W42.14

UNITED STATES OF AMERICA:
WAR DEPARTMENT.

SIGNAL SERVICE NOTES, NO. XXII.

CORRECTIONS OF THERMOMETERS.

PREPARED UNDER THE DIRECTION OF
BRIG. & BVT. MAJ. GEN'L W. B. HAZEN,
CHIEF SIGNAL OFFICER OF THE ARMY,

BY
THOMAS RUSSELL,
JUNIOR PROFESSOR, OFFICE OF THE CHIEF SIGNAL OFFICER.

BY AUTHORITY OF THE SECRETARY OF WAR.

WASHINGTON CITY:
SIGNAL OFFICE.
1885.

UNITED STATES OF AMERICA:
WAR DEPARTMENT.

SIGNAL SERVICE NOTES, NO. XXII.

CORRECTIONS OF THERMOMETERS.

PREPARED UNDER THE DIRECTION OF
BRIG. & BVT. MAJ. GEN'L W. B. HAZEN,
CHIEF SIGNAL OFFICER OF THE ARMY,

BY
THOMAS RUSSELL,
JUNIOR PROFESSOR, OFFICE OF THE CHIEF SIGNAL OFFICER.

BY AUTHORITY OF THE SECRETARY OF WAR.

WASHINGTON CITY:
SIGNAL OFFICE.
1885.

NOTE.

The publication of this Signal Service Note is made for the purpose of bringing it to the attention of the public. The Chief Signal Officer does not thereby necessarily endorse the views set forth.

WASHINGTON CITY, *April* 3, 1885.

To the CHIEF SIGNAL OFFICER.

SIR: I have prepared the following notes on the corrections of the thermometer, on account of the many calls made upon the office as to the way in which the corrections are applied given on the Signal Service correction-cards. Instructions are also given here as to the methods of removing air-bubbles from mercurial thermometers, the joining of detached columns in alchohol thermometers, and other information that it is hoped will be useful to those using thermometers. If approved I would request that they be printed.

Very respectfully, your obedient servant,

T. RUSSELL,
Junior Professor, Signal Service.

THERMOMETERS AND THEIR CORRECTIONS.

The corrections of thermometers given in the Signal Service correction-cards are for points ten degrees, F., apart, usually from —28° F. to +112° F. These corrections are to be applied algebraically to the scale-readings of the thermometers to give the true temperatures. For a scale-reading between those for which corrections are given, an interpolated value of the correction must be used.

The corrections of a mercurial and an alcohol thermometer are given below:

Scale reading.	Exposed. No. 1016.	Minimum. No. 904.
Deg. F.	*Deg. F.*	*Deg. F.*
—28	—2.0	+7.8
—18	—1.5	+5.0
— 8	—1.0	+4.4
+ 2	—0.6	+3.2
12	—0.2	+2.4
22	—0.1	+1.5
32	0.0	+0.6
42	—0.3	+0.4
52	—0.4	+0.1
62	—0.5	+0.1
72	—0.5	0.0
82	—0.5	0.0
92	—0.5	+0.3
102	—0.6	....

The following are examples of the method of applying the corrections: For a reading of 62°.0 on No. 1016 the correction is —0°.5. The true temperature is therefore 62°.0 — 0°.5 = 61°.5. For the reading —13°.5 the interpolated value of the correction is — 1°.3. The true temperature for this reading is therefore —13°.5 — 1°.3 = —14°.8. For a reading on No. 904 of 37°.0 the true temperature would be 37°.0 + 0°.5 = 37°.5. For a reading of —28°.0 on the same thermometer, the correction being + 7°.8, the true temperature would be —28°.0 + 7°.8 = —20°.2.

The corrections of thermometers are given on the cards only as low as actual comparisons have been made with sub-standards. If it should happen that a reading of a thermometer is obtained at a point lower than any for which its corrections are given, then the correction for that point must be derived by extrapolation. It will be found best in most cases of this kind to use as a basis for this extrapolation the change in the correction for the last thirty degrees for which the corrections are given. On thermometer No. 1016, for instance, the change of correction between +2° and —28° is — 1°.4. For seven degrees the change is about — 0°.3. For the reading —35°.0, then, which is seven degrees below —28°, the correction is — 2°.3, and the true temperature is —35°.0 — 2°.3 = —37°.3.

For minimum thermometer No. 904 the change of correction from +2° to —28° is + 4°.6. In twenty degrees the change would be + 3°.1. For the reading —48°.0 the correction is + 10°.9, and the true temperature —48°.0 + 10°.9 = 37°.1. It goes without saying that, when carried very far, the corrections obtained in this way cannot be precise.

There is a gradual rise in the freezing-points of mercurial thermometers with age. The rise is rapid at first. Within a week after a thermometer is filled it is sometimes as much as 2°.0 F., and in a year after that it may rise an additional 1°.0 F. After a number of years the rise may be only a few tenths of a degree. For this reason thermometers are usually filled about a year and a half before they are graduated. The amount of this change is very different for thermometers made of different kinds of glass. Signal Service thermometers eight years old usually have the freezing-points about 0°.5 F. too high. Sometimes, however, the freezing-point of a thermometer will rise 0°.4 F. in a year.

The change of freezing-point is more rapid when the thermometer is often subjected to great changes of temperature. A thermometer raised to a high temperature has its freezing-point lowered. If subjected to a low temperature the freezing-point is raised. A thermometer raised to 100° F. will have its freezing-point depressed about 0°.05 F. If kept at a temperature of —20° F. for several hours the freezing-point will rise about 0°.10 F.

The rise in the freezing-point of a thermometer comes from the constantly diminishing capacity of the bulb, due to some change in the nature of the glass.

When the freezing-point changes, all the corrections of a thermometer are changed by the same amount. If, for example, at some time in the future on testing "exposed" thermometer No. 1016 in melting ice its correction at +32° F. is found to be — 0°.5 F. instead of 0°.0 F. as given in the preceding list of corrections, then the corrections to be used will be as follows:

Scale reading.	Exposed No. 1016.
Deg. F.	*Deg. F.*
—28	—2.5
—18	—2.0
— 8	—1.6
+ 2	—1.1
12	—0.7
22	—0.6
32	—0.5
42	—0.8
52	—0.9
62	—1.0
72	—1.0
82	—1.0
92	—1.0
102	—1.1

The valid freezing-point of a thermometer to be used in connection with any temperature, is that observered in melting ice immediately after exposure to the temperature for which the correction is required. The freezing-point varies so little from time time that for meteorological observations it is not necessary to observe it oftener than every three months. But if the highest accuracy is required at any particular observation of a temperature the freezing-point of the thermometer should be determined immediately after the observation of the temperature.

In testing the freezing-point of a thermometer the finely chipped ice or melting snow should be heaped up around the stem above the top of the mercurial column. In testing thermometers in snow in winter-time care must be taken that the snow is surely melting, or they will read too low. Snow, even after being kept in a warm room for many hours, will often be found several tenths of a degree lower in temperature than 32°.0 F. To ensure the correct temperature the snow should be moistened with distilled water.

The same changes take place in the glass bulbs of alcohol thermometers, but they are not so apparent as in the case of mercurial thermometers, for the reason that the expansion of alcohol is so much greater than that of mercury. Mercury expands between six and seven times as much as glass, while alcohol expands about forty times as much. A change of 0°.6 F. in the freezing-point of a mercurial thermometer caused by a contraction of the bulb would, therefore, in the case of a similar contraction in the bulb of an alcohol thermometer cause a rise in its reading at freezing-point of only 0°.1 F.

As most alcohol thermometers cannot be relied upon any nearer than 0°.5 F., any change of this kind in its freezing-point can only be certainly perceived after a great many years, if at all. Sometimes chemical changes in the alcohol cause alcohol thermometers to read lower than when they are first made. An alcohol thermometer, exposed a great deal to the sun, will have a film form along the bore which may cause it to read 2°.0 F. too low.

The observation of the freezing-point of a thermometer from time to time is necessary on account of other changes; such for instance as the shifting of the tube with respect to the scale when the graduation is not on the tube itself.

The atmospheric pressure causes a difference in the reading of a thermometer. The spherical-bulb thermometers in use in the Signal Service read about 0°.6 F. lower in melting ice in a vacuum than when subject to the pressure of the atmosphere. On Pike's Peak, where the barometer reads about 18 inches, the freezing-point of an "exposed" thermometer will read about 0°.2 F. lower than when at the level of the sea. The amount of this change varies with different thermometers, depending on the thickness of the glass in the bulb. When the tip of a thermometer-tube is broken off, opening the bore to the air, its freezing-point will be lowered about 0°.6 F.

The mercurial thermometer can be relied upon down to temperatures on the verge of the freezing-point of mercury, even as low as —38°. F., as long as the temperature to which it is exposed is falling. When the temperature has been lower than the freezing-point of mercury and is rising, the readings will be very erroneous as long as there is any of the mercury in the bulb solid.

Thermometers are not usually pointed by makers at low temperatures, and it is not surprising that they often have large corrections at low points. Makers mark thermometers by comparison with a standard at 32°, 52°, 72°, and 92°, or often at points thirty degrees apart. The graduation of the thermometer is then continued above and below these points. Unless the bore of the thermometer happens to be of nearly uniform diameter, its corrections will be large at temperatures outside of the interval pointed by the maker.

The corrections of alcohol thermometers are given to tenths of a degree, but two independent determinations of the corrections will often be found to differ by half a degree F. at the same point. This is in part owing to the fact that the degree spaces are short. The different quantity of liquid, wetting the interior surface of the tube above the column of alcohol at different times, causes a variation in the reading. There is no special significance, therefore, when it is fonnd that after applying the corrections of an "exposed" and minimum thermometer read at the same time, they show temperatures differing by half a degree. The reading of the "exposed" mercurial thermometer is always to be preferred to the alcohol thermometer at temperatures above —38° F.

A source of great annoyance in the use of alcohol thermometers is the continual condensation of the alcohol in the tube above the column. The tube ought frequently to be examined for this. When the "exposed" and minimum thermometers differ much more than half a degree it may be suspected that part of the alcohol column is detached. A device sometimes tried to keep this detached column from forming is to wrap tin-foil around the thermometer-tube and its brass attached scale. This does not always prevent it, however.

When the detached alcohol is only a few degrees in length the most convenient way to reunite it with the main column is to take the thermometer about vertically in one hand, with the bulb down, and strike the brass edge sharply against a block of wood held in the other. A countinued jarring in this way soon causes the alcohol to run down. The larger the bore of the thermometer the better this method succeeds, but it can be made to work even in the case of narrow bore thermometers.

Another method of uniting the detached column is to heat up the bulb in warm water until the column is driven into the enlargement at the top of the tube and the main column joins on to it. The thermometer is allowed to cool down while it is kept in a vertical position. In transportation of a thermometer the alcohol is often scattered along the bore by the motion of the index.

When there is much of the alcohol detached and the thermometer is heated up, it sometimes occurs that before joining on to the alcohol in the enlargement a separation will take place in the main column of the alcohol, or that bubbles will form in the bulb. The best way to do in this case is to swing the thermometer. For this purpose a loop of several strands of copper wire should be made in the eye at the top of the brass scale, and to this a stout cord should be fastened. If the cord is put into the eye of the scale, without the loop, it may become cut through in whirling and the thermometer is apt to fly off and break. The length of cord from the loop to the hand should be about eighteen inches. To make the column join in a thermometer with a narrow bore it must in some cases be whirled with very great rapidity. The detached column works down gradually as the whirling is continued. In the case of very refractory thermometers, instead of a continued uniform velocity of rotation it is sometimes found that the column runs down more readily to whirl by jerks, so that the thermometer has a very high velocity for only a part of a revolution.

Sometimes in joining on a detached column, in order to save trouble in fitting on a cord or heating up water, the thermometer is taken in the hand about the middle of the scale and swung in an arc of a circle. To swing a narrow bore thermometer in this way with sufficient force to drive down the alcohol it must be grasped so firmly that there is danger of breaking the stem. The large number of minimum thermometers returned from stations with the stems broken is evidence that this is the favorite method.

There is always some air in the tube of a mercurial thermometer above the column. The continual jarring and reversing of the instrument in transportation sometimes forces the air into the bulb or scatters the mercury along the bore. If there is much air in the bulb it will cause erroneous readings of the thermometer and it must be removed. If there is any in the bulb it will be seen as a speck. If the thermometer is inclined with the bulb uppermost the mercury will run out in the tube readily as the speck grows larger.

To remove the air it must first be brought to the junction of the tube and the bulb. To do this, take the thermometer in one hand and jar the bulb gently against the open palm of the other hand. When the bubble is brought to the junction, cool the thermometer to as low a temperature as can be done conveniently, by putting the bulb in ice or cold water. When the thermometer has cooled down invert it and jar slightly. This will cause all the mercury above the bubble to run to the end of the tube. While the thermometer is still inverted, or held horizontally, warm up the bulb in the hand. This will cause the mercury to rise in the tube and drive the air before it. Then bring the thermometer vertical and the detached mercury will run down and join on to the main column. The junction will not be complete; the air-bubble will be on one side. Put the bulb in ice or cold water again, and as the temperature falls the air bubble will be stationary, the mercury passing by it. When the temperature is as low as it will go, then again inverting the thermometer and jarring, the mercury will run down as before. Then by heating up with the hand and joining on the column and cooling as before, the air-speck can gradually be worked to the top of the column.

In cooling off the thermometer for the last time, care should be taken that the top of the column falls below the last position of the air-speck. The latter part of the cooling must also be done slowly, or otherwise when there is only a few degrees of mercury above the air-speck, the mercury will become detached. When the detached column is very short, it cannot be made to partially reunite with the main column again, as the elasticity of the intervening air is too great for the weight of the column.

When the short column cannot be partially reunited again, if the gap is only two or three hundredths of an inch, the column can be lengthened by jarring the thermometer, held vertically in the open palm of the hand. When the column has become long enough to reunite the process described above can be repeated.

If after a few trials it is found impossible to get the air above the column in this way, it may be accomplished in case the thermometer has but little scale below freezing-point, by putting the thermometer in a freezing mixture, as of salt and ice, and when the mercury has sunk into the bulb jarring the detached column down into it also. If this does not succeed then the detached column must be disposed of in the following manner:

Take the tube from the brass scale and gradually heat that part above the main column of mercury in a Bunsen burner, or the flame of an alcohol lamp, by running it back and forth through the flame and twirling it in the fingers all the time. Unless the tube is turned and heated uniformly all around it is apt to break. The mercury will be volatilized and scattered along the bore. Then by heating up the thermometer, or by jarring it with the bulb held uppermost, until the mercury runs from the bulb, the main column will pick up the various detached portions.

In the absence of a Bunsen burner or alcohol lamp the red hot coals of a charcoal furnace may be used for this purpose. A substitute for an alcohol lamp may be made by taking a shallow earthen-ware dish, such as the bottom of a flower pot, and filling it with sand or salt and saturating it with alcohol. An ordinary gas flame or candle will not do, as the tube becomes coated with soot. This keeps the thermometer from becoming sufficiently heated, and moreover prevents one seeing what is going on inside the tube.

When there is so much air in a thermometer-bulb that there is always a complete separation between the main body of mercury and the detached part, no matter how long the detached column may be, then an effort must be made to scatter it in the bulb and remove it part at a time. If this can not be made to work the thermometer must have an enlargement blown at the top of the bore. This can only be done by an expert glass-blower with safety to the thermometer. The top of the glass tube is softened in the flame of a blow-pipe. The bulb is warmed up until the mercury reaches the hot glass. It is vaporized and the tension of the mercurial vapor expands the tube.

Thermometers provided with these enlargements at the top of the tube, called calibrating chambers, have many advantages over ordinary instruments. Bubbles of air interposed in the column of mercury can be easily removed by driving the detached portion into the chamber and then heating up the thermometer, or causing the mercury to flow from the bulb by jarring until it runs into the chamber. When it joins on to the detached portion, by inclining the thermometer and allowing the mercury to run down slowly the air will be left behind in the chamber. In thermometers with capillary tubes it is very difficult to get the mercury to run from the bulb by jarring. If it does not run after a few trials it is safest to heat the thermometer until the junction with the detached mercury is formed.

It sometimes happens when the detached column is at the entrance of the chamber and partly extending into the tube that when the main body of mercury is brought up to the chamber, instead of forming a junction with the mercury there it will join on a piece at a time, until the chamber is entirely filled. The air-bubble will remain where it was, with a complete separation between the main body of mercury and that in the chamber. This can be obviated by at first sending the detached column to the very bottom of the chamber before starting the main body of mercury from the bulb. To do this, jar the thermometer slightly with the bulb held uppermost. When the detached mercury has fallen to the other side of the chamber and the main column of mercury has reached the entrance to the chamber, then by holding the thermometer horizontally and jarring the top on the finger the mercury can be united and allowed to flow down.

When the chamber becomes completely filled with mercury it can only be driven out by heating the top of the tube in a Bunsen burning or alcohol lamp.

The very best kind of a maximum thermometer can be made out of a thermometer with a chamber at the top of the bore, provided the bore is sufficiently capillary. The narrower the bore the better the index sticks. To convert a thermometer of this kind into a maximum, heat it up or cause the mercury to run from the bulb until it enters and partially fills the chamber. Then jar the top on the finger until a litte globule is detached and falls in. Allow the main body of mercury to flow back into the bulb. Heat the top of the thermometer in a flame, with the globule lying in the chamber, but not at the entrance to the bore, so as to drive some of the air in the chamber down in the tube. Then incline the thermometer with the bulb down and jar slightly so as to bring the globule to the entrance of the chamber. Heat the top of the thermometer in the flame again until the mercury is driven down in the bore. This index can be set by whirling the thermometer or jarring it down while held vertically.

It is important to observe that the bulb of a thermometer ought never to be presented to a flame.

The corrections of maximum thermometers with constriction in tube are not usually given lower than +12° F. Whenever the corrections are given for points below this they are not derived from comparisons with a standard, but by means of a calibration. With thermometers of this kind a calibration for low temperatures is easily made, as follows:

In a mixture of salt and ice work down the detached column of the maximum thermometer until it reads about +12° F. Then invert the thermometer and the part of the column above the constriction will move to the end of the tube. Take the thermometer from the mixture and lay it horizontally. When the thermometer has warmed up sufficiently to drive a column of twenty degrees in length, or thereabout, above the constriction, raise the bulb end of the thermometer until the twenty-degree column moves and its lower end is at about —8° F. Then read the position of the lower and upper ends of the column as accurately as possible. Raise the bulb end of the thermometer again until the lower end of the detached column moves to +12° F. Read both ends in this position and shift the column again until the lower end is at 32° F. The upper end will be at about 52° F. From the observed lengths of the column in the various positions and the corrections of the thermometer at 32° F. and 52° F. the corrections at +12° F. and —8° F. can be derived, as is best shown in the following example:

Calibration of maximum thermometer No. 1130.

Position of column.	Reading of lower end.	Reading of upper end.	Length of column.
— 8° to +12°	— 7°.8	+12°.1	19°.9
+12° to 32°	12°.1	32°.3	20°.2
32° to 52°	32°.0	52°.4	20°.4

The corrections of No. 1130 are at 32° F., — 0°.2 F., and at 52° F., 0°.0 F.

The true length of the detached column, that is its length expressed in degrees F., is equal to the measured length, plus the correction at its upper end, minus the correction at its lower end. This length for No. 1130 from the measured length over 32° to 52°, is then 20°.4 + 0°.0 — (0°.2) = 20°.6, The length from 12° to 32°, measured with the same column, is 20°.2. This stretch is, there, too short by 0°.4 F., and the 12° mark is not as far from the 32° mark as it ought to be by 0°.4. The correction at 32° being —0°.2 F., the correction at 12° will, therefore, be —0°.6 F. The measured length of column from —8° to +22° is 19°.9. The distance is, therefore, too short by 0°.7, and hence the correction at —8° is — 0°.6 — 0°.7 = —1°.3.

The maximum thermometer with constriction in the bore is very apt to read two degrees or more too high at very low temperatures, unless the thermometer is very nearly vertical when read. The capilarity of the constriction pushes the detached column up, unless the column is long. The thermometer ought to be inclined enough when mounted to prevent this pushing. The distance in a vertical direction between the constriction and the top of the column ought not to be less than two inches.

When a thermometer is wetted repeatedly, or put in alcohol or ether, the marks in the etchings get washed out. To replace the marking, artists' black pigment is used. It should be rubbed on the thermometer when the tube is quite dry, and then the tube should be wiped with paper to remove all the pigment not in the marks.