force of gravity with latitude.

(*b*) *Altitude term.*—The correction based on the variation of gravity with altitude above sea level.

*Removal correction.*—The correction necessitated by the removal of an office, and based on the difference between the actual elevation of the barometers in the new location and the adopted elevation for the station in question. Strictly speaking, the "removal correction" varies from day to day, or from winter to summer, with large changes of temperature, but this variation, in most cases, can be neglected. When, however, the change in elevation is large, and especially when great differences of temperature, as between winter and summer, are considered, the change in the value of the "removal correction" may exceed 0.01 inch or more, and it then becomes desirable to employ a "variable" correction, as more fully explained in paragraph 182 (*a*).

*Sum of corrections.*—A term embracing all the corrections that are practically constant for a given instrument in a given location, namely, the correction for scale errors, capillarity, and gravity, and the removal correction. This sum is given on the certificate of corrections (Form No. 1059–Met'l) furnished for each instrument.

*Total correction.*—The correction for temperature, plus the "sum of corrections" as defined above.

*Reduction to sea level.*—The quantity which must be added to the "actual" or "station" pressure in order to obtain the "reduced" pressure.

*Reduction for elevation.*—A quantity which must be added to or subtracted from the pressure at a given elevation in order to deduce therefrom the pressure appropriate to some other specified elevation.

## VII.—SUMMARY OF SPECIAL INSTRUCTIONS FOR OBSERVERS OF THE WEATHER BUREAU.

175. *Station and extra barometers.*—It is the intention to keep each station supplied as far as possible with two good barometers. The names *station* and *extra* apply, respectively, to the one used in the regular observations and the one held in reserve. Observers will

promptly report, by letter, any defect observed in either instrument, giving full details as to its nature and probable cause.

176. *Exposure of barometers.*—Observers will expose their barometers and barographs in accordance with the provisions of paragraphs 89 and 152.

177. *Cisterns of extra barometers.*—When not in use the cistern of the extra barometer may be screwed up so as to raise the level of the mercury about halfway up the ivory point. *The cistern should not be filled* nor the mercury forced to the top of the tube, except when the barometer is to be moved.

178. *Elevation of barometers above sea level.*—At the earliest practicable opportunity after establishing a new station or moving into a new office the observer will ascertain and report, upon Form No. 1058–Met'l, the elevation of the barometer above sea level. This measurement should refer to the elevation of the lower end of the ivory point of the barometer. Specific instructions in regard thereto are given in paragraphs 161 to 166, and on the back of the form mentioned.

179. When observations are commenced at a new station and the appropriate table of reductions to sea level has not, as yet, been received from the central office, only the corrections given on Form No. 1059–Met'l and for temperature will be applied to barometer readings, and the results will be recorded on all forms required and telegraphed in the usual manner until tables of reduction are received.

180. *Regular barometric observations.*—Settings and readings of the "station" barometer, as required by the instructions providing for the regular observations of the station, will be made in accordance with the provisions of paragraphs 97 to 100, and these readings will be corrected for errors, as illustrated in the example given in paragraph 171.

181. *Reduction of barometric readings to sea level.*—In reducing barometer readings to sea level the special tables supplied each station according to its elevation will be used.

The temperature argument will be obtained by taking the mean of the current and the previous 8 a. m. or 8 p. m. observation. For example: Dodge City, Kans., March 1, 1905, temperature, 8 a. m., 33.7°; 8 p. m., 45.4°; the mean of these, 39.6°, is the temperature to be used in reducing the 8 p. m. reading to sea level.

182. *Provisional removal correction.*—When the elevation of the barometer has been changed by removal or otherwise, and the observer has ascertained with reasonable accuracy the new, that is, the "actual elevation" (see paragraph 174), he will immediately report the same to the central office, even if Form No. 1058–Met'l can not be submitted at the same time. Furthermore, pending the receipt of new copies of Form No. 1059–Met'l, he will reduce his daily barometric

observations at the new location by the use of a *provisional removal correction* deduced in the manner illustrated in paragraph 198. In his letter the observer will give the value and algebraic sign of the correction he proposes to use.

182a. *Variable removal correction.*—When extreme changes of temperature, such as occur at different seasons of the year, taken in conjunction with considerable changes of elevation due to removal of office, cause variations in the "removal correction" amounting to, or exceeding 0.010 inch, it then becomes necessary to employ a "variable removal correction," which is taken out for each observation and which depends upon the temperature of the outside air. In such cases this "variable" correction for different temperatures is given in a special table on the back of Form 1059–Met'l, and is used for reducing the observations in the following manner:

The barometric observations will be reduced practically the same as heretofore (see par. 171), except that the proper "sum of corrections" to be used at each observation will be taken from the table mentioned above corresponding to the air temperature observed at the same time. It is important to note that this temperature is the *dry-bulb* reading in the instrument shelter, *not* that of the attached thermometer of the barometer. The "Sum of corrections" thus taken from this supplemental table will be added algebraically to the temperature correction in the usual manner, and the resulting total correction applied to the barometer reading, and also entered in the customary spaces on Form 1001, in the column headed "Total correction," on pages 2 and 3. Finally, in entering the data on Form 1001–Met'l, a supplementary column will be ruled adjacent to the date column on the left. This column will be headed: "Removal cor.," and therein will be entered, from observation to observation, the particular value of the "Removal correction" from the table given on back of Form 1059–Met'l, corresponding to the "Sum of corrections" employed in reducing the observations.

Whenever *new* correction cards (Form 1059–Met'l) are furnished to a station from the central office, the cards previously in use will be *destroyed*.

183. *Comparative barometer readings.*—The provisions of paragraphs 118 to 121 will be observed in making comparative readings; the results will be tabulated and reported on Form No. 1027–Met'l, and the detailed instructions printed on the back thereof fully complied with. Form No. 1027–Met'l will either be duplicated for the station file, or a letterpress copy retained for the station record.

Five comparative readings at intervals of hours, half hours, or quarter hours will be made in accordance with the foregoing provisions and on the occasions specified as follows:

(*a*) When new barometers are received for the establishment of a station, or, in general, whenever any serviceable Weather Bureau barometer is received at station, by transfer or otherwise.

(*b*) Regular monthly readings will be made on the 15th of each month. When the 15th falls on a Sunday or a holiday, the readings will be deferred until the next regular working day.

(*c*) Before and after removal of office or change in the location of the barometers, also when a line of levels is not run, a set with the station barometer in new office and extra in old office (see paragraph 166).

(*d*) Before and after cleaning a barometer.

184. Except in the case of the regular monthly readings, observers will forward special comparative barometer readings with a letter of transmittal, giving any pertinent remarks relative to the condition of the instruments, the occasion for making the readings and other particulars that may enable the central office to understand more fully the matter under consideration.

185. *Barometers not to be changed.*—Barometers will not be changed in location nor one instrument substituted for another without authority from the central office, unless the circumstances are such that immediate action is necessary. Neither the "station" nor the "extra" instrument will be loaned without authority.

186. Changes in the location of barometers, especially when the elevation is changed, as in the removal of an office, should be made at the end of the month, if practicable, and the station barometer will be moved in the interval between the last observation of one day and the first observation of the following day. The foregoing will also apply, as far as practicable, when a new barometer is substituted for the station instrument.

187. *Authority to clean barometers.*—Authority to clean barometers will be granted only in special cases, and applications therefore should be made with due consideration of the provisions of paragraph 116. Unless otherwise provided for, only one barometer will be cleaned within any given month, and then just after the regular monthly comparative readings have been made. The set of readings required, *after cleaning*, may be made the same or the following day, preferably the latter. The specific instructions for cleaning barometers, paragraphs 124 to 144, will be carefully observed.

188. *Requisition for mercury.*—Mercury will be furnished to stations only on special requisition, which will be made when the mercury is needed for immediate use in connection with the authorized cleaning and repairing of barometers.

189. *Impure mercury.*—Mercury of an impure character that has been removed from barometers, or otherwise acquired on station, should be carefully preserved, and in quantities of from a half pound

to a pound or more will be forwarded by mail to the central office, in strong bottles or other suitable receptacles, securely wrapped in proper packing material to prevent breakage. The stopper of the bottle should fit tightly and be strongly tied and sealed if practicable. The mercury is easily reduced to great purity at this office by distillation, etc. The package should be marked: Instrument Division.

190. *Mercury not to be removed.*—When an unserviceable barometer is returned to this office the mercury will not be removed except as provided for in paragraph 151, and if not returned to Washington with the instrument, will be disposed of as specified in paragraph 189.

191. *Barographs.*—The winding and regulating of barograph clocks, the changing of sheets, and the adjustment of pens to standard pressures, will be attended to in accordance with the provisions of Section (B), pages 80 and 81.

192. *Time error checked.*—The barograph will be checked for time error at 12 noon, each day, in the manner explained in paragraph 158.

193. *Hourly readings.*—Detailed instructions for compiling and transcribing records from barographs are given in Circular A, Instrument Division.

194. *Comparison of private barometers.*—Observers will extend every courtesy to shipmasters and others who may apply at the office for information or submit barometers for comparison, adjustment, etc. The mercurial barometers at a station can not as a rule be removed from the office for comparison and adjustment of barometers on board vessels, etc., but in some cases aneroid barometers serve very conveniently for this purpose and may be supplied when required.

A memorandum or tag, showing date of comparison, the correction to be applied, and other pertinent facts should accompany an instrument that has been compared.

## VIII.—TABLES.

### EXPLANATION OF TABLES.

#### TABLES I AND II.—*Correction for temperature.*

195. Tables I and II give, in English and metric measures, respectively, the corrections that should be applied to the observed readings of a mercurial barometer having a brass scale, in order to eliminate from the barometer reading the effect of temperature in expanding the mercury and the scale. The following example will elucidate the use of either table:

| | |
|---|---|
| The attached thermometer of a barometer reads | 72.5° |
| The barometer reads | 29.415 |

In Table I, the pressure nearest 29.415 is 29.5. Horizontally opposite 72.5° in the vertical column under this pressure we find 0.117, which is the correction required, and we note that it must be subtracted.

| | |
|---|---|
| The reading corrected for temperature is, therefore | 29.415 |
| | —.117 |
| | 29.298 |

196. *Interpolation explained.*—Suppose the pressure had been 29.281, which is about midway between 29 and 29.5. The correction in this case should be about midway between 0.115 and 0.117, or 0.116. The same rules must be followed if the temperature is intermediate between the values of the table.

TABES III AND IV.—*Influence of gravity on barometric observations.*

197. Table III gives the correction required to reduce readings of the mercurial barometer to standard gravity at latitude 45°.

There is, in addition to the above, another gravity correction required to eliminate the effect of change of gravity with elevation. This is small and is given in Table IV.

The aneroid barometer does not require any gravity correction.

Example: For latitude 38° and pressure 29 inches, the gravity correction is *minus* 0.018 of an inch. For an altitude of 2,490 feet and a pressure of 27.3 inches the gravity correction is —0.004 of an inch.

TABLE V.—*Pressure in inches corresponding to changes of 100 feet in elevation.*

198. Table V is employed for computing "removal corrections," paragraph 182, and its use is illustrated by the following example:

Suppose the "adopted or station elevation" of a given station is 1,482.7 feet, and that after removal the "actual elevation" is 1,516.4 feet; hence the change in elevation will be 33.7 feet.

Suppose, also, that the mean annual temperature at the station is 56°.

Table V gives 0.103 for 1,500 feet and temperature 56°. To reduce, therefore, from the "actual elevation" of 1,516.4 feet to the "station elevation" of 1,482.7 feet, the following correction is necessary, viz, $\frac{33.7}{100}\times 0.103=0.035$, which is the "removal correction" required on Form No. 1059-Met'l. The correction in this case must be used with the plus sign.

TABLES VI AND VII.—*Determination of heights by barometer.*

199. The use of these tables requires that at least two observations of the temperature and the pressure of the air be made, simultaneously if possible, at two stations. The elevation of one of the stations must be known.

From Table VI we find the first approximate difference of elevation of the two stations. Table VII gives the allowance that must be made on account of the temperature of the air.

To be strictly accurate, allowance should also be made for three other effects: (*a*) For the amount of moisture in the air; (*b*) for the effect of gravity on the weight of the air; (*c*) for the effect of gravity on the weight of the mercury (not required when the aneroid is used or when the readings of a mercurial barometer are separately corrected for gravity). By neglecting these effects in computing a high elevation, say 10,000 feet, other conditions being average, an error of fully 100 feet may be made. Greater inaccuracies than this, however, are likely to result if the computations are based upon only a few barometric and temperature readings, and especially if the readings are not strictly simultaneous. Moreover, the air temperature required is the mean temperature of the whole column between the two stations, but this is only approximately given by the mean of the observed temperatures.

The two tables following are, therefore, sufficiently accurate for use of tourists who desire a knowledge of the approximate altitude corresponding to the more or less limited and incomplete observations they may make. Example:

| | | |
|---|---|---|
| Barometer reading at base station | inches | 27.58 |
| Barometer reading at at upper station | do | 21.47 |
| Air temperature at base station | degrees | 68 |
| Air temperature at upper station | | 42 |

Estimated mean temperature of air column is—

$$\frac{68+42}{2}=\frac{110}{2}=55^\circ=T.$$

| | Feet. |
|---|---|
| Table III, at 21.47, gives | 9,002 |
| at 27.58, gives | 2,195 |
| First approximate difference of elevation | 6,807 |

Table IV, for T=55° and 6,800 feet gives:

| | Feet. |
|---|---|
| Allowance for temperature of air | +69 |
| Hence difference of elevation is | 6,876 |
| Suppose the elevation of the base station is | 1,851 |
| Then the elevation of upper station is | 8,727 |

TABLE I.—*Correction of mercurial barometer for temperature, English measures.*

| °F. | Observed reading of the barometer, in inches. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| | *Inches.* | | | | | | | ADD. | | | | | *Inches.* | | |
| −20 | 0.075 | 0.080 | 0.084 | 0.089 | 0.093 | 0.098 | 0.102 | 0.107 | 0.111 | 0.115 | 0.120 | 0.124 | 0.129 | 0.133 | 0.138 |
| −19 | .074 | .078 | .083 | .087 | .091 | .096 | .100 | .104 | .109 | .113 | .117 | .122 | .126 | .130 | .135 |
| −18 | .072 | .077 | .081 | .085 | .089 | .094 | .098 | .102 | .106 | .111 | .115 | .119 | .123 | .128 | .132 |
| −17 | .071 | .075 | .079 | .083 | .087 | .092 | .096 | .100 | .104 | .108 | .112 | .117 | .121 | .125 | .129 |
| −16 | .069 | .073 | .077 | .081 | .086 | .090 | .094 | .098 | .102 | .106 | .110 | .114 | .118 | .122 | .126 |
| −15 | .068 | .072 | .076 | .080 | .084 | .088 | .092 | .096 | .100 | .103 | .107 | .111 | .115 | .119 | .123 |
| −14 | .066 | .070 | .074 | .078 | .082 | .086 | .089 | .093 | .097 | .101 | .105 | .109 | .113 | .117 | .121 |
| −13 | .065 | .068 | .072 | .076 | .080 | .084 | .087 | .091 | .095 | .099 | .103 | .106 | .110 | .114 | .118 |
| −12 | .063 | .067 | .070 | .074 | .078 | .082 | .085 | .089 | .093 | .096 | .100 | .104 | .107 | .111 | .115 |
| −11 | .061 | .065 | .069 | .072 | .076 | .080 | .083 | .087 | .090 | .094 | .098 | .101 | .105 | .108 | .112 |
| −10 | .060 | .063 | .067 | .070 | .074 | .077 | .081 | .085 | .088 | .092 | .095 | .099 | .102 | .106 | .109 |
| − 9 | .058 | .062 | .065 | .069 | .072 | .075 | .079 | .082 | .086 | .089 | .093 | .096 | .099 | .103 | .106 |
| − 8 | .057 | .060 | .063 | .067 | .070 | .073 | .077 | .080 | .083 | .087 | .090 | .094 | .097 | .100 | .104 |
| − 7 | .055 | .058 | .062 | .065 | .068 | .071 | .075 | .078 | .081 | .084 | .088 | .091 | .094 | .097 | .101 |
| − 6 | .054 | .057 | .060 | .063 | .066 | .069 | .073 | .076 | .079 | .082 | .085 | .088 | .092 | .095 | .098 |
| − 5 | .052 | .055 | .058 | .061 | .064 | .067 | .070 | .074 | .077 | .080 | .083 | .086 | .089 | .092 | .095 |
| − 4 | .051 | .054 | .056 | .059 | .062 | .065 | .068 | .071 | .074 | .077 | .080 | .083 | .086 | .089 | .092 |
| − 3 | .049 | .052 | .055 | .058 | .061 | .063 | .066 | .069 | .072 | .075 | .078 | .081 | .084 | .086 | .089 |
| − 2 | .047 | .050 | .053 | .056 | .059 | .061 | .064 | .067 | .070 | .073 | .075 | .078 | .081 | .084 | .087 |
| − 1 | .046 | .049 | .051 | .054 | .057 | .059 | .062 | .065 | .067 | .070 | .073 | .076 | .078 | .081 | .084 |
| 0 | .044 | .047 | .050 | .052 | .055 | .057 | .060 | .063 | .065 | .068 | .070 | .073 | .076 | .078 | .081 |
| 1 | .043 | .045 | .048 | .050 | .053 | .055 | .058 | .060 | .063 | .065 | .068 | .070 | .073 | .076 | .078 |
| 2 | .041 | .044 | .046 | .049 | .051 | .053 | .056 | .058 | .061 | .063 | .065 | .068 | .070 | .073 | .075 |
| 3 | .040 | .042 | .044 | .047 | .049 | .051 | .054 | .056 | .058 | .061 | .063 | .065 | .068 | .070 | .072 |
| 4 | .038 | .040 | .043 | .045 | .047 | .049 | .052 | .054 | .056 | .058 | .061 | .063 | .065 | .067 | .070 |
| 5 | .037 | .039 | .041 | .043 | .045 | .047 | .049 | .052 | .054 | .056 | .058 | .060 | .062 | .065 | .067 |
| 6 | .035 | .037 | .039 | .041 | .043 | .045 | .047 | .049 | .052 | .054 | .056 | .058 | .060 | .062 | .064 |
| 7 | .033 | .035 | .037 | .039 | .041 | .043 | .045 | .047 | .049 | .051 | .053 | .055 | .057 | .059 | .061 |
| 8 | .032 | .034 | .036 | .038 | .039 | .041 | .043 | .045 | .047 | .049 | .051 | .053 | .054 | .056 | .058 |
| 9 | .030 | .032 | .034 | .036 | .038 | .039 | .041 | .043 | .045 | .046 | .048 | .050 | .052 | .054 | .055 |
| 10 | .029 | .031 | .032 | .034 | .036 | .037 | .039 | .041 | .042 | .044 | .046 | .047 | .049 | .051 | .053 |
| 11 | .027 | .029 | .030 | .032 | .034 | .035 | .037 | .039 | .040 | .042 | .043 | .045 | .047 | .048 | .050 |
| 12 | .026 | .027 | .029 | .030 | .032 | .033 | .035 | .036 | .038 | .039 | .041 | .042 | .044 | .045 | .047 |
| 13 | .024 | .026 | .027 | .028 | .030 | .031 | .033 | .034 | .036 | .037 | .038 | .040 | .041 | .043 | .044 |
| 14 | .023 | .024 | .025 | .027 | .028 | .029 | .031 | .032 | .033 | .035 | .036 | .037 | .039 | .040 | .041 |
| 15 | .021 | .022 | .024 | .025 | .026 | .027 | .029 | .030 | .031 | .032 | .033 | .035 | .036 | .037 | .038 |
| 16 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .028 | .029 | .030 | .031 | .032 | .033 | .034 | .036 |
| 17 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 | .029 | .030 | .031 | .032 | .033 |
| 18 | .016 | .017 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 | .028 | .029 | .030 |
| 19 | .015 | .016 | .017 | .018 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .025 | .026 | .027 |
| 20 | .013 | .014 | .015 | .016 | .016 | .017 | .018 | .019 | .020 | .020 | .021 | .022 | .023 | .024 | .024 |
| 21 | .012 | .012 | .013 | .014 | .015 | .015 | .016 | .017 | .017 | .018 | .019 | .019 | .020 | .021 | .022 |
| 22 | .010 | .011 | .011 | .012 | .013 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .017 | .018 | .019 |
| 23 | .009 | .009 | .010 | .010 | .011 | .011 | .012 | .012 | .013 | .013 | .014 | .014 | .015 | .015 | .016 |
| 24 | .007 | .008 | .008 | .008 | .009 | .009 | .010 | .010 | .011 | .011 | .011 | .012 | .012 | .013 | .013 |
| 25 | .006 | .006 | .006 | .007 | .007 | .007 | .008 | .008 | .008 | .009 | .009 | .009 | .010 | .010 | .010 |
| 26 | .004 | .004 | .005 | .005 | .005 | .005 | .005 | .006 | .006 | .006 | .006 | .007 | .007 | .007 | .007 |
| 27 | .003 | .003 | .003 | .003 | .003 | .003 | .003 | .004 | .004 | .004 | .004 | .004 | .004 | .004 | .005 |
| 28 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .002 | .002 | .002 | .002 | .002 |
| | | | | | | | | SUBTRACT. | | | | | | | |
| 29 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| 30 | .002 | .002 | 0.002 | .002 | .003 | .003 | .003 | .003 | .003 | .003 | .003 | .003 | .004 | .004 | .004 |
| 31 | .004 | .004 | .004 | .004 | .005 | .005 | .005 | .005 | .005 | .006 | .006 | .006 | .006 | .006 | .007 |
| 32 | .005 | .006 | .006 | .006 | .006 | .007 | .007 | .007 | .008 | .008 | .008 | .009 | .009 | .009 | .009 |
| 33 | .007 | .007 | .008 | .008 | .008 | .009 | .009 | .010 | .010 | .010 | .011 | .011 | .012 | .012 | .012 |
| 34 | .008 | .009 | .009 | .010 | .010 | .011 | .011 | .012 | .012 | .013 | .013 | .014 | .014 | .015 | .015 |
| 35 | .010 | .010 | .011 | .012 | .012 | .013 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .017 | .018 |
| 36 | .011 | .012 | .013 | .013 | .014 | .015 | .015 | .016 | .017 | .017 | .018 | .019 | .019 | .020 | .021 |
| 37 | .013 | .014 | .014 | .015 | .016 | .017 | .017 | .018 | .019 | .020 | .021 | .021 | .022 | .023 | .024 |
| 38 | .014 | .015 | .016 | .017 | .018 | .019 | .020 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .026 |
| 39 | .016 | .017 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .024 | .025 | .026 | .027 | .028 | .029 |
| 40 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 | .028 | .029 | .030 | .031 | .032 |

TABLE I.—*Correction of mercurial barometer for temperature, English measures*—Continued.

| ° F. | Observed reading of the barometer, in inches. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 | 22.5 | 23 | 23.5 | 24 |
| | *Inches.* | | | | | | SUBTRACT. | | | | | *Inches.* | | | |
| 35 | 0.010 | 0.010 | 0.010 | 0.011 | 0.011 | 0.011 | 0.012 | 0.012 | 0.012 | 0.012 | 0.013 | 0.013 | 0.013 | 0.014 | 0.014 |
| 35.5 | .011 | .011 | .011 | .012 | .012 | .012 | .012 | .013 | .013 | .013 | .014 | .014 | .014 | .015 | .015 |
| 36 | .011 | .012 | .012 | .012 | .013 | .013 | .013 | .014 | .014 | .014 | .015 | .015 | .015 | .016 | .016 |
| 36.5 | .012 | .012 | .013 | .013 | .014 | .014 | .014 | .015 | .015 | .015 | .016 | .016 | .016 | .017 | .017 |
| 37 | .013 | .013 | .014 | .014 | .014 | .015 | .015 | .016 | .016 | .016 | .017 | .017 | .017 | .018 | .018 |
| 37.5 | .014 | .014 | .014 | .015 | .015 | .016 | .016 | .017 | .017 | .017 | .018 | .018 | .019 | .019 | .019 |
| 38 | .014 | .015 | .015 | .016 | .016 | .017 | .017 | .017 | .018 | .018 | .019 | .019 | .020 | .020 | .020 |
| 38.5 | .015 | .016 | .016 | .016 | .017 | .017 | .018 | .018 | .019 | .019 | .020 | .020 | .021 | .021 | .021 |
| 39 | .016 | .016 | .017 | .017 | .018 | .018 | .019 | .019 | .020 | .020 | 021 | .021 | .022 | .022 | .023 |
| 39.5 | .017 | .017 | .018 | .018 | .019 | .019 | .020 | .020 | .021 | .021 | .022 | .022 | .023 | .023 | .024 |
| 40 | .018 | .018 | .019 | .019 | .020 | .020 | .021 | .021 | .022 | .022 | .023 | .023 | .024 | .024 | .025 |
| 40.5 | .018 | .019 | .019 | .020 | .020 | .021 | .022 | .022 | .023 | .023 | .024 | .024 | .025 | .025 | .026 |
| 41 | .019 | .020 | .020 | .021 | .021 | .022 | .022 | .023 | .024 | .024 | .025 | .025 | .026 | .026 | .027 |
| 41.5 | .020 | .020 | .021 | .022 | .022 | .023 | .023 | .024 | .025 | .025 | .026 | .026 | .027 | .027 | .028 |
| 42 | .021 | .021 | .022 | .022 | .023 | .024 | .024 | .025 | .025 | .026 | .027 | .027 | .028 | .029 | .029 |
| 42.5 | .021 | .022 | .023 | .023 | .024 | .025 | .025 | .026 | .026 | .027 | .028 | .028 | .029 | .030 | .030 |
| 43 | .022 | .023 | .023 | .024 | .025 | .025 | .026 | .027 | .027 | .028 | .029 | .029 | .030 | .031 | .031 |
| 43.5 | .023 | .024 | .024 | .025 | .026 | .026 | .027 | .028 | .028 | .029 | .030 | .030 | .031 | .032 | .032 |
| 44 | .024 | .024 | .025 | .026 | .026 | .027 | .028 | .029 | .029 | .030 | .031 | .031 | .032 | .033 | .033 |
| 44.5 | .024 | .025 | .026 | .027 | .027 | .028 | .029 | .030 | .030 | .031 | .032 | .032 | .033 | .034 | .035 |
| 45 | .025 | .026 | .027 | .027 | .028 | .029 | .030 | .030 | .031 | .032 | .033 | .033 | .034 | .035 | .036 |
| 45.5 | .026 | .027 | .028 | .028 | .029 | .030 | .031 | .031 | .032 | .033 | .034 | .034 | .035 | .036 | .037 |
| 46 | .027 | .028 | .028 | .029 | .030 | .031 | .031 | .032 | .033 | .034 | .035 | .035 | .036 | .037 | .038 |
| 46.5 | .028 | .028 | .029 | .030 | .031 | .032 | .032 | .033 | .034 | .035 | .036 | .036 | .037 | .038 | .039 |
| 47 | .028 | .029 | .030 | .031 | .032 | .032 | .033 | .034 | .035 | .036 | .037 | .037 | .038 | .039 | .040 |
| 47.5 | .029 | .030 | .031 | .032 | .033 | .033 | .034 | .035 | .036 | .037 | .038 | .038 | .039 | .040 | .041 |
| 48 | .030 | .031 | .032 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .040 | .041 | .042 |
| 48.5 | .031 | .032 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .041 | .042 | .043 |
| 49 | .031 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .042 | .043 | .044 |
| 49.5 | .032 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .044 | .045 |
| 50 | .033 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .046 | .046 |
| 50.5 | .034 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .046 | .047 | .048 |
| 51 | .034 | .035 | .036 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .046 | .047 | .048 | .049 |
| 51.5 | .035 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .044 | .045 | .046 | .047 | .048 | .049 | .050 |
| 52 | .036 | .037 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .046 | .047 | .048 | .049 | .050 | .051 |
| 52.5 | .037 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .047 | .048 | .049 | .050 | .051 | .052 |
| 53 | .038 | .039 | .040 | .041 | .042 | .043 | .044 | .045 | .046 | .047 | .049 | .050 | .051 | .052 | .053 |
| 53.5 | .038 | .039 | .041 | .042 | .043 | .044 | .045 | .046 | .047 | .048 | .050 | .051 | .052 | .053 | 054 |
| 54 | .039 | .040 | .041 | .043 | .044 | .045 | .046 | .047 | .048 | .049 | .051 | .052 | .053 | .054 | .055 |
| 54.5 | 040 | .041 | .042 | .043 | .045 | .046 | .047 | .048 | .049 | .050 | .052 | .053 | .054 | .055 | .056 |
| 55 | .041 | .042 | .043 | .044 | .045 | .047 | .048 | .049 | .050 | .051 | .053 | .054 | .055 | .056 | .057 |
| 55.5 | .041 | .043 | .044 | .045 | .046 | .047 | .049 | .050 | .051 | .052 | .054 | .055 | .056 | .057 | .058 |
| 56 | .042 | .043 | .045 | .046 | .047 | .048 | .050 | .051 | .052 | .053 | .055 | .056 | .057 | .058 | .060 |
| 56.5 | .043 | .044 | .045 | .047 | .048 | .049 | .050 | .052 | .053 | .054 | .056 | .057 | .058 | .059 | .061 |
| 57 | .044 | .045 | .046 | .048 | .049 | .050 | .051 | .053 | .054 | .055 | .057 | .058 | .059 | .060 | .062 |
| 57.5 | .044 | .046 | .047 | .048 | .050 | .051 | .052 | .054 | .055 | .056 | .058 | .059 | .060 | .061 | .063 |
| 58 | .045 | .047 | .048 | .049 | .051 | .052 | .053 | .055 | .056 | .057 | .059 | .060 | .061 | .063 | .064 |
| 58.5 | .046 | .048 | .049 | .050 | .051 | .053 | .054 | .055 | .057 | .058 | .060 | .061 | .062 | .064 | .065 |
| 59 | .047 | .048 | .050 | .051 | .052 | .054 | .055 | .056 | .058 | .059 | .061 | .062 | .063 | .065 | .066 |
| 59.5 | .048 | .049 | .050 | .052 | .053 | .055 | .056 | .057 | .059 | .060 | .061 | .063 | .064 | .066 | .067 |
| 60 | .048 | .050 | .051 | .053 | .054 | .055 | .057 | .058 | .060 | .061 | .062 | .064 | .065 | .067 | .068 |
| 60.5 | .049 | .050 | .052 | .053 | .055 | .056 | .058 | .059 | .061 | .062 | .063 | .065 | .066 | .068 | .069 |
| 61 | .050 | .051 | .053 | .054 | .056 | .057 | .059 | .060 | .062 | .063 | .064 | .066 | .067 | .069 | .070 |
| 61.5 | .051 | .052 | .054 | .055 | .057 | .058 | .060 | .061 | .062 | .064 | .065 | .067 | .068 | .070 | .071 |
| 62 | .051 | .053 | .054 | .056 | .057 | .059 | .060 | .062 | .063 | .065 | .066 | .068 | .069 | .071 | .073 |
| 62.5 | .052 | .054 | .055 | .057 | .058 | .060 | .061 | .063 | .064 | .066 | .067 | .069 | .071 | .072 | .074 |
| 63 | .053 | .054 | .056 | .058 | .059 | .061 | .062 | .064 | .065 | .067 | .068 | .070 | .072 | .073 | .075 |
| 63.5 | .054 | .055 | .057 | .058 | .060 | .062 | .063 | .065 | .066 | .068 | .069 | .071 | .073 | .074 | .076 |
| 64 | .054 | .056 | .058 | .059 | .061 | 062 | .064 | .066 | .067 | .069 | .070 | .072 | .074 | .075 | .077 |
| 64.5 | .055 | .057 | .058 | .060 | .062 | .063 | .065 | .067 | .068 | .070 | .071 | .073 | .075 | .076 | .078 |
| 65 | .056 | .058 | .059 | .061 | .063 | .064 | .066 | .067 | .069 | .071 | .072 | .074 | .076 | .077 | .079 |
| 65.5 | .057 | .058 | .060 | .062 | .063 | .065 | .067 | .068 | .070 | .072 | .073 | .075 | .077 | .078 | .080 |
| 66 | .057 | .059 | .061 | .063 | .064 | .066 | .068 | .069 | .071 | .073 | .074 | .076 | .078 | .079 | .081 |
| 66.5 | .058 | .060 | .062 | .063 | .065 | .067 | .069 | .070 | .072 | .074 | .075 | .077 | .079 | .081 | .082 |
| 67 | .059 | .061 | .062 | .064 | .066 | .068 | .069 | .071 | .073 | .075 | .076 | .078 | .080 | .082 | .083 |

TABLE I.—*Correction of mercurial barometer for temperature, English measures*—Continued.

| ° F. | Observed reading of the barometer, in inches. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | 24.5 | 25 | 25.5 | 26 | 26.5 | 27 | 27.5 | 28 | 28.5 | 29 | 29.5 | 30 | 30.5 | 31 |
| | *Inches.* | | | | | | SUBTRACT. | | | | | | *Inches.* | | |
| 35 | 0.014 | 0.014 | 0.014 | 0.015 | 0.015 | .015 | 0.016 | 0.016 | 0.016 | 0.016 | 0.017 | 0.017 | 0.017 | 0.018 | 0.018 |
| 35.5 | .015 | .015 | .016 | .016 | .016 | .017 | .017 | .017 | .017 | .018 | .018 | .018 | .019 | .019 | .019 |
| 36 | .016 | .016 | .017 | .017 | .017 | .018 | .018 | .018 | .019 | .019 | .019 | .020 | .020 | .020 | .021 |
| 36.5 | .017 | .017 | .018 | .018 | .019 | .019 | .019 | .020 | .020 | .020 | .021 | .021 | .021 | .022 | .022 |
| 37 | .018 | .019 | .019 | .019 | .020 | .020 | .021 | .021 | .021 | .022 | .022 | .022 | .023 | .023 | .024 |
| 37.5 | .019 | .020 | .020 | .021 | .021 | .021 | .022 | .022 | .023 | .023 | .023 | .024 | .024 | .025 | .025 |
| 38 | .020 | .021 | .021 | .022 | .022 | .023 | .023 | .023 | .024 | .024 | .025 | .025 | .026 | .026 | .026 |
| 38.5 | .021 | .022 | .022 | .023 | .023 | .024 | .024 | .025 | .025 | .026 | .026 | .026 | .027 | .027 | .028 |
| 39 | .023 | .023 | .024 | .024 | .024 | .025 | .025 | .026 | .026 | .027 | .027 | .028 | .028 | .029 | .029 |
| 39.5 | .024 | .024 | .025 | .025 | .026 | .026 | .027 | .027 | .028 | .028 | .029 | .029 | .030 | .030 | .031 |
| 40 | .025 | .025 | .026 | .026 | .027 | .027 | .028 | .028 | .029 | .029 | .030 | .030 | .031 | .031 | .032 |
| 40.5 | .026 | .026 | .027 | .027 | .028 | .029 | .029 | .030 | .030 | .031 | .031 | .032 | .032 | .033 | .033 |
| 41 | .027 | .027 | .028 | .029 | .029 | .030 | .030 | .031 | .031 | .032 | .033 | .033 | .034 | .034 | .035 |
| 41.5 | .028 | .029 | .029 | .030 | .030 | .031 | .032 | .032 | .033 | .033 | .034 | .034 | .035 | .036 | .036 |
| 42 | .029 | .030 | .030 | .031 | .032 | .032 | .033 | .033 | .034 | .035 | .035 | .036 | .036 | .037 | .038 |
| 42.5 | .030 | .031 | .031 | .032 | .033 | .033 | .034 | .035 | .035 | .036 | .036 | .037 | .038 | .038 | .039 |
| 43 | .031 | .032 | .033 | .033 | .034 | .035 | .035 | .036 | .036 | .037 | .038 | .038 | .039 | .040 | .040 |
| 43.5 | .032 | .033 | .034 | .034 | .035 | .036 | .036 | .037 | .038 | .038 | .039 | .040 | .040 | .041 | .042 |
| 44 | .033 | .034 | .035 | .036 | .036 | .037 | .038 | .038 | .039 | .040 | .040 | .041 | .042 | .042 | .043 |
| 44.5 | .035 | .035 | 036 | .037 | .037 | .038 | .039 | .040 | .040 | .041 | .042 | .042 | .043 | .044 | .045 |
| 45 | .036 | .036 | .037 | .038 | .039 | .039 | .040 | .041 | .042 | .042 | .043 | .044 | .045 | .045 | .046 |
| 45.5 | .037 | .037 | .038 | .039 | .040 | .041 | .011 | .042 | .043 | .044 | .044 | .045 | .046 | .047 | .047 |
| 46 | .038 | .039 | .039 | .040 | .041 | .042 | .043 | .043 | .044 | .045 | .046 | .046 | .047 | .048 | .049 |
| 46.5 | .039 | .040 | .041 | .041 | .042 | .043 | .044 | .045 | .045 | .046 | .047 | .048 | .049 | .049 | .050 |
| 47 | .040 | .041 | .042 | .042 | .043 | .044 | .045 | 046 | .047 | .047 | .048 | .019 | .050 | .051 | .052 |
| 47.5 | .041 | .042 | .043 | .044 | .045 | .045 | .046 | .047 | .048 | .049 | .050 | .050 | .051 | .052 | .053 |
| 48 | .042 | .043 | .044 | .045 | .046 | .047 | .047 | .048 | .049 | .050 | .051 | .052 | .053 | .054 | .054 |
| 48.5 | .043 | .044 | .045 | .046 | .047 | .048 | .049 | .050 | .050 | .051 | .052 | .053 | .054 | .055 | .056 |
| 49 | .044 | .045 | .046 | .047 | .048 | .049 | .050 | .051 | .052 | .053 | .054 | .054 | .055 | .056 | .057 |
| 49.5 | .045 | .046 | .047 | .048 | .049 | .050 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 |
| 50 | .046 | .047 | .048 | .049 | .050 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 | .060 |
| 50.5 | .048 | .049 | .050 | .051 | .052 | .053 | .054 | .055 | .055 | .056 | .057 | .058 | .059 | .060 | .061 |
| 51 | .049 | .050 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 | .060 | .061 | .062 | .063 |
| 51.5 | .050 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 | .060 | .061 | .062 | .063 | .064 |
| 52 | .051 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 | .060 | .061 | .062 | .064 | .065 | .066 |
| 52.5 | .052 | .053 | .054 | .055 | .056 | .057 | .058 | .059 | .061 | .062 | .063 | .064 | .065 | .066 | .067 |
| 53 | .053 | .054 | .055 | .056 | .057 | .059 | .060 | .061 | .062 | .063 | .064 | .065 | .066 | .067 | .068 |
| 53.5 | .054 | .055 | .056 | .057 | .059 | .060 | .061 | .062 | .063 | .064 | .065 | .066 | .068 | .069 | .070 |
| 54 | .055 | .056 | .057 | .059 | .060 | .061 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .070 | .071 |
| 54.5 | .056 | .057 | .059 | .060 | .061 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .070 | .071 | .073 |
| 55 | .057 | .059 | .060 | .061 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .070 | .072 | .073 | .074 |
| 55.5 | .058 | .060 | .061 | .062 | .063 | .065 | .066 | .067 | .068 | .069 | .071 | .072 | .073 | .074 | .075 |
| 56 | .060 | .061 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .071 | .072 | .073 | .074 | .076 | .077 |
| 56.5 | .061 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .071 | .072 | .073 | .074 | .076 | .077 | .078 |
| 57 | .062 | .063 | .064 | .066 | .067 | .068 | .069 | .071 | .072 | .073 | .075 | .076 | .077 | .078 | .080 |
| 57.5 | .063 | .064 | .065 | .067 | .068 | .069 | .071 | .072 | .073 | .075 | .076 | .077 | .078 | .080 | .081 |
| 58 | .064 | .035 | .066 | .068 | .069 | .070 | .072 | .073 | .074 | .076 | .077 | .078 | .080 | .081 | .082 |
| 58.5 | .065 | .066 | .068 | .069 | .070 | .072 | .073 | .074 | .076 | .077 | .078 | .080 | .081 | .083 | .084 |
| 59 | .066 | .067 | .069 | .070 | .072 | .073 | .074 | .076 | .077 | .078 | .080 | .081 | .083 | .084 | .085 |
| 59.5 | .067 | .068 | .070 | .071 | .073 | .074 | .075 | .077 | .078 | .080 | .081 | .082 | .084 | .085 | .087 |
| 60 | .068 | .070 | .071 | .072 | .074 | .075 | .077 | .078 | .080 | .081 | .082 | .084 | .085 | .087 | .088 |
| 60.5 | .069 | .071 | .072 | .074 | .075 | .076 | .078 | .079 | .081 | .082 | .081 | .085 | .087 | .088 | .089 |
| 61 | .070 | .072 | .073 | .075 | .076 | .078 | .079 | .081 | .082 | .084 | .085 | .086 | .088 | .089 | .091 |
| 61.5 | .071 | .073 | .074 | .076 | .077 | .079 | .080 | .082 | .083 | .085 | .086 | .088 | .089 | .091 | .092 |
| 62 | .073 | .074 | .076 | .077 | .079 | .080 | .082 | .083 | .085 | .086 | .088 | .089 | .091 | .092 | .094 |
| 62.5 | .074 | .075 | .077 | .078 | .080 | .081 | .083 | .084 | .086 | .087 | .089 | .090 | .092 | .094 | .095 |
| 63 | .075 | .076 | .078 | .079 | .081 | .082 | .084 | .086 | .087 | .089 | .090 | .092 | .093 | .095 | .096 |
| 63.5 | .076 | .077 | .079 | .080 | .082 | .084 | .085 | .087 | .088 | .090 | .092 | .093 | .095 | .096 | .098 |
| 64 | .077 | .078 | .080 | .082 | .083 | .085 | .086 | .088 | .090 | .091 | .093 | .094 | .096 | .098 | .099 |
| 64.5 | .078 | .080 | .081 | .083 | .084 | .086 | .088 | .089 | .091 | .093 | .094 | .096 | .097 | .099 | .101 |
| 65 | .079 | .081 | .082 | .084 | .086 | .087 | .089 | .091 | .092 | .094 | .095 | .097 | .099 | .100 | .102 |
| 65.5 | .080 | .082 | .083 | .085 | .087 | .088 | .090 | .092 | .093 | .095 | .097 | .098 | .100 | .102 | .103 |
| 66 | .081 | .083 | .085 | .086 | .088 | .090 | .091 | .093 | .095 | .096 | .098 | .100 | .101 | .103 | .105 |
| 66.5 | .082 | .084 | .086 | .087 | .089 | .091 | .093 | .094 | .096 | .098 | .099 | .101 | .103 | .105 | .106 |
| 67 | .083 | .085 | .087 | .089 | .090 | .092 | .094 | .095 | .097 | .099 | .101 | .102 | .104 | .106 | .108 |

TABLE I.—*Correction of mercurial barometer for temperature, English measures*—Continued.

| ° F. | Observed reading of the barometer, in inches. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 | 22.5 | 23 | 23.5 | 24 |
| | *Inches.* | | | | | | SUBTRACT. | | | | *Inches.* | | | | |
| 67 | 0.059 | 0.061 | 0.062 | 0.064 | 0.066 | 0.068 | 0.069 | 0.071 | 0.073 | 0.075 | 0.076 | 0.078 | 0.080 | 0.082 | 0.083 |
| 67.5 | .060 | .062 | .063 | .065 | .067 | .069 | .070 | .072 | .074 | .076 | .077 | .079 | .081 | .083 | .084 |
| 68 | .061 | .062 | .064 | .066 | .068 | .069 | .071 | .073 | .075 | .077 | .078 | .080 | .082 | .084 | .085 |
| 68.5 | .061 | .063 | .065 | .067 | .069 | .070 | .072 | .074 | .076 | .078 | .079 | .081 | .083 | .085 | .087 |
| 69 | .062 | .064 | .066 | .068 | .069 | .071 | .073 | .075 | .077 | .079 | .080 | .082 | .084 | .086 | .088 |
| 69.5 | .063 | .065 | .067 | .068 | .070 | .072 | .074 | .076 | .078 | .079 | .081 | .083 | .085 | .087 | .089 |
| 70 | .064 | .065 | .067 | .069 | .071 | .073 | .075 | .077 | .079 | .080 | .082 | .084 | .086 | .088 | .090 |
| 70.5 | .064 | .066 | .068 | .070 | .072 | .074 | .076 | .078 | .080 | .081 | .083 | .085 | .087 | .089 | .091 |
| 71 | .065 | .067 | .069 | .071 | .073 | .075 | .077 | .079 | .080 | .082 | .084 | .086 | .088 | .090 | .092 |
| 71.5 | .066 | .068 | .070 | .072 | .074 | .076 | .078 | .079 | .081 | .083 | .085 | .087 | .089 | .091 | .093 |
| 72 | .067 | .069 | .071 | .073 | .075 | .076 | .078 | .080 | .082 | .084 | .086 | .088 | .090 | .092 | .094 |
| 72.5 | .067 | .069 | .071 | .073 | .075 | .077 | .079 | .081 | .083 | .085 | .087 | .089 | .091 | .093 | .095 |
| 73 | .068 | .070 | .072 | .074 | .076 | .078 | .080 | .082 | .084 | .086 | .088 | .090 | .092 | .094 | .096 |
| 73.5 | .069 | .071 | .073 | .075 | .077 | .079 | .081 | .083 | .085 | .087 | .089 | .091 | .093 | .095 | .097 |
| 74 | .070 | .072 | .074 | .076 | .078 | .080 | .082 | .084 | .086 | .088 | .090 | .092 | .094 | .096 | .098 |
| 74.5 | .070 | .073 | .075 | .077 | .079 | .081 | .083 | .085 | .087 | .089 | .091 | .093 | .095 | .097 | .100 |
| 75 | .071 | .073 | .075 | .078 | .080 | .082 | .084 | .086 | .088 | .090 | .092 | .094 | .096 | .099 | .101 |
| 75.5 | .072 | .074 | .076 | .078 | .081 | .083 | .085 | .087 | .089 | .091 | .093 | .095 | .097 | .100 | .10[illegible] |
| 76 | .073 | .075 | .077 | .079 | .081 | .084 | .086 | .088 | .090 | .092 | .094 | .096 | .098 | .101 | .103 |
| 76.5 | .074 | .076 | .078 | .080 | .082 | .084 | .087 | .089 | .091 | .093 | .095 | .097 | .100 | .102 | .104 |
| 77 | .074 | .077 | .079 | .081 | .083 | .085 | .087 | .090 | .092 | .094 | .096 | .098 | .101 | .103 | .105 |
| 77.5 | .075 | .077 | .080 | .082 | .084 | .086 | .088 | .091 | .093 | .095 | .097 | .099 | .102 | .104 | .106 |
| 78 | .076 | .078 | .080 | .083 | .085 | .087 | .089 | .091 | .094 | .096 | .098 | .100 | .103 | .105 | .107 |
| 78.5 | .077 | .079 | .081 | .083 | .086 | .088 | .090 | .092 | .095 | .097 | .099 | .101 | .104 | .106 | .108 |
| 79 | .077 | .080 | .082 | .084 | .086 | .089 | .091 | .093 | .096 | .098 | .100 | .102 | .105 | .107 | .109 |
| 79.5 | .078 | .080 | .083 | .085 | .087 | .090 | .092 | .094 | .097 | .099 | .101 | .103 | .106 | .108 | .110 |
| 80 | .079 | .081 | .084 | .086 | .088 | .091 | .093 | .095 | .097 | .100 | .102 | .104 | .107 | .109 | .111 |
| 80.5 | .080 | .082 | .084 | .087 | .089 | .091 | .094 | .096 | .098 | .101 | .103 | .105 | .108 | .110 | .112 |
| 81 | .080 | .083 | .085 | .088 | .090 | .092 | .095 | .097 | .099 | .102 | .104 | .106 | .109 | .111 | .114 |
| 81.5 | .081 | .084 | .086 | .088 | .091 | .093 | .096 | .098 | .100 | .103 | .105 | .107 | .110 | .112 | .115 |
| 82 | .082 | .084 | .087 | .089 | .092 | .094 | .096 | .099 | .101 | .104 | .106 | .108 | .111 | .113 | .116 |
| 82.5 | .083 | .085 | .088 | .090 | .092 | .095 | .097 | .100 | .102 | .105 | .107 | .109 | .112 | .114 | .117 |
| 83 | .083 | .086 | .088 | .091 | .093 | .096 | .098 | .101 | .103 | .106 | .108 | .111 | .113 | .115 | .118 |
| 83.5 | .084 | .087 | .089 | .092 | .094 | .097 | .099 | .102 | .104 | .107 | .109 | .112 | .114 | .117 | .119 |
| 84 | .085 | .088 | .090 | .093 | .095 | .098 | .100 | .103 | .105 | .108 | .110 | .113 | .115 | .118 | .120 |
| 84.5 | .086 | .088 | .091 | .093 | .096 | .098 | .101 | .103 | .106 | .108 | .111 | .114 | .116 | .119 | .121 |
| 85 | .087 | .089 | .092 | .094 | .097 | .099 | .102 | .104 | .107 | .109 | .112 | .115 | .117 | .120 | .122 |
| 85.5 | .087 | .090 | .092 | .095 | .098 | .100 | .103 | .105 | .108 | .110 | .113 | .116 | .118 | .121 | .123 |
| 86 | .088 | .091 | .093 | .096 | .098 | .101 | .104 | .106 | .109 | .111 | .114 | .117 | .119 | .122 | .124 |
| 86.5 | .089 | .091 | .094 | .097 | .099 | .102 | .105 | .107 | .110 | .112 | .115 | .118 | .120 | .123 | .125 |
| 87 | .090 | .092 | .095 | .098 | .100 | .103 | .105 | .108 | .111 | .113 | .116 | .119 | .121 | .124 | .126 |
| 87.5 | .090 | .093 | .096 | .098 | .101 | .104 | .106 | .109 | .112 | .114 | .117 | .120 | .122 | .125 | .128 |
| 88 | .091 | .094 | .096 | .099 | .102 | .105 | .107 | .110 | .113 | .115 | .118 | .121 | .123 | .126 | .129 |
| 88.5 | .092 | .095 | .097 | .100 | .103 | .105 | .108 | .111 | .114 | .116 | .119 | .122 | .124 | .127 | .130 |
| 89 | .093 | .095 | .098 | .101 | .104 | .106 | .109 | .112 | .114 | .117 | .120 | .123 | .125 | .128 | .131 |
| 89.5 | .093 | .096 | .099 | .102 | .104 | .107 | .110 | .113 | .115 | .118 | .121 | .124 | .126 | .129 | .132 |
| 90 | .094 | .097 | .100 | .102 | .105 | .108 | .111 | .114 | .116 | .119 | .122 | .125 | .127 | .130 | .133 |
| 90.5 | .095 | .098 | .101 | .103 | .106 | .109 | .112 | .114 | .117 | .120 | .123 | .126 | .128 | .131 | .134 |
| 91 | .096 | .099 | .101 | .104 | .107 | .110 | .113 | .115 | .118 | .121 | .124 | .127 | .129 | .132 | .135 |
| 91.5 | .096 | .099 | .102 | .105 | .108 | .111 | .113 | .116 | .119 | .122 | .125 | .128 | .131 | .133 | .136 |
| 92 | .097 | .100 | .103 | .106 | .109 | .112 | .114 | .117 | .120 | .123 | .126 | .129 | .132 | .134 | .137 |
| 92.5 | .098 | .101 | .104 | .107 | .110 | .112 | .115 | .118 | .121 | .124 | .127 | .130 | .133 | .135 | .138 |
| 93 | .099 | .102 | .105 | .107 | .110 | .113 | .116 | .119 | .122 | .125 | .128 | .131 | .134 | .137 | .139 |
| 93.5 | .100 | .102 | .105 | .108 | .111 | .114 | .117 | .120 | .123 | .126 | .129 | .132 | .135 | .138 | .140 |
| 94 | .100 | .103 | .106 | .109 | .112 | .115 | .118 | .121 | .124 | .127 | .130 | .133 | .136 | .139 | .142 |
| 94.5 | .101 | .104 | .107 | .110 | .113 | .116 | .119 | .122 | .125 | .128 | .131 | .134 | .137 | .140 | .143 |
| 95 | .102 | .105 | .108 | .111 | .114 | .117 | .120 | .123 | .126 | .129 | .132 | .135 | .138 | .141 | .144 |
| 95.5 | .103 | .106 | .109 | .112 | .115 | .118 | .121 | .124 | .127 | .130 | .133 | .136 | .139 | .142 | .145 |
| 96 | .103 | .106 | .109 | .112 | .115 | .119 | .122 | .125 | .128 | .131 | .134 | .137 | .140 | .143 | .146 |
| 96.5 | .104 | .107 | .110 | .113 | .116 | .119 | .122 | .126 | .129 | .132 | .135 | .138 | .141 | .144 | .147 |
| 97 | .105 | .108 | .111 | .114 | .117 | .120 | .123 | .126 | .130 | .133 | .136 | .139 | .142 | .145 | .148 |
| 97.5 | .106 | .109 | .112 | .115 | .118 | .121 | .124 | .127 | .130 | .134 | .137 | .140 | .143 | .146 | .149 |
| 98 | .106 | .109 | .113 | .116 | .119 | .122 | .125 | .128 | .131 | .135 | .138 | .141 | .144 | .147 | .150 |
| 98.5 | .107 | .110 | .113 | .117 | .120 | .123 | .126 | .129 | .132 | .135 | .139 | .142 | .145 | .148 | .151 |
| 99 | .108 | .111 | .114 | .117 | .121 | .124 | .127 | .130 | .133 | .136 | .140 | .143 | .146 | .149 | .152 |
| 99.5 | .109 | .112 | .115 | .118 | .121 | .125 | .128 | .131 | .134 | .137 | .141 | .144 | .147 | .150 | .153 |
| 100 | .109 | .113 | .116 | .119 | .122 | .126 | .129 | .132 | .135 | .138 | .142 | .145 | .148 | .151 | .154 |

TABLE I.—*Correction of mercurial barometer for temperature, English measures*—Continued.

| ° F. | Observed reading of the barometer, in inches. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | 24.5 | 25 | 25.5 | 26 | 26.5 | 27 | 27.5 | 28 | 28.5 | 29 | 29.5 | 30 | 30.5 | 31 |
| | *Inches.* | | | | | | SUBTRACT. | | | | | *Inches.* | | | |
| 67 | 0.083 | 0.085 | 0.087 | 0.089 | 0.090 | 0.092 | 0.094 | 0.095 | 0.097 | 0.099 | 0.101 | 0.102 | 0.104 | 0.106 | 0.108 |
| 67.5 | .084 | .086 | .088 | .090 | .092 | .093 | .095 | .097 | .098 | .100 | .102 | .104 | .106 | .107 | .109 |
| 68 | .085 | .087 | .089 | .091 | .093 | .094 | .096 | .098 | .100 | .102 | .103 | .105 | .107 | .109 | .110 |
| 68.5 | .087 | .088 | .090 | .092 | .094 | .096 | .097 | .099 | .101 | .103 | .105 | .106 | .108 | .110 | .112 |
| 69 | .088 | .089 | .091 | .093 | .095 | .097 | .099 | .100 | .102 | .104 | .106 | .108 | .110 | .111 | .113 |
| 69.5 | .089 | .091 | .092 | .094 | .096 | .098 | .100 | .102 | .104 | .105 | .107 | .109 | .111 | .113 | .115 |
| 70 | .090 | .092 | .094 | .095 | .097 | .099 | .101 | .103 | .105 | .107 | .109 | .110 | .112 | .114 | .116 |
| 70.5 | .091 | .093 | .095 | .097 | .098 | .100 | .102 | .104 | .106 | .108 | .110 | .112 | .114 | .116 | .117 |
| 71 | .092 | .094 | .096 | .098 | .100 | .102 | .103 | .105 | .107 | .109 | .111 | .113 | .115 | .117 | .119 |
| 71.5 | .093 | .095 | .097 | .099 | .101 | .103 | .105 | .107 | .109 | .110 | .112 | .114 | .116 | .118 | .120 |
| 72 | .094 | .096 | .098 | .100 | .102 | .104 | .106 | .108 | .110 | .112 | .114 | .116 | .118 | .120 | .122 |
| 72.5 | .095 | .097 | .099 | .101 | .103 | .105 | .107 | .109 | .111 | .113 | .115 | .117 | .119 | .121 | .123 |
| 73 | .096 | .098 | .100 | .102 | .104 | .106 | .108 | .110 | .112 | .114 | .116 | .118 | .120 | .122 | .124 |
| 73.5 | .097 | .099 | .101 | .103 | .105 | .108 | .110 | .112 | .114 | .116 | .118 | .120 | .122 | .124 | .126 |
| 74 | .098 | .101 | .103 | .105 | .107 | .109 | .111 | .113 | .115 | .117 | .119 | .121 | .123 | .125 | .127 |
| 74.5 | .100 | .102 | .104 | .106 | .108 | .110 | .112 | .114 | .116 | .118 | .120 | .122 | .124 | .126 | .129 |
| 75 | .101 | .103 | .105 | .107 | .109 | .111 | .113 | .115 | .117 | .119 | .122 | .124 | .126 | .128 | .130 |
| 75.5 | .102 | .104 | .106 | .108 | .110 | .112 | .114 | .117 | .119 | .121 | .123 | .125 | .127 | .129 | .131 |
| 76 | .103 | .105 | .107 | .109 | .111 | .113 | .116 | .118 | .120 | .122 | .124 | .126 | .128 | .131 | .133 |
| 76.5 | .104 | .106 | .108 | .111 | .113 | .115 | .117 | .119 | .121 | .123 | .125 | .128 | .130 | .132 | .134 |
| 77 | .105 | .107 | .109 | .112 | .114 | .116 | .118 | .120 | .122 | .125 | .127 | .129 | .131 | .133 | .136 |
| 77.5 | .106 | .108 | .110 | .113 | .115 | .117 | .119 | .121 | .124 | .126 | .128 | .130 | .133 | .135 | .137 |
| 78 | .107 | .109 | .112 | .114 | .116 | .118 | .120 | .123 | .125 | .127 | .129 | .132 | .134 | .136 | .138 |
| 78.5 | .108 | .110 | .113 | .115 | .117 | .119 | .122 | .124 | .126 | .128 | .131 | .133 | .135 | .137 | .140 |
| 79 | .109 | .112 | .114 | .116 | .118 | .121 | .123 | .125 | .127 | .130 | .132 | .134 | .137 | .139 | .141 |
| 79.5 | .110 | .113 | .115 | .117 | .120 | .122 | .124 | .126 | .129 | .131 | .133 | .136 | .138 | .140 | .143 |
| 80 | .111 | .114 | .116 | .118 | .121 | .123 | .125 | .128 | .130 | .132 | .135 | .137 | .139 | .142 | 144 |
| 80.5 | .112 | .115 | .117 | .120 | .122 | .124 | .127 | .129 | .131 | .134 | .136 | .138 | .141 | .143 | .145 |
| 81 | .114 | .116 | .118 | .121 | .123 | .125 | .128 | .130 | .132 | .135 | .137 | .140 | .142 | .144 | .147 |
| 81.5 | .115 | .117 | .119 | .122 | .124 | .127 | .129 | .131 | .134 | .136 | .139 | .141 | .143 | .146 | .148 |
| 82 | .116 | .118 | .121 | .123 | .125 | .128 | .130 | .133 | .135 | .137 | .140 | .142 | .145 | .147 | .149 |
| 82.5 | .117 | .119 | .122 | .124 | .127 | .129 | .131 | .134 | .136 | .139 | .141 | .144 | .146 | .148 | .151 |
| 83 | .118 | .120 | .123 | .125 | .128 | .130 | .133 | .135 | .138 | .140 | .142 | .145 | .147 | .150 | .152 |
| 83.5 | .119 | .121 | .124 | .126 | .129 | .131 | .134 | .136 | .139 | .141 | .144 | .146 | .149 | .151 | .154 |
| 84 | .120 | .123 | .125 | .128 | .130 | .133 | .135 | .138 | .140 | .143 | .145 | .148 | .150 | .153 | .155 |
| 84.5 | .121 | .124 | .126 | .129 | .131 | .134 | .136 | .139 | .141 | .144 | .146 | .149 | .151 | .154 | .156 |
| 85 | .122 | .125 | .127 | .130 | .132 | .135 | .137 | .140 | .143 | .145 | .148 | .150 | .153 | .155 | .158 |
| 85.5 | .123 | .126 | .128 | .131 | .134 | .136 | .139 | .141 | .144 | .146 | .149 | .152 | .154 | .157 | .159 |
| 86 | .124 | .127 | .130 | .132 | .135 | .137 | .140 | .142 | .145 | .148 | .150 | .153 | .155 | .158 | .161 |
| 86.5 | .125 | .128 | .131 | .133 | .136 | .138 | .141 | .144 | .146 | .149 | .152 | .154 | .157 | .159 | .162 |
| 87 | .126 | .129 | .132 | .134 | .137 | .140 | .142 | .145 | .148 | .150 | .153 | .155 | .158 | .161 | .163 |
| 87.5 | .128 | .130 | .133 | .136 | .138 | .141 | .144 | .146 | .149 | .151 | .154 | .157 | .159 | .162 | .165 |
| 88 | .129 | .131 | .134 | .137 | .139 | .142 | .145 | .147 | .150 | .153 | .155 | .158 | .161 | .163 | .166 |
| 88.5 | .130 | .132 | .135 | .138 | .141 | .143 | .146 | .149 | .151 | .154 | .157 | .159 | .162 | .165 | .168 |
| 89 | .131 | .134 | .136 | .139 | .142 | .144 | .147 | .150 | .153 | .155 | .158 | .161 | .164 | .166 | .169 |
| 89.5 | .132 | .135 | .137 | .140 | .143 | .146 | .148 | .151 | .154 | .157 | .159 | .162 | .165 | .168 | .170 |
| 90 | .133 | .136 | .138 | .141 | .144 | .147 | .150 | .152 | .155 | .158 | .161 | .163 | .166 | .169 | .172 |
| 90.5 | .134 | .137 | .140 | .142 | .145 | .148 | .151 | .154 | .156 | .159 | .162 | .165 | .168 | .170 | .173 |
| 91 | .135 | .138 | .141 | .144 | .146 | .149 | .152 | .155 | .158 | .160 | .163 | .166 | .169 | .172 | .175 |
| 91.5 | .136 | .139 | .142 | .145 | .148 | .150 | .153 | .156 | .159 | .162 | .165 | .167 | .170 | .173 | .176 |
| 92 | .137 | .140 | .143 | .146 | .149 | .152 | .154 | .157 | .160 | .163 | .166 | .169 | .172 | .174 | .177 |
| 92.5 | .138 | .141 | .144 | .147 | .150 | .153 | .156 | .159 | .161 | .164 | .167 | .170 | .173 | .176 | .179 |
| 93 | .139 | .142 | .145 | .148 | .151 | .154 | .157 | .160 | .163 | .166 | .168 | .171 | .174 | .177 | .180 |
| 93.5 | .140 | .143 | .146 | .149 | .152 | .155 | .158 | .161 | .164 | .167 | .170 | .173 | 176 | .179 | .181 |
| 94 | .142 | .145 | .147 | .150 | .153 | .156 | .159 | .162 | .165 | .168 | .171 | .174 | .177 | .180 | .183 |
| 94.5 | .143 | .146 | .149 | .152 | .155 | .158 | .160 | .163 | .166 | .169 | .172 | .175 | .178 | .181 | .184 |
| 95 | .144 | .147 | .150 | .153 | .156 | .159 | .162 | .165 | .168 | .171 | .174 | .177 | .180 | .183 | .186 |
| 95.5 | .145 | .148 | .151 | .154 | .157 | .160 | .163 | .166 | .169 | .172 | .175 | .178 | .181 | .184 | .187 |
| 96 | .146 | .149 | .152 | .155 | .158 | .161 | .164 | .167 | .170 | .173 | .176 | .179 | .182 | .185 | .188 |
| 96.5 | .147 | .150 | .153 | .156 | .159 | .162 | .165 | .168 | .171 | .174 | .178 | .181 | .184 | .187 | .190 |
| 97 | .148 | .151 | .154 | .157 | .160 | .163 | .167 | .170 | .173 | .176 | .179 | .182 | .185 | .188 | .191 |
| 97.5 | .149 | .152 | .155 | .158 | .162 | .165 | .168 | .171 | .174 | .177 | .180 | .183 | .186 | .189 | .193 |
| 98 | .150 | .153 | .156 | .160 | .163 | .166 | .169 | .172 | .175 | .178 | .181 | .185 | .188 | .191 | .194 |
| 98.5 | .151 | .154 | .158 | .161 | .164 | .167 | .170 | .173 | .176 | .180 | .183 | .186 | .189 | .192 | .195 |
| 99 | .152 | .155 | .159 | .162 | .165 | .168 | .171 | .175 | .178 | .181 | .184 | .187 | .190 | .194 | .197 |
| 99.5 | .153 | .157 | .160 | .163 | .166 | .169 | .173 | .176 | .179 | .182 | .185 | .189 | .192 | .195 | .198 |
| 100 | .154 | .158 | .161 | .164 | .167 | .171 | .174 | .177 | .180 | .183 | .187 | .190 | .193 | .196 | .200 |

TABLE II.—*Correction of mercurial barometers for temperature, metric measures.*

| Temperature, C. | Observed reading of the barometer, in millimeters. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 640 | 650 | 660 | 670 | 680 | 690 | 700 | 710 | 720 | 730 | 740 | 750 | 760 | 770 | 780 |
| 0.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.0 | .10 | .11 | .11 | .11 | .11 | .11 | .11 | .12 | .12 | .12 | .12 | .12 | .12 | .13 | .13 |
| 2.0 | .21 | .21 | .22 | .22 | .22 | .23 | .23 | .23 | .24 | .24 | .24 | .25 | .25 | .25 | .25 |
| 3.0 | .31 | .32 | .32 | .33 | .33 | .34 | .34 | .35 | .35 | .36 | .36 | .37 | .37 | .38 | .38 |
| 4.0 | .42 | .42 | .43 | .44 | .44 | .45 | .46 | .46 | .47 | .48 | .48 | .49 | .50 | .50 | .51 |
| 5. | .52 | .53 | .54 | .55 | .56 | .56 | .57 | .58 | .59 | .60 | .60 | .61 | .62 | .63 | .64 |
| 5.5 | .57 | .58 | .59 | .60 | .61 | .62 | .63 | .64 | .65 | .66 | .66 | .67 | .68 | .69 | .70 |
| 6. | .63 | .64 | .65 | .66 | .67 | .68 | .69 | .70 | .71 | .71 | .72 | .73 | .74 | .75 | .76 |
| 6.5 | .68 | .69 | .70 | .71 | .72 | .73 | .74 | .75 | .76 | .77 | .79 | .80 | .81 | .82 | .83 |
| 7. | .73 | .74 | .75 | .77 | .78 | .79 | .80 | .81 | .82 | .83 | .85 | .86 | .87 | .88 | .89 |
| 7.5 | .78 | .80 | .81 | .82 | .83 | .84 | .86 | .87 | .88 | .89 | .91 | .92 | .93 | .94 | .95 |
| 8. | .84 | .85 | .86 | .87 | .89 | .90 | .91 | .93 | .94 | .95 | .97 | .98 | .99 | 1.01 | 1.02 |
| 8.5 | .89 | .90 | .92 | .93 | .94 | .96 | .97 | .98 | 1.00 | 1.01 | 1.03 | 1.04 | 1.05 | 1.07 | 1.08 |
| 9. | .94 | .95 | .97 | .98 | 1.00 | 1.01 | 1.03 | 1.04 | 1.06 | 1.07 | 1.09 | 1.10 | 1.12 | 1.13 | 1.15 |
| 9.5 | .99 | 1.01 | 1.02 | 1.04 | 1.05 | 1.07 | 1.08 | 1.10 | 1.12 | 1.13 | 1.15 | 1.16 | 1.18 | 1.19 | 1.21 |
| 10.0 | 1.04 | 1.06 | 1.08 | 1.09 | 1.11 | 1.13 | 1.14 | 1.16 | 1.17 | 1.19 | 1.21 | 1.22 | 1.24 | 1.26 | 1.27 |
| .2 | .06 | .08 | .10 | .11 | .13 | .15 | .16 | .18 | .20 | .21 | .23 | .25 | .26 | .28 | .30 |
| .4 | .09 | .10 | .12 | .14 | .15 | .17 | .19 | .20 | .22 | .24 | .26 | .27 | .29 | .31 | .32 |
| .6 | .11 | .12 | .14 | .16 | .18 | .19 | .21 | .23 | .24 | .26 | .28 | .30 | .31 | .33 | .35 |
| .8 | .13 | .14 | .16 | .18 | .20 | .22 | .23 | .25 | .27 | .29 | .30 | .32 | .34 | .36 | .37 |
| 11.0 | 1.15 | 1.17 | 1.18 | 1.20 | 1.22 | 1.24 | 1.26 | 1.27 | 1.29 | 1.31 | 1.33 | 1.35 | 1.36 | 1.38 | 1.40 |
| .2 | .17 | .19 | .21 | .22 | .24 | .26 | .28 | .30 | .31 | .33 | .35 | .37 | .39 | .41 | .42 |
| .4 | .19 | .21 | .23 | .25 | .26 | .28 | .30 | .32 | .34 | .36 | .38 | .39 | .41 | .43 | .45 |
| .6 | .21 | .23 | .25 | .27 | .29 | .31 | .32 | .34 | .36 | .38 | .40 | .42 | .44 | .46 | .48 |
| .8 | .23 | .25 | .27 | .29 | .31 | .33 | .35 | .37 | .39 | .40 | .42 | .44 | .46 | .48 | .50 |
| 12.0 | 1.25 | 1.27 | 1.29 | 1.31 | 1.33 | 1.35 | 1.37 | 1.39 | 1.41 | 1.43 | 1.45 | 1.47 | 1.49 | 1.51 | 1.53 |
| .2 | .27 | .29 | .31 | .33 | .35 | .37 | .39 | .41 | .43 | .45 | .47 | .49 | .51 | .53 | .55 |
| .4 | .29 | .31 | .33 | .35 | .37 | .39 | .42 | .44 | .46 | .48 | .50 | .52 | .54 | .56 | .58 |
| .6 | .31 | .34 | .36 | .38 | .40 | .42 | 44 | .46 | .48 | .50 | .52 | .54 | .56 | .58 | .60 |
| .8 | .34 | .36 | .38 | .40 | .42 | .44 | .46 | .48 | .50 | .52 | .54 | .56 | .59 | .61 | .63 |
| 13.0 | 1.36 | 1.38 | 1.40 | 1.42 | 1.44 | 1.46 | 1.48 | 1.50 | 1.53 | 1.55 | 1.57 | 1.59 | 1.61 | 1.63 | 1.65 |
| .2 | .38 | .40 | .42 | .44 | .46 | .48 | .51 | .53 | .55 | .57 | .59 | .61 | .64 | .66 | .68 |
| .4 | .40 | .42 | .44 | .46 | .49 | .51 | .53 | .55 | .57 | .59 | .62 | .64 | .66 | .68 | .70 |
| .6 | .42 | .44 | .46 | .49 | .51 | .53 | .55 | .57 | .60 | .62 | .64 | .66 | .68 | .71 | .73 |
| .8 | .44 | .46 | .48 | .51 | .53 | .55 | .57 | .60 | .62 | .64 | .66 | .69 | .71 | .73 | .75 |
| 14.0 | 1.46 | 1.48 | 1.51 | 1.53 | 1.55 | 1.57 | 1.60 | 1.62 | 1.64 | 1.67 | 1.69 | 1.71 | 1.73 | 1.76 | 1.78 |
| .2 | .48 | .50 | .53 | .55 | .57 | .60 | .62 | .64 | .67 | .69 | .71 | .74 | .76 | .78 | .81 |
| .4 | .50 | .53 | .55 | .57 | .60 | .62 | .64 | .67 | .69 | .71 | .74 | .76 | .78 | .81 | .83 |
| .6 | .52 | .55 | .57 | .59 | .62 | .64 | .67 | .69 | .71 | .74 | .76 | .78 | .81 | .83 | .86 |
| .8 | .54 | .57 | .59 | .62 | .64 | .66 | .69 | .71 | .74 | .76 | .78 | .81 | .83 | .86 | .88 |
| 15.0 | 1.56 | 1.59 | 1.61 | 1.64 | 1.66 | 1.69 | 1.71 | 1.74 | 1.76 | 1.78 | 1.81 | 1.83 | 1.86 | 1.88 | 1.91 |
| .2 | .59 | .61 | .63 | .66 | .68 | .71 | .73 | .76 | .78 | .81 | .83 | .86 | .88 | .91 | .93 |
| .4 | .61 | .63 | .66 | .68 | .71 | .73 | .76 | .78 | .81 | .83 | .86 | .88 | .91 | .93 | .96 |
| .6 | .63 | .65 | .68 | .70 | .73 | .75 | .78 | .80 | .83 | .86 | .88 | .91 | .93 | .96 | .98 |
| .8 | .65 | .67 | .70 | .72 | .75 | .78 | .80 | .83 | .85 | .88 | .90 | .93 | .96 | .98 | 2.01 |
| 16.0 | 1.67 | 1.69 | 1.72 | 1.75 | 1.77 | 1.80 | 1.82 | 1.85 | 1.88 | 1.90 | 1.93 | 1.96 | 1.98 | 2.01 | 2.03 |
| .2 | .69 | .72 | .74 | .77 | .79 | .82 | .85 | .87 | .90 | .93 | .95 | .98 | 2.01 | .03 | .06 |
| .4 | .71 | .74 | .76 | .79 | .82 | .84 | .87 | .90 | .92 | .95 | .98 | 2.00 | .03 | .06 | .08 |
| .6 | .73 | .76 | .78 | .81 | .84 | .87 | .89 | .92 | .95 | .97 | 2.00 | .03 | .06 | .08 | .11 |
| .8 | .75 | .78 | .81 | .83 | .86 | .89 | .92 | .94 | .97 | 2.00 | .03 | .05 | .08 | .11 | .13 |
| 17.0 | 1.77 | 1.80 | 1.83 | 1.86 | 1.88 | 1.91 | 1.94 | 1.97 | 1.99 | 2.02 | 2.05 | 2.08 | 2.10 | 2.13 | 2.16 |
| .2 | .79 | .82 | .85 | .88 | .91 | .93 | .96 | .99 | 2.02 | .05 | .07 | .10 | .13 | .16 | .19 |
| .4 | .81 | .84 | .87 | .90 | .93 | .96 | .98 | 2.01 | .04 | .07 | .10 | .13 | .15 | .18 | .21 |
| .6 | .83 | .86 | .89 | .92 | .95 | .98 | 2.01 | .04 | .06 | .09 | .12 | .15 | .18 | .21 | .24 |
| .8 | .86 | .88 | .91 | .94 | .97 | 2.00 | .03 | .06 | .09 | .12 | .15 | .17 | .20 | .23 | .26 |
| 18.0 | 1.88 | 1.91 | 1.93 | 1.96 | 1.99 | 2.02 | 2.05 | 2.08 | 2.11 | 2.14 | 2.17 | 2.20 | 2.23 | 2.26 | 2.29 |
| .2 | .90 | .93 | .96 | .99 | 2.02 | .05 | .07 | .10 | .13 | .16 | .19 | .22 | .25 | .28 | .31 |
| .4 | .92 | .95 | .98 | 2.01 | .04 | .07 | .10 | .13 | .16 | .19 | .22 | .25 | .28 | .31 | .34 |
| .6 | .94 | .97 | 2.00 | .03 | .06 | .09 | .12 | .15 | .18 | .21 | .24 | .27 | .30 | .33 | .36 |
| .8 | .96 | .99 | .02 | .05 | .08 | .11 | .14 | .17 | .20 | .23 | .27 | .30 | .33 | .36 | .39 |
| 19.0 | 1.98 | 2.01 | 2.04 | 2.07 | 2.10 | 2.13 | 2.17 | 2.20 | 2.23 | 2.26 | 2.29 | 2.32 | 2.35 | 2.38 | 2.41 |
| .2 | 2.00 | .03 | .06 | .09 | .13 | .16 | .19 | .22 | .25 | .28 | .31 | .34 | .38 | .41 | .44 |
| .4 | .02 | .05 | .08 | .12 | .15 | .18 | .21 | .24 | .27 | .31 | .34 | .37 | .40 | .43 | .46 |
| .6 | .04 | .07 | .11 | .14 | .17 | .20 | .23 | .27 | .30 | .33 | .36 | .39 | .43 | .46 | .49 |
| .8 | .06 | .10 | .13 | .16 | .19 | .22 | .26 | .29 | .32 | .35 | .39 | .42 | .45 | .48 | .51 |

**Table II.**—*Correction of mercurial barometers for temperature, metric measures*—Continued.

| Temperature, C. | Observed reading of the barometer, in millimeters. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 640 | 650 | 660 | 670 | 680 | 690 | 700 | 710 | 720 | 730 | 740 | 750 | 760 | 770 | 780 |
| 19.8 | 2.06 | 2.10 | 2.13 | 2.16 | 2.19 | 2.22 | 2.26 | 2.29 | 2.32 | 2.35 | 2.39 | 2.42 | 2.45 | 2.48 | 2.51 |
| 20.0 | 2.08 | 2.12 | 2.15 | 2.18 | 2.21 | 2.25 | 2.28 | 2.31 | 2.34 | 2.38 | 2.41 | 2.44 | 2.47 | 2.51 | 2.54 |
| .2 | .10 | .14 | .17 | .20 | .24 | .27 | .30 | .33 | .37 | .40 | .43 | .47 | .50 | .53 | .57 |
| .4 | .13 | .16 | .19 | .23 | .26 | .29 | .32 | .36 | .39 | .42 | .46 | .49 | .52 | .56 | .59 |
| .6 | .15 | .18 | .21 | .25 | .28 | .31 | .35 | .38 | .41 | .45 | .48 | .52 | .55 | .58 | .62 |
| .8 | .17 | .20 | .23 | .27 | .30 | .34 | .37 | .40 | .44 | .47 | .51 | .54 | .57 | .61 | .64 |
| 21.0 | 2.19 | 2.22 | 2.26 | 2.29 | 2.32 | 2.36 | 2.39 | 2.43 | 2.46 | 2.50 | 2.53 | 2.56 | 2.60 | 2.63 | 2.67 |
| .2 | .21 | .24 | .28 | .31 | .35 | .38 | .42 | .45 | .48 | .52 | .55 | .59 | .62 | .66 | .69 |
| .4 | .23 | .26 | .30 | .33 | .37 | .40 | .44 | .47 | .51 | .54 | .58 | .61 | .65 | .68 | .72 |
| .6 | .25 | .29 | .32 | .36 | .39 | .43 | .46 | .50 | .53 | .57 | .60 | .64 | .67 | .71 | .74 |
| .8 | .27 | .31 | .34 | .38 | .41 | .45 | .48 | .52 | .55 | .59 | .63 | .66 | .70 | .73 | .77 |
| 22.0 | 2.29 | 2.33 | 2.36 | 2.40 | 2.43 | 2.47 | 2.51 | 2.54 | 2.58 | 2.61 | 2.65 | 2.69 | 2.72 | 2.76 | 2.79 |
| .2 | .31 | .35 | .38 | .42 | .46 | .49 | .53 | .57 | .60 | .64 | .67 | .71 | .75 | .78 | .82 |
| .4 | .33 | .37 | .41 | .44 | .48 | .52 | .55 | .59 | .62 | .66 | .70 | .73 | .77 | .81 | .84 |
| .6 | .35 | .39 | .43 | .46 | .50 | .54 | .57 | .61 | .65 | .68 | .72 | .76 | .80 | .83 | .87 |
| .8 | .37 | .41 | .45 | .49 | .52 | .56 | .60 | .63 | .67 | .71 | .75 | .78 | .82 | .86 | .89 |
| 23.0 | 2.40 | 2.43 | 2.47 | 2.51 | 2.54 | 2.58 | 2.62 | 2.66 | 2.69 | 2.73 | 2.77 | 2.81 | 2.84 | 2.88 | 2.92 |
| .2 | .42 | .45 | .49 | .53 | .57 | .60 | .64 | .68 | .72 | .76 | .79 | .83 | .87 | .91 | .94 |
| .4 | .44 | .47 | .51 | .55 | .59 | .63 | .67 | .70 | .74 | .78 | .82 | .86 | .89 | .93 | .97 |
| .6 | .46 | .50 | .53 | .57 | .61 | .65 | .69 | .73 | .76 | .80 | .84 | .88 | .92 | .96 | 3.00 |
| .8 | .48 | .52 | .56 | .59 | .63 | .67 | .71 | .75 | .79 | .83 | .87 | .90 | .94 | .98 | .02 |
| 24.0 | 2.50 | 2.54 | 2.58 | 2.62 | 2.66 | 2.69 | 2.73 | 2.77 | 2.81 | 2.85 | 2.89 | 2.93 | 2.97 | 3.01 | 3.05 |
| .2 | .52 | .56 | .60 | .64 | .68 | .72 | .76 | .80 | .83 | .87 | .91 | .95 | .99 | .03 | .07 |
| .4 | .54 | .58 | .62 | .66 | .70 | .74 | .78 | .82 | .86 | .90 | .94 | .98 | 3.02 | .06 | .10 |
| .6 | .56 | .60 | .64 | .68 | .72 | .76 | .80 | .84 | .88 | .92 | .96 | 3.00 | .04 | .08 | .12 |
| .8 | .58 | .62 | .66 | .70 | .74 | .78 | .82 | .86 | .90 | .94 | .99 | .03 | .07 | .11 | .15 |
| 25.0 | 2.60 | 2.64 | 2.68 | 2.72 | 2.77 | 2.81 | 2.85 | 2.89 | 2.93 | 2.97 | 3.01 | 3.05 | 3.09 | 3.13 | 3.17 |
| .2 | .62 | .66 | .71 | .75 | .79 | .83 | .87 | .91 | .95 | .99 | .03 | .07 | .12 | .16 | .20 |
| .4 | .64 | .69 | .73 | .77 | .81 | .85 | .89 | .93 | .97 | 3.02 | .06 | .10 | .14 | .18 | .22 |
| .6 | .66 | .71 | .75 | .79 | .83 | .87 | .91 | .96 | 3.00 | .04 | .08 | .12 | .16 | .21 | .25 |
| .8 | .69 | .73 | .77 | .81 | .85 | .90 | .94 | .98 | .02 | .06 | .11 | .15 | .19 | .23 | .27 |
| 26.0 | 2.71 | 2.75 | 2.79 | 2.83 | 2.88 | 2.92 | 2.96 | 3.00 | 3.04 | 3.09 | 3.13 | 3.17 | 3.21 | 3.26 | 3.30 |
| .2 | .73 | .77 | .81 | .85 | .90 | .94 | .98 | .03 | .07 | .11 | .15 | .20 | .24 | .28 | .32 |
| .4 | .75 | .79 | .83 | .88 | .92 | .96 | 3.01 | .05 | .09 | .13 | .18 | .22 | .26 | .31 | .35 |
| .6 | .77 | .81 | .85 | .90 | .94 | .99 | .03 | .07 | .11 | .16 | .20 | .24 | .29 | .33 | .37 |
| .8 | .79 | .83 | .88 | .92 | .96 | 3.01 | .05 | .09 | .14 | .18 | .22 | .27 | .31 | .36 | .40 |
| 27.0 | 2.81 | 2.85 | 2.90 | 2.94 | 2.99 | 3.03 | 3.07 | 3.12 | 3.16 | 3.20 | 3.25 | 3.29 | 3.34 | 3.38 | 3.42 |
| .2 | .83 | .87 | .92 | .96 | 3.01 | .05 | .10 | .14 | .18 | .23 | .27 | .32 | .36 | .41 | .45 |
| .4 | .85 | .90 | .94 | .98 | .03 | .07 | .12 | .16 | .21 | .25 | .30 | .34 | .39 | .43 | .47 |
| .6 | .87 | .92 | .96 | 3.01 | .05 | .10 | .14 | .19 | .23 | .28 | .32 | .37 | .41 | .46 | .50 |
| .8 | .89 | .94 | .98 | .03 | .07 | .12 | .16 | .21 | .25 | .30 | .34 | .39 | .43 | .48 | .53 |
| 28.0 | 2.91 | 2.96 | 3.00 | 3.05 | 3.10 | 3.14 | 3.19 | 3.23 | 3.28 | 3.32 | 3.37 | 3.41 | 3.46 | 3.51 | 3.55 |
| .2 | .93 | .98 | .03 | .07 | .12 | .16 | .21 | .25 | .30 | .35 | .39 | .44 | .48 | .53 | .58 |
| .4 | .95 | 3.00 | .05 | .09 | .14 | .19 | .23 | .28 | .32 | .37 | .42 | .46 | .51 | .56 | .60 |
| .6 | .98 | .02 | .07 | .11 | .16 | .21 | .25 | .30 | .35 | .39 | .44 | .49 | .53 | .58 | .63 |
| .8 | 3.00 | .04 | .09 | .14 | .18 | .23 | .28 | .32 | .37 | .42 | .46 | .51 | .56 | .60 | .65 |
| 29.0 | 3.02 | 3.06 | 3.11 | 3.16 | 3.21 | 3.25 | 3.30 | 3.35 | 3.39 | 3.44 | 3.49 | 3.54 | 3.58 | 3.63 | 3.68 |
| .2 | .04 | .08 | .13 | .18 | .23 | .27 | .32 | .37 | .42 | .46 | .51 | .56 | .61 | .65 | .70 |
| .4 | .06 | .11 | .15 | .20 | .25 | .30 | .34 | .39 | .44 | .49 | .54 | .58 | .63 | .68 | .73 |
| .6 | .08 | .13 | .18 | .22 | .27 | .32 | .37 | .42 | .46 | .51 | .56 | .61 | .66 | .70 | .75 |
| .8 | .10 | .15 | .20 | .24 | .29 | .34 | .39 | .44 | .49 | .54 | .58 | .63 | .68 | .73 | .78 |
| 30.0 | 3.12 | 3.17 | 3.22 | 3.27 | 3.32 | 3.36 | 3.41 | 3.46 | 3.51 | 3.56 | 3.61 | 3.66 | 3.71 | 3.75 | 3.80 |
| .2 | .14 | .19 | .24 | .29 | .34 | .39 | .44 | .48 | .53 | .58 | .63 | .68 | .73 | .78 | .83 |
| .4 | .16 | .21 | .26 | .31 | .36 | .41 | .46 | .51 | .56 | .61 | .66 | .71 | .75 | .80 | .85 |
| .6 | .18 | .23 | .28 | .33 | .38 | .43 | .48 | .53 | .58 | .63 | .68 | .73 | .78 | .83 | .88 |
| .8 | .20 | .25 | .30 | .35 | .40 | .45 | .50 | .55 | .60 | .65 | .70 | .75 | .80 | .85 | .90 |
| 31.0 | 3.22 | 3.27 | 3.32 | 3.37 | 3.43 | 3.48 | 3.53 | 3.58 | 3.63 | 3.68 | 3.73 | 3.78 | 3.83 | 3.88 | 3.93 |
| 31.5 | .28 | .33 | .38 | .43 | .48 | .53 | .58 | .63 | .68 | .74 | .79 | .84 | .89 | .94 | .99 |
| 32.0 | .33 | .38 | .43 | .48 | .54 | .59 | .64 | .69 | .74 | .79 | .85 | .90 | .95 | 4.00 | 4.05 |
| 32.5 | .38 | .43 | .48 | .54 | .59 | .64 | .70 | .75 | .80 | .85 | .91 | .96 | 4.01 | .07 | .12 |
| 33.0 | .43 | .48 | .54 | .59 | .64 | .70 | .75 | .81 | .86 | .91 | .97 | 4.02 | .07 | .13 | .18 |
| 33.5 | 3.48 | 3.54 | 3.59 | 3.65 | 3.70 | 3.75 | 3.81 | 3.86 | 3.92 | 3.97 | 4.03 | 4.08 | 4.13 | 4.19 | 4.24 |
| 34.0 | .53 | .59 | .64 | .70 | .75 | .81 | .87 | .92 | .98 | 4.03 | .09 | .14 | .20 | .25 | .31 |
| 34.5 | .59 | .64 | .70 | .75 | .81 | .87 | .92 | .98 | 4.03 | .09 | .15 | .20 | .26 | .31 | .37 |
| 35.0 | .64 | .69 | .75 | .81 | .86 | .92 | .98 | 4.03 | .09 | .15 | .21 | .26 | .32 | .38 | .43 |
| 35.5 | .69 | .75 | .80 | .86 | .92 | .98 | 4.03 | .09 | .15 | .21 | .26 | .32 | .38 | .44 | .50 |

TABLE III.—*Influence of gravity on barometric observations, English units.*

[Abridged from International Tables.]

REDUCTION TO LATITUDE 45°.

For latitudes............{above 45° / below 45°} the values are to be........{added. / subtracted.

| Latitude. | | Reading of the barometer, in inches. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| ° | ° | | | | | | | | | | | | | |
| 0 | 90 | 0.047 | 0.049 | 0.052 | 0.054 | .057 | 0.060 | 0.062 | 0.065 | 0.067 | 0.070 | 0.073 | 0.075 | 0.078 |
| 5 | 85 | .046 | .048 | .051 | .054 | .056 | .059 | .061 | .064 | .066 | .069 | .071 | .074 | .077 |
| 6 | 84 | .046 | .048 | .051 | .053 | .056 | .058 | .061 | .063 | .066 | .068 | .071 | .073 | .076 |
| 7 | 83 | .045 | .048 | .050 | .053 | .055 | .058 | .060 | .063 | .065 | .068 | .070 | .073 | .075 |
| 8 | 82 | .045 | .047 | .050 | .052 | .055 | .057 | .060 | .062 | .065 | .067 | .070 | .072 | .075 |
| 9 | 81 | .044 | .047 | .049 | .052 | .054 | .057 | .059 | .062 | .064 | .067 | .069 | .071 | .074 |
| 10 | 80 | .044 | .046 | .049 | .051 | .054 | .056 | .058 | .061 | .063 | .066 | .068 | .071 | .073 |
| 11 | 79 | .043 | .046 | .048 | .050 | .053 | .055 | .058 | .060 | .062 | .065 | .067 | .070 | .072 |
| 12 | 78 | .043 | .045 | .047 | .050 | .052 | .054 | .057 | .059 | .062 | .064 | .066 | .069 | .071 |
| 13 | 77 | .042 | .044 | .047 | .049 | .051 | .054 | .056 | .058 | .061 | .063 | .065 | .068 | .070 |
| 14 | 76 | .041 | .043 | .046 | .048 | .050 | .053 | .055 | .057 | .059 | .062 | .064 | .066 | .069 |
| 15 | 75 | .040 | .043 | .045 | .047 | .049 | .052 | .054 | .056 | .058 | .061 | .063 | .065 | .067 |
| 16 | 74 | .040 | .042 | .044 | .046 | .048 | .051 | .053 | .055 | .057 | .059 | .061 | .064 | .066 |
| 17 | 73 | .039 | .041 | .043 | .045 | .047 | .049 | .052 | .054 | .056 | .058 | .060 | .062 | .064 |
| 18 | 72 | .038 | .040 | .042 | .044 | .046 | .048 | .050 | .052 | .054 | .057 | .059 | .061 | .063 |
| 19 | 71 | .037 | .039 | .041 | .043 | .045 | .047 | .049 | .051 | .053 | .055 | .057 | .059 | .061 |
| 20 | 70 | .036 | .038 | .040 | .042 | .044 | .046 | .048 | .050 | .052 | .054 | .056 | .058 | .060 |
| 21 | 69 | .035 | .037 | .038 | .040 | .042 | .044 | .046 | .048 | .050 | .052 | .054 | .056 | .058 |
| 22 | 68 | .034 | .035 | .037 | .039 | .041 | .043 | .045 | .047 | .048 | .050 | .052 | .054 | .056 |
| 23 | 67 | .032 | .034 | .036 | .038 | .040 | 041 | 043 | 045 | .047 | .049 | .050 | .052 | .054 |
| 24 | 66 | .031 | .033 | .035 | .036 | .038 | .040 | .042 | .043 | .045 | .047 | .049 | .050 | .052 |
| 25 | 65 | .030 | .032 | .033 | .035 | .037 | .038 | .040 | .042 | .043 | .045 | .047 | .048 | .050 |
| 26 | 64 | .029 | .030 | .032 | .033 | .035 | .037 | .038 | .040 | .041 | .043 | .045 | .046 | .048 |
| 27 | 63 | .027 | .029 | .030 | .032 | .033 | .035 | .037 | .038 | .040 | .041 | .043 | .044 | .046 |
| 28 | 62 | .026 | .028 | .029 | .030 | .032 | .033 | .035 | .036 | .038 | .039 | .041 | .042 | .043 |
| 29 | 61 | .025 | .026 | .027 | .029 | .030 | .032 | .033 | .034 | .036 | .037 | .038 | .040 | .041 |
| 30 | 60 | .023 | .025 | .026 | .027 | .028 | .030 | .031 | .032 | .034 | .035 | .036 | .038 | .039 |
| 31 | 59 | .022 | .023 | .024 | .026 | .027 | .028 | .029 | .030 | .032 | .033 | .034 | .035 | .036 |
| 32 | 58 | .020 | .022 | .023 | .024 | .025 | .026 | .027 | .028 | .030 | .031 | .032 | .033 | .034 |
| 33 | 57 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 | .028 | .029 | .031 | .032 |
| 34 | 56 | .017 | .018 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 | .028 | .029 |
| 35 | 55 | .016 | .017 | .018 | .019 | .019 | .020 | .021 | .022 | .023 | .024 | .025 | .026 | .027 |
| 36 | 54 | .014 | .015 | .016 | .017 | .018 | .018 | .019 | .020 | .021 | .022 | .022 | .023 | .024 |
| 37 | 53 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .018 | .019 | .019 | .020 | .021 | .021 |
| 38 | 52 | .011 | .012 | .013 | .013 | .014 | .014 | .015 | .016 | .016 | .017 | .018 | .018 | .019 |
| 39 | 51 | .010 | .010 | .011 | .011 | .012 | .012 | .013 | .013 | .014 | .015 | .015 | .016 | .016 |
| 40 | 50 | .008 | .009 | .009 | .009 | .010 | .010 | .011 | .011 | .012 | .012 | .013 | .013 | .013 |
| 41 | 49 | .006 | .007 | .007 | .008 | .008 | .008 | .009 | .009 | .009 | .010 | .010 | .010 | .011 |
| 42 | 48 | .005 | .005 | .005 | .006 | .006 | .006 | .006 | .007 | .007 | .007 | .008 | .008 | .008 |
| 43 | 47 | .003 | .003 | .004 | .004 | .004 | .004 | .004 | .005 | .005 | .005 | .005 | .005 | .005 |
| 44 | 46 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .003 | .003 | .003 |
| 45 | 45 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |

126453—19——7

TABLE IV.—*Influence of gravity on barometric observations, English units.*

[From International Tables.]

REDUCTION FOR ALTITUDE.

To be subtracted.

| Height in feet. | Reading of the barometer, in inches. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 500 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .001 | .001 | .001 | .001 | .001 |
| 1,000 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .002 | .002 | .002 | .002 | .002 |
| 1,500 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 0.002 | .002 | .003 | .003 | .003 | ...... |
| 2,000 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .003 | .003 | .003 | .003 | .004 | ...... |
| 2,500 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 0.004 | .004 | .004 | .004 | .004 | ...... | ...... |
| 3,000 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .004 | .005 | .005 | .005 | .005 | ...... | ...... |
| 3,500 | ...... | ...... | ...... | ...... | ...... | ...... | 0.005 | .005 | .005 | .006 | .006 | ...... | ...... | ...... |
| 4,000 | ...... | ...... | ...... | ...... | ...... | ...... | .006 | .006 | .006 | .006 | .007 | ...... | ...... | ...... |
| 4,500 | ...... | ...... | ...... | ...... | ...... | 0.006 | .006 | .007 | .007 | .007 | ...... | ...... | ...... | ...... |
| 5,000 | ...... | ...... | ...... | ...... | ...... | .007 | .007 | .007 | .008 | .008 | ...... | ...... | ...... | ...... |
| 5,500 | ...... | ...... | ...... | ...... | 0.007 | .008 | .008 | .008 | .009 | ...... | ...... | ...... | ...... | ...... |
| 6,000 | ...... | ...... | ...... | ...... | .008 | .008 | .009 | .009 | .009 | ...... | ...... | ...... | ...... | ...... |
| 6,500 | ...... | ...... | ...... | 0.008 | .009 | .009 | .009 | .010 | ...... | ...... | ...... | ...... | ...... | ...... |
| 7,000 | ...... | ...... | ...... | .009 | .009 | .010 | .010 | .010 | ...... | ...... | ...... | ...... | ...... | ...... |
| 7,500 | ...... | ...... | 0.009 | .009 | .010 | .010 | .011 | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 8,000 | ...... | ...... | .010 | .010 | .011 | .011 | .011 | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 8,500 | ...... | 0.010 | .010 | .011 | .011 | .012 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 9,000 | ...... | .010 | .011 | .011 | .012 | .012 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 9,500 | 0.010 | .011 | .011 | .012 | .012 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 10,000 | .011 | .011 | .012 | .013 | .013 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

TABLE V.—*Pressure, in inches, corresponding to changes of 100 feet in elevation.*

[BIGELOW.]

| Height, in feet. | Temperature, Fahrenheit. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | −20 | −10 | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 0 | 0.128 | 0.125 | 0.122 | 0.119 | 0.117 | 0.114 | 0.112 | 0.110 | 0.108 | 0.106 | 0.104 | 0.102 |
| 500 | .125 | .122 | .120 | .117 | .115 | .112 | .110 | .108 | .106 | .104 | .102 | .100 |
| 1,000 | .122 | .120 | .118 | .115 | .113 | .110 | .108 | .106 | .104 | .102 | .100 | .098 |
| 1,500 | .120 | .117 | .115 | .112 | .110 | .108 | .106 | .104 | .102 | .100 | .098 | .096 |
| 2,000 | .118 | .115 | .113 | .110 | .108 | .106 | .104 | .102 | .100 | .098 | .096 | .094 |
| 2,500 | .115 | .112 | .110 | .108 | .106 | .104 | .102 | .100 | .098 | .096 | .094 | .092 |
| 3,000 | .113 | .110 | .108 | .106 | .104 | .102 | .100 | .098 | .096 | .094 | .092 | .090 |
| 3,500 | .111 | .108 | .106 | .104 | .102 | .100 | .098 | .096 | .094 | .092 | .090 | .088 |
| 4,000 | .108 | .106 | .104 | .102 | .100 | .098 | .096 | .094 | .092 | .090 | .088 | .086 |
| 4,500 | .106 | .104 | .102 | .100 | .098 | .096 | .094 | .092 | .090 | .088 | .086 | .084 |
| 5,000 | .104 | .102 | .100 | .098 | .096 | .094 | .092 | .090 | .088 | .086 | .084 | .082 |
| 5,500 | .102 | .100 | .098 | .096 | .094 | .092 | .090 | .088 | .086 | .084 | .082 | .081 |
| 6,000 | .100 | .098 | .096 | .094 | .092 | .090 | .088 | .086 | .084 | .082 | .081 | .080 |
| 6,500 | .098 | .096 | .094 | .092 | .090 | .088 | .086 | .085 | .083 | .081 | .080 | .079 |
| 7,000 | .097 | .095 | .093 | .091 | .089 | .087 | .085 | .084 | .082 | .080 | .079 | .078 |

**Table VI.**—*Determination of heights by the barometer, English measures.*

[Abridged from the Smithsonian Tables.]

Values of 60368 $[1+0.0010195\times 36] \log. \frac{29.90}{B.}$

| Barometric pressure, B. | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 17.00 | 15,347 | 15,331 | 15,315 | 15,299 | 15,283 | 15,267 | 15,251 | 15,235 | 15,219 | 15,203 |
| .10 | 15,187 | 15,172 | 15,156 | 15,140 | 15,124 | 15,108 | 15,092 | 15,076 | 15,061 | 15,045 |
| .20 | 15,029 | 15,013 | 14,997 | 14,982 | 14,966 | 14,950 | 14,934 | 14,919 | 14,903 | 14,887 |
| .30 | 14,871 | 14,856 | 14,840 | 14,824 | 14,809 | 14,793 | 14,777 | 14,762 | 14,746 | 14,730 |
| .40 | 14,715 | 14,699 | 14,684 | 14,668 | 14,652 | 14,637 | 14,621 | 14,606 | 14,590 | 14,575 |
| 17.50 | 14,559 | 14,544 | 14,528 | 14,512 | 14,497 | 14,481 | 14,466 | 14,451 | 14,435 | 14,420 |
| .60 | 14,404 | 14,389 | 14,373 | 14,358 | 14,342 | 14,327 | 14,312 | 14,296 | 14,281 | 14,266 |
| .70 | 14,250 | 14,235 | 14,219 | 14,204 | 14,189 | 14,173 | 14,158 | 14,143 | 14,128 | 14,112 |
| .80 | 14,097 | 14,082 | 14,067 | 14,051 | 14,036 | 14,021 | 14,006 | 13,990 | 13,975 | 13,960 |
| .90 | 13,945 | 13,930 | 13,914 | 13,899 | 13,884 | 13,869 | 13,854 | 13,839 | 13,824 | 13,808 |
| 18.00 | 13,793 | 13,778 | 13,763 | 13,748 | 13,733 | 13,718 | 13,703 | 13,688 | 13,673 | 13,658 |
| .10 | 13,643 | 13,628 | 13,613 | 13,598 | 13,583 | 13,568 | 13,553 | 13,538 | 13,523 | 13,508 |
| .20 | 13,493 | 13,478 | 13,463 | 13,448 | 13,433 | 13,418 | 13,404 | 13,389 | 13,374 | 13,359 |
| .30 | 13,344 | 13,329 | 13,314 | 13,300 | 13,285 | 13,270 | 13,255 | 13,240 | 13,226 | 13,211 |
| .40 | 13,196 | 13,181 | 13,166 | 13,152 | 13,137 | 13,122 | 13,107 | 13,093 | 13,078 | 13,063 |
| 18.50 | 13,049 | 13,034 | 13,019 | 13,005 | 12,990 | 12,975 | 12,961 | 12,946 | 12,931 | 12,917 |
| .60 | 12,902 | 12,888 | 12,873 | 12,858 | 12,844 | 12,829 | 12,815 | 12,800 | 12,785 | 12,771 |
| .70 | 12,756 | 12,742 | 12,727 | 12,713 | 12,698 | 12,684 | 12,669 | 12,655 | 12,640 | 12,626 |
| .80 | 12,611 | 12,597 | 12,583 | 12,568 | 12,554 | 12,539 | 12,525 | 12,510 | 12,496 | 12,482 |
| .90 | 12,467 | 12,453 | 12,438 | 12,424 | 12,410 | 12,395 | 12,381 | 12,367 | 12,352 | 12,338 |
| 19.00 | 12,324 | 12,310 | 12,295 | 12,281 | 12,267 | 12,252 | 12,238 | 12,224 | 12,210 | 12,195 |
| .10 | 12,181 | 12,167 | 12,153 | 12,138 | 12,124 | 12,110 | 12,096 | 12,082 | 12,068 | 12,053 |
| .20 | 12,039 | 12,025 | 12,011 | 11,997 | 11,983 | 11,969 | 11,954 | 11,940 | 11,926 | 11,912 |
| .30 | 11,898 | 11,884 | 11,870 | 11,856 | 11,842 | 11,828 | 11,814 | 11,800 | 11,786 | 11,772 |
| .40 | 11,758 | 11,744 | 11,730 | 11,716 | 11,702 | 11,688 | 11,674 | 11,660 | 11,646 | 11,632 |
| 19.50 | 11,618 | 11,604 | 11,590 | 11,576 | 11,562 | 11,548 | 11,534 | 11,520 | 11,507 | 11,493 |
| .60 | 11,479 | 11,465 | 11,451 | 11,437 | 11,423 | 11,410 | 11,396 | 11,382 | 11,368 | 11,354 |
| .70 | 11,340 | 11,327 | 11,313 | 11,299 | 11,285 | 11,272 | 11,258 | 11,244 | 11,230 | 11,217 |
| .80 | 11,203 | 11,189 | 11,175 | 11,162 | 11,148 | 11,134 | 11,121 | 11,107 | 11,093 | 11,080 |
| .90 | 11,066 | 11,052 | 11,039 | 11,025 | 11,011 | 10,998 | 10,984 | 10,970 | 10,957 | 10,943 |
| 20.00 | 10,930 | 10,916 | 10,903 | 10,889 | 10,875 | 10,862 | 10,848 | 10,835 | 10,821 | 10,808 |
| .10 | 10,794 | 10,781 | 10,767 | 10,754 | 10,740 | 10,727 | 10,713 | 10,700 | 10,686 | 10,673 |
| .20 | 10,659 | 10,646 | 10,632 | 10,619 | 10,605 | 10,592 | 10,579 | 10,565 | 10,552 | 10,538 |
| .30 | 10,525 | 10,512 | 10,498 | 10,485 | 10,472 | 10,458 | 10,445 | 10,431 | 10,418 | 10,405 |
| .40 | 10,391 | 10,378 | 10,365 | 10,352 | 10,338 | 10,325 | 10,312 | 10,298 | 10,285 | 10,272 |
| 20.50 | 10,259 | 10,245 | 10,232 | 10,219 | 10,206 | 10,192 | 10,179 | 10,166 | 10,153 | 10,139 |
| .60 | 10,126 | 10,113 | 10,100 | 10,087 | 10,074 | 10,060 | 10,047 | 10,034 | 10,021 | 10,008 |
| .70 | 9,995 | 9,982 | 9,968 | 9,955 | 9,942 | 9,929 | 9,916 | 9,903 | 9,890 | 9,877 |
| .80 | 9,864 | 9,851 | 9,838 | 9,825 | 9,812 | 9,799 | 9,786 | 9,772 | 9,759 | 9,746 |
| .90 | 9,733 | 9,720 | 9,707 | 9,694 | 9,681 | 9,668 | 9,655 | 9,642 | 9,629 | 9,617 |
| 21.00 | 9,604 | 9,591 | 9,578 | 9,565 | 9,552 | 9,539 | 9,526 | 9,513 | 9,500 | 9,487 |
| .10 | 9,474 | 9,462 | 9,449 | 9,436 | 9,423 | 9,410 | 9,397 | 9,384 | 9,372 | 9,359 |
| .20 | 9,346 | 9,333 | 9,320 | 9,307 | 9,295 | 9,282 | 9,269 | 9,256 | 9,244 | 9,231 |
| .30 | 9,218 | 9,205 | 9,193 | 9,180 | 9,167 | 9,154 | 9,142 | 9,129 | 9,116 | 9,103 |
| .40 | 9,091 | 9,078 | 9,065 | 9,053 | 9,040 | 9,027 | 9,015 | 9,002 | 8,989 | 8,977 |
| 21.50 | 8,964 | 8,951 | 8,939 | 8,926 | 8,913 | 8,901 | 8,888 | 8,876 | 8,863 | 8,850 |
| .60 | 8,838 | 8,825 | 8,813 | 8,800 | 8,788 | 8,775 | 8,762 | 8,750 | 8,737 | 8,725 |
| .70 | 8,712 | 8,700 | 8,687 | 8,675 | 8,662 | 8,650 | 8,637 | 8,625 | 8,612 | 8,600 |
| .80 | 8,587 | 8,575 | 8,562 | 8,550 | 8,538 | 8,525 | 8,513 | 8,500 | 8,488 | 8,475 |
| .90 | 8,463 | 8,451 | 8,438 | 8,426 | 8,413 | 8,401 | 8,389 | 8,376 | 8,364 | 8,352 |
| 22.00 | 8,339 | 8,327 | 8,314 | 8,302 | 8,290 | 8,277 | 8,265 | 8,253 | 8,240 | 8,228 |
| .10 | 8,216 | 8,204 | 8,191 | 8,179 | 8,167 | 8,154 | 8,142 | 8,130 | 8,118 | 8,105 |
| .20 | 8,093 | 8,081 | 8,069 | 8,056 | 8,044 | 8,032 | 8,020 | 8,008 | 7,995 | 7,983 |
| .30 | 7,971 | 7,959 | 7,947 | 7,935 | 7,922 | 7,910 | 7,898 | 7,886 | 7,874 | 7,862 |
| .40 | 7,849 | 7,837 | 7,825 | 7,813 | 7,801 | 7,789 | 7,777 | 7,765 | 7,753 | 7,740 |
| 22.50 | 7,728 | 7,716 | 7,704 | 7,692 | 7,680 | 7,668 | 7,656 | 7,644 | 7,632 | 7,620 |
| .60 | 7,608 | 7,596 | 7,584 | 7,572 | 7,560 | 7,548 | 7,536 | 7,524 | 7,512 | 7,500 |
| .70 | 7,488 | 7,476 | 7,464 | 5,452 | 7,440 | 7,428 | 7,416 | 7,404 | 7,392 | 7,380 |
| .80 | 7,368 | 7,356 | 7,345 | 7,333 | 7,321 | 7,309 | 7,297 | 7,285 | 7,273 | 7,261 |
| .90 | 7,249 | 7,238 | 7,226 | 7,214 | 7,202 | 7,190 | 7,178 | 7,166 | 7,155 | 7,143 |

TABLE VI.—*Determination of heights by the barometer, English measures*—Cont.

| Barometric pressure, B. | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet* |
| 23.00 | 7,131 | 7,119 | 7,107 | 7,096 | 7,084 | 7,072 | 7,060 | 7,048 | 7,037 | 7,025 |
| .10 | 7,013 | 7,001 | 6,990 | 6,978 | 6,966 | 6,954 | 6,943 | 6,931 | 6,919 | 6,907 |
| .20 | 6,896 | 6,884 | 6,872 | 6,861 | 6,849 | 6,837 | 6,825 | 6,814 | 6,802 | 6,790 |
| .30 | 6,779 | 6,767 | 6,755 | 6,744 | 6,732 | 6,721 | 6,709 | 6,697 | 6,686 | 6,674 |
| .40 | 6,662 | 6,651 | 6,639 | 6,628 | 6,616 | 6,604 | 6,593 | 6,581 | 6,570 | 6,558 |
| 23.50 | 6,546 | 6,535 | 6,523 | 6,512 | 6,500 | 6,489 | 6,477 | 6,466 | 6,454 | 6,443 |
| .60 | 6,431 | 6,420 | 6,408 | 6,397 | 6,385 | 6,374 | 6,362 | 6,351 | 6,339 | 6,328 |
| .70 | 6,316 | 6,305 | 6,293 | 6,282 | 6,270 | 6,259 | 6,247 | 6,236 | 6,225 | 6,213 |
| .80 | 6,202 | 6,190 | 6,179 | 6,167 | 6,156 | 6,145 | 6,133 | 6,122 | 6,110 | 6,099 |
| .90 | 6,088 | 6,076 | 6,065 | 6,054 | 6,042 | 6,031 | 6,020 | 6,008 | 5,997 | 5,986 |
| 24.00 | 5,974 | 5,963 | 5,952 | 5,940 | 5,929 | 5,918 | 5,906 | 5,895 | 5,884 | 5,872 |
| .10 | 5,861 | 5,850 | 5,839 | 5,827 | 5,816 | 5,805 | 5,794 | 5,782 | 5,771 | 5,760 |
| .20 | 5,749 | 5,737 | 5,726 | 5,715 | 5,704 | 5,693 | 5,681 | 5,670 | 5,659 | 5,648 |
| .30 | 5,637 | 5,625 | 5,614 | 5,603 | 5,593 | 5,581 | 5,570 | 5,558 | 5,547 | 5,536 |
| .40 | 5,525 | 5,514 | 5,503 | 5,492 | 5,480 | 5,469 | 5,458 | 5,447 | 5,436 | 5,425 |
| 24.50 | 5,414 | 5,403 | 5,392 | 5,381 | 5,369 | 5,358 | 5,347 | 5,336 | 5,325 | 5,314 |
| .60 | 5,303 | 5,292 | 5,281 | 5,270 | 5,259 | 5,248 | 5,237 | 5,226 | 5,215 | 5,204 |
| .70 | 5,193 | 5,182 | 5,171 | 5,160 | 5,149 | 5,138 | 5,127 | 5,116 | 5,105 | 5,094 |
| .80 | 5,083 | 5,072 | 5,061 | 5,050 | 5,039 | 5,028 | 5,017 | 5,006 | 4,995 | 4,985 |
| .90 | 4,974 | 4,963 | 4,952 | 4,941 | 4,930 | 4,919 | 4,908 | 4,897 | 4,886 | 4,876 |
| 25.00 | 4,865 | 4,854 | 4,843 | 4,832 | 4,821 | 4,810 | 4,800 | 4,789 | 4,778 | 4,767 |
| .10 | 4,756 | 4,745 | 4,735 | 4,724 | 4,713 | 4,702 | 4,691 | 4,681 | 4,670 | 4,659 |
| .20 | 4,648 | 4,637 | 4,627 | 4,616 | 4,605 | 4,594 | 4,584 | 4,573 | 4,562 | 4,551 |
| .30 | 4,540 | 4,530 | 4,519 | 4,508 | 4,498 | 4,487 | 4,476 | 4,465 | 4,455 | 4,444 |
| .40 | 4,433 | 4,423 | 4,412 | 4,401 | 4,391 | 4,380 | 4,369 | 4,358 | 4,348 | 4,337 |
| 25.50 | 4,326 | 4,316 | 4,305 | 4,295 | 4,284 | 4,273 | 4,263 | 4,252 | 4,241 | 4,231 |
| .60 | 4,220 | 4,209 | 4,199 | 4,188 | 4,178 | 4,167 | 4,156 | 4,146 | 4,135 | 4,125 |
| .70 | 4,114 | 4,104 | 4,093 | 4,082 | 4,072 | 4,061 | 4,051 | 4,040 | 4,030 | 4,019 |
| .80 | 4,009 | 3,998 | 3,988 | 3,977 | 3,966 | 3,956 | 3,945 | 3,935 | 3,924 | 3,914 |
| .90 | 3,903 | 3,893 | 3,882 | 3,872 | 3,861 | 3,851 | 3,841 | 3,830 | 3,820 | 3,809 |
| 26.00 | 3,799 | 3,788 | 3,778 | 3,767 | 3,757 | 3,746 | 3,736 | 3,726 | 3,715 | 3,705 |
| .10 | 3,694 | 3,684 | 3,674 | 3,663 | 3,653 | 3,642 | 3,632 | 3,622 | 3,611 | 3,601 |
| .20 | 3,590 | 3,580 | 3,570 | 3,559 | 3,549 | 3,539 | 3,528 | 3,518 | 3,508 | 3,497 |
| .30 | 3,487 | 3,477 | 3,466 | 3,456 | 3,446 | 3,435 | 3,425 | 3,415 | 3,404 | 3,394 |
| .40 | 3,384 | 3,373 | 3,363 | 3,353 | 3,343 | 3,332 | 3,322 | 3,312 | 3,301 | 3,291 |
| 26.50 | 3,281 | 3,270 | 3,260 | 3,250 | 3,240 | 3,230 | 3,219 | 3,209 | 3,199 | 3,189 |
| .60 | 3,179 | 3,168 | 3,158 | 3,148 | 3,138 | 3,128 | 3,117 | 3,107 | 3,097 | 3,087 |
| .70 | 3,077 | 3,066 | 3,056 | 3,046 | 3,036 | 3,026 | 3,016 | 3,005 | 2,995 | 2,985 |
| .80 | 2,975 | 2,965 | 2,955 | 2,945 | 2,934 | 2,924 | 2,914 | 2,904 | 2,894 | 2,884 |
| .90 | 2,874 | 2,864 | 2,854 | 2,843 | 2,833 | 2,823 | 2,813 | 2,803 | 2,793 | 2,783 |
| 27.00 | 2,773 | 2,763 | 2,753 | 2,743 | 2,733 | 2,723 | 2,713 | 2,703 | 2,692 | 2,682 |
| .10 | 2,672 | 2,662 | 2,652 | 2,642 | 2,632 | 2,622 | 2,612 | 2,602 | 2,592 | 2,582 |
| .20 | 2,572 | 2,562 | 2,552 | 2,542 | 2,532 | 2,522 | 2,512 | 2,502 | 2,493 | 2,483 |
| .30 | 2,473 | 2,463 | 2,453 | 2,443 | 2,433 | 2,423 | 2,413 | 2,403 | 2,393 | 2,383 |
| .40 | 2,373 | 2,363 | 2,353 | 2,343 | 2,334 | 2,324 | 2,314 | 2,304 | 2,294 | 2,284 |
| 27.50 | 2,274 | 2,264 | 2,254 | 2,245 | 2,235 | 2,225 | 2,215 | 2,205 | 2,195 | 2,185 |
| .60 | 2,176 | 2,166 | 2,156 | 2,146 | 2,136 | 2,126 | 2,116 | 2,107 | 2,097 | 2,087 |
| .70 | 2,077 | 2,067 | 2,058 | 2,048 | 2,038 | 2,028 | 2,018 | 2,009 | 1,999 | 1,989 |
| .80 | 1,979 | 1,970 | 1,960 | 1,950 | 1,940 | 1,930 | 1,921 | 1,911 | 1,901 | 1,891 |
| .90 | 1,882 | 1,872 | 1,862 | 1,852 | 1,843 | 1,833 | 1,823 | 1,814 | 1,804 | 1,794 |
| 28.00 | 1,784 | 1,775 | 1,765 | 1,755 | 1,746 | 1,736 | 1,726 | 1,717 | 1,707 | 1,697 |
| .10 | 1,688 | 1,678 | 1,668 | 1,659 | 1,649 | 1,639 | 1,630 | 1,620 | 1,610 | 1,601 |
| .20 | 1,591 | 1,581 | 1,572 | 1,562 | 1,552 | 1,543 | 1,533 | 1,524 | 1,514 | 1,504 |
| .30 | 1,495 | 1,485 | 1,476 | 1,466 | 1,456 | 1,447 | 1,437 | 1,428 | 1,418 | 1,408 |
| .40 | 1,399 | 1,389 | 1,380 | 1,370 | 1,361 | 1,351 | 1,342 | 1,332 | 1,322 | 1,313 |
| 28.50 | 1,303 | 1,294 | 1,284 | 1,275 | 1,265 | 1,256 | 1,246 | 1,237 | 1,227 | 1,218 |
| .60 | 1,208 | 1,199 | 1,189 | 1,180 | 1,170 | 1,161 | 1,151 | 1,142 | 1,132 | 1,123 |
| .70 | 1,113 | 1,104 | 1,094 | 1,085 | 1,075 | 1,066 | 1,057 | 1,047 | 1,038 | 1,028 |
| .80 | 1,019 | 1,009 | 1,000 | 990 | 981 | 972 | 962 | 953 | 943 | 934 |
| .90 | 925 | 915 | 906 | 896 | 887 | 878 | 868 | 859 | 849 | 840 |
| 29.00 | 831 | 821 | 812 | 803 | 794 | 784 | 775 | 765 | 756 | 746 |
| .10 | 737 | 728 | 718 | 709 | 700 | 690 | 681 | 672 | 663 | 653 |
| .20 | 644 | 635 | 625 | 616 | 607 | 597 | 588 | 579 | 570 | 560 |
| .30 | 551 | 542 | 532 | 523 | 514 | 505 | 495 | 486 | 477 | 468 |
| .40 | 458 | 449 | 440 | 431 | 421 | 412 | 403 | 394 | 384 | 375 |

Table VI.—*Determination of heights by the barometer, English measures*—Cont.

| Barometric pressur, B. | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Inches.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *eet.* | *Feet.* | *Feet.* |
| 29.50 | 366 | 357 | 348 | 338 | 329 | 320 | 311 | 302 | 292 | 283 |
| .60 | 274 | 265 | 256 | 247 | 237 | 228 | 219 | 210 | 201 | 192 |
| .70 | 182 | 173 | 164 | 155 | 146 | 137 | 128 | 118 | 109 | 100 |
| .80 | + 91 | + 82 | + 73 | + 64 | + 55 | + 45 | + 36 | + 27 | + 18 | + 9 |
| .90 | 0 | − 9 | − 18 | − 27 | − 36 | − 45 | − 55 | − 64 | − 73 | − 82 |
| 30.00 | − 91 | −100 | −109 | −118 | −127 | −136 | −145 | −154 | −163 | −172 |
| .10 | −181 | −190 | −199 | −208 | −217 | −226 | −235 | −244 | −253 | −262 |
| .20 | −271 | −280 | −289 | −298 | −307 | −316 | −325 | −334 | −343 | −352 |
| .30 | −361 | −370 | −379 | −388 | −397 | −406 | −415 | −424 | −433 | −442 |
| .40 | −451 | −460 | −469 | −478 | −486 | −495 | −504 | −513 | −522 | −531 |
| 30.50 | −540 | −549 | −558 | −567 | −576 | −585 | −593 | −602 | −611 | −620 |
| .60 | −629 | −638 | −647 | −656 | −665 | −673 | −682 | −691 | −700 | −709 |
| .70 | −718 | −727 | −735 | −744 | −753 | −762 | −771 | −780 | −788 | −797 |
| .80 | −806 | −815 | −824 | −833 | −841 | −850 | −859 | −868 | −877 | −885 |

**TABLE VII.**—*Determination of heights by the barometer, English measures.*

[Abridged from the Smithsonian Tables.]

Term for temperature: 0.002039 (T−50°) z.

For temperatures {above 50° F. / below 50° F.} the values are to be {added. / subtracted.

| Mean temperature T. | | Approximate elevations obtained from Table VI. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 |
| °*F.* | °*F.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 49 | 51 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| 48 | 52 | 4 | 8 | 12 | 16 | 20 | 24 | 29 | 33 | 37 | 41 |
| 47 | 53 | 6 | 12 | 18 | 24 | 31 | 37 | 43 | 49 | 55 | 61 |
| 46 | 54 | 8 | 16 | 24 | 33 | 41 | 49 | 57 | 65 | 73 | 82 |
| 45 | 55 | 10 | 20 | 31 | 41 | 51 | 61 | 71 | 82 | 92 | 102 |
| 44 | 56 | 12 | 24 | 37 | 49 | 61 | 73 | 86 | 98 | 110 | 122 |
| 43 | 57 | 14 | 29 | 43 | 57 | 71 | 86 | 100 | 114 | 128 | 143 |
| 42 | 58 | 16 | 33 | 49 | 65 | 82 | 98 | 114 | 130 | 147 | 163 |
| 41 | 59 | 18 | 37 | 55 | 73 | 92 | 110 | 128 | 147 | 165 | 184 |
| 40 | 60 | 20 | 41 | 61 | 82 | 102 | 122 | 143 | 163 | 184 | 204 |
| 39 | 61 | 22 | 45 | 67 | 90 | 112 | 135 | 157 | 179 | 202 | 224 |
| 38 | 62 | 24 | 49 | 73 | 98 | 122 | 147 | 171 | 196 | 220 | 245 |
| 37 | 63 | 27 | 53 | 80 | 106 | 133 | 159 | 186 | 212 | 239 | 265 |
| 36 | 64 | 29 | 57 | 86 | 114 | 143 | 171 | 200 | 228 | 257 | 285 |
| 35 | 65 | 31 | 61 | 92 | 122 | 153 | 184 | 214 | 245 | 275 | 306 |
| 34 | 66 | 33 | 65 | 98 | 130 | 163 | 196 | 228 | 261 | 294 | 326 |
| 33 | 67 | 35 | 69 | 104 | 139 | 173 | 208 | 243 | 277 | 312 | 347 |
| 32 | 68 | 37 | 73 | 110 | 147 | 184 | 220 | 257 | 294 | 330 | 367 |
| 31 | 69 | 39 | 77 | 116 | 155 | 194 | 232 | 271 | 310 | 349 | 387 |
| 30 | 70 | 41 | 82 | 122 | 163 | 204 | 245 | 285 | 326 | 367 | 408 |
| 29 | 71 | 43 | 86 | 128 | 171 | 214 | 257 | 300 | 343 | 385 | 428 |
| 28 | 72 | 45 | 90 | 135 | 179 | 224 | 269 | 314 | 359 | 404 | 449 |
| 27 | 73 | 47 | 94 | 141 | 188 | 234 | 281 | 328 | 375 | 422 | 469 |
| 26 | 74 | 49 | 98 | 147 | 196 | 245 | 294 | 343 | 391 | 440 | 489 |
| 25 | 75 | 51 | 102 | 153 | 204 | 255 | 306 | 357 | 408 | 459 | 510 |
| 24 | 76 | 53 | 106 | 159 | 212 | 265 | 318 | 371 | 424 | 477 | 530 |
| 23 | 77 | 55 | 110 | 165 | 220 | 275 | 330 | 385 | 440 | 495 | 551 |
| 22 | 78 | 57 | 114 | 171 | 228 | 285 | 343 | 400 | 457 | 514 | 571 |
| 21 | 79 | 59 | 118 | 177 | 236 | 296 | 355 | 414 | 473 | 532 | 591 |
| 20 | 80 | 61 | 122 | 184 | 245 | 306 | 367 | 428 | 489 | 551 | 612 |
| 19 | 81 | 63 | 126 | 190 | 253 | 316 | 379 | 442 | 506 | 569 | 632 |
| 18 | 82 | 65 | 130 | 196 | 261 | 326 | 391 | 457 | 522 | 587 | 652 |
| 17 | 83 | 67 | 135 | 202 | 269 | 336 | 404 | 471 | 538 | 606 | 673 |
| 16 | 84 | 69 | 139 | 208 | 277 | 347 | 416 | 485 | 555 | 624 | 693 |
| 15 | 85 | 71 | 143 | 214 | 285 | 357 | 428 | 500 | 571 | 642 | 714 |
| 14 | 86 | 73 | 147 | 220 | 294 | 367 | 440 | 514 | 587 | 661 | 734 |
| 13 | 87 | 75 | 151 | 226 | 302 | 377 | 453 | 528 | 604 | 679 | 754 |
| 12 | 88 | 77 | 155 | 232 | 310 | 387 | 465 | 542 | 620 | 697 | 775 |
| 11 | 89 | 80 | 159 | 239 | 318 | 398 | 477 | 557 | 636 | 716 | 795 |
| 10 | 90 | 82 | 163 | 245 | 326 | 408 | 489 | 571 | 652 | 734 | 816 |
| 9 | 91 | 84 | 167 | 251 | 334 | 418 | 502 | 585 | 669 | 752 | 836 |
| 8 | 92 | 86 | 171 | 257 | 343 | 428 | 514 | 599 | 685 | 771 | 856 |
| 7 | 93 | 88 | 175 | 263 | 351 | 438 | 526 | 614 | 701 | 789 | 877 |
| 6 | 94 | 90 | 179 | 269 | 359 | 449 | 538 | 628 | 718 | 807 | 897 |
| 5 | 95 | 92 | 184 | 275 | 367 | 459 | 551 | 642 | 734 | 826 | 918 |
| 4 | 96 | 94 | 188 | 281 | 375 | 469 | 563 | 657 | 750 | 844 | 938 |
| 3 | 97 | 96 | 192 | 287 | 383 | 479 | 575 | 671 | 767 | 862 | 958 |
| 2 | 98 | 98 | 196 | 294 | 391 | 489 | 587 | 685 | 783 | 881 | 979 |
| 1 | 99 | 100 | 200 | 300 | 400 | 500 | 599 | 699 | 799 | 899 | 999 |
| 0 | 100 | 102 | 204 | 306 | 408 | 510 | 612 | 714 | 816 | 918 | 1,020 |

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