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George K. Burgess, Director

TESTING OF THERMOMETERS

[4th edition, 1926]

CIRCULAR OF THE BUREAU OF STANDARDS, No. 8

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[4th Edition
October 14, 1926

PRICE 10 CENTS
Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1926

TESTING OF THERMOMETERS

ABSTRACT

This circular contains general information of interest to those who desire to submit thermometers to the bureau for test. The bureau is prepared to test the various types of laboratory thermometers, also clinical thermometers, platinum resistance thermometers, and thermocouples. A thermometer should be tested at an adequate number of points, and when so tested is eligible for certification, provided it is free from defects of design, material, or construction, and is correct within reasonable tolerances. Fees depend upon the number of test points and the kind of test.

CONTENTS

I. INTRODUCTION

This circular is intended for the information of those who wish to send thermometers to this bureau for test or who have occasion to use thermometers which have been tested by the bureau. The present (fourth) edition does not differ appreciably from the previous one, issued in 1921, except in arrangement. More detailed information on thermometry may be found in other publications of the bureau. A complete descriptive list of these publications is contained in B. S. Circular No. 24, which may be had upon request, or may be consulted in "Government depository libraries."

II. STANDARD SCALE OF TEMPERATURE

The fundamental scale upon which temperature measurements are based is the thermodynamic centigrade scale. To establish this scale, it is necessary to refer to measurements with a gas thermometer. The gas thermometer is, however, too cumbersome, slow, and difficult to use to be a practicable working standard, and it is used primarily to determine the temperature of thermometric fixed points and to establish the form of the calibration curves of other types of thermometers which serve as convenient working standards. For the temperature interval 0 to 650° C., and also for the interval

0 to −193° C., the platinum resistance thermometer serves as the working standard.

If R_0 represents the resistance of the platinum resistance thermometer at 0° C., R_{100} its resistance at 100° C., and R its resistance at any temperature t between 0 and 650° C., this temperature is given by the well-known Callendar equation

$$t=100\frac{R-R_0}{R_{100}-R_0}+\delta\left(\frac{t}{100}-1\right)\frac{t}{100}$$

The three constants in this equation, R_0, R_{100}, and δ, are determined by calibrating the thermometer at the melting point of ice, at the steam point, and at the sulphur boiling point, which at normal atmospheric pressure have temperatures of 0° C., 100° C., and 444.6° C., respectively.

If the resistance thermometer is made of pure platinum, the constant δ will have a value between 1.48 and 1.50. High values of δ are an indication of impure platinum, so that the value found for δ becomes a valuable index as to the purity of the platinum. No further calibration for the temperature interval 0 to 650° C. is required because practically all available data indicate that all resistance thermometers define nearly the same scale and that temperatures calculated by the formula given do not differ from those determined with the gas thermometer by more than the experimental errors.

For the temperature interval 0 to −193° C., temperatures are calculated by use of the equation

$$t=100\frac{R-R_0}{R_{100}-R_0}+\delta\left(\frac{t}{100}-1\right)\frac{t}{100}+\beta\left(\frac{t}{100}-1\right)\frac{t^3}{100^3}$$

in which the constants R_0, R_{100}, and δ are determined as described above, while the additional constant β is determined by calibrating the thermometer at the boiling point of oxygen, which has a temperature of −183° C. at normal atmospheric pressure.

It is worthy of note that although the working standard is derived from gas-thermometer measurements, it can now be considered as completely defined by the equations connecting resistance and temperature, when once the constants of the formulas have been determined by calibration at the designated fixed points. The scale defined in this way is, in fact, accepted in practice as the standard scale and is subject to modification only if new and very thorough researches shall indicate the need of such modification. Since the indications of various resistance thermometers differ from each other by less than the experimental errors of gas thermometry, the standard scale, defined by reference to the platinum resistance thermometer is more reproducible than the scale defined by the gas thermometer, but may differ from the thermodynamic scale by the amount of the error in the gas thermometric measurements upon which the standard scale is based.

III. KINDS OF THERMOMETERS ACCEPTED FOR TEST

The types of thermometers regularly accepted for test include clinical thermometers and all ordinary thermometers of the type employed in temperature measurements in the laboratory and commonly known as laboratory and special thermometers, including laboratory and working standards, clinical standards, calorimetric, Beckmann, hypsometric, hygrometric, flash point, distillation, and viscometer thermometers, and special low-temperature thermometers. Thermometers of the so-called industrial or mechanical types—that is, thermometers provided with special mountings to adapt them to various industrial uses—will not, in general, be accepted for test, because the special testing equipment required for testing the large variety of thermometers of this class is not available. Ordinary household and meteorological thermometers will not, in general, be accepted for test unless the scale is graduated on the glass stem itself, so that the thermometer can be detached from its mounting and inserted into the testing baths.

Platinum resistance thermometers will be accepted for standardization within the temperature ranges for which they are suitable. At present the lower limit is set at $-193°$ C., while the upper limit is determined by the characteristics of the instrument submitted.

Thermocouples will be accepted for standardization in the range $-193+500°$ C. The standardization of rare metal and base metal thermocouples for use at higher temperatures (300 to 1,500° C.) is a regular test of the high-temperature laboratories. (B. S. Circular No. 7.)

Thermometers of the pressure gauge type have not been submitted for test in sufficient quantity to warrant the installation of facilities for routine testing. Such thermometers will not, in general, be accepted for test, except in special cases where an investigative test may yield information desired by the bureau relating to the type of instrument submitted.

Thermometers which are so constructed that they can not be tested with the facilities available, or which have defects rendering them unsuitable for use, will necessarily be returned untested. Among defects of mercury-in-glass thermometers are dirty mercury, dirt or moisture in the capillary, entrapped gas in the mercury, omission of gas filling where needed, insufficient annealing, and numerous others. A complete list of possible defects can not be compiled. In case the test of a defective thermometer is completed, the results will be given in a report.

STANDARDIZED TYPES OF PARTIAL IMMERSION THERMOMETERS.—The stem temperatures for certain types of partial immersion thermometers, made under definite specifications, have been standardized to correspond to average conditions of use. This procedure makes it possible to produce partial immersion thermometers within the tolerances allowed for total immersion thermometers, and simplifies testing. Such thermometers can be made much more uniform and are generally more satisfactory than miscellaneous partial immersion thermometers. It is very desirable that production of partial immersion thermometers be restricted to a small number of standardized types. Originality and variety of design in this field should be discouraged. The Bureau of Standards has assisted in the design of a number of standardized partial immersion thermometers and is prepared to test such thermometers according to the specifications.

IV. NUMBER AND CHOICE OF TEST POINTS

The standardization of a thermometer consists of a comparison with standards at a number of points sufficient to give reasonable assurance that the corrections between test points can properly be inferred by interpolation from the corrections determined at the test points. In general, if the readings of a thermometer are to be trusted to one or two-tenths of the smallest scale division, the interval between test points should not exceed 100 divisions and need not be less than 40. For ordinary thermometers graduated in 1 or 2° intervals, test points 100° apart are usually sufficient. If, for example, a thermometer is graduated in 0.1° intervals, and the correction at 20° is −0.07° and at 25° it is −0.12°, the correction at 22° may be taken as −0.09° with some confidence as to its correctness. If interpolations between test points from 40 to 100 divisions apart on any particular thermometer are considered untrustworthy, it is better to discard the thermometer and obtain one which is worthy of confidence.

Occasionally requests are received for tests of thermometers graduated in 1 or 2° intervals at a series of points only 1 or 2° apart. Such requests are doubtless due to unfamiliarity with the matters explained in the preceding paragraphs. In other cases, a request may call for test at only two points on a long thermometer. If the thermometer is to be used only at or near these points, such a test may serve the purpose satisfactorily, but a report, instead of a certificate, will be issued if the number of test points is insufficient to justify an inference as to the reliability of the thermometer throughout its range. In no case will a thermometer be tested at less than two points.

In general, when a thermometer is to be tested without reference to any special use, the choice of points may well be left to the testing laboratory. If the thermometer is to be used for a special purpose, a knowledge of the use for which it is intended will be useful to the laboratory in choosing test points. The bureau can not, however, undertake to make tests at more points than in its judgment are necessary, although due consideration will be given special requests. In some cases the proper number and distribution of test points can be decided only after a careful inspection of the thermometer, and occasionally only after the test has been partly completed.

V. CERTIFICATES AND REPORTS FOR LABORATORY THERMOMETERS

A certificate of test issued by this bureau for a laboratory thermometer, in addition to giving the results of the test, may be taken as an indication that the instrument is free from serious defects of design, material, or workmanship, and that it has been tested at a sufficient number of points to provide reasonable assurance that the indications throughout the scale are as nearly correct as can be expected with good manufacturing practice.

If a thermometer is not eligible for certification, a report giving the results of the test will be issued. This report also contains a statement of the reasons for refusing certification. The issuing of a report means that the thermometer is usable, but in most cases it also means that the manufacturer has failed to meet requirements such as those listed at the end of this section which he could reasonably be expected to meet. A report of test will usually serve, if the thermometer is properly used and corrections are applied, to enable the user to secure satisfactory and reliable temperature measurements.

The test requirements and tolerances outlined in sections 6 and 7 indicate the standard to which a thermometer should conform in order to be eligible for certification.

A certificate or report of test will contain, in addition to the results of the test, the following information: Identification markings and numbers on the instrument; the name of the person for whom the test was made; a brief description of the instrument; the test number and date of test; and such explanatory notes as will define the conditions under which the results of test are applicable and which will enable the user at all times to use the results of the test to advantage; as further evidence of its origin, the certificate or report contains finally the signature of the director and the impressed seal of the bureau. When necessary, the certificate will be accompanied by a sheet showing how to calculate the correction for emergent stem. If the thermometer is of the metastatic (Beckmann) type, the certificate will be accompanied by a table of setting factors to enable the user to apply the results of the test, if the thermometer is used with a setting other than that for which the corrections are given.

Figure 1 shows the face of a certificate and Figure 2 the back of the same certificate.

DEPARTMENT OF COMMERCE

PTH:LM
III-1

Bureau of Standards

Certificate

FOR

MERCURIAL THERMOMETER

Marked A.B.T. Co.

Maker's No. 12

B. S. No. 36984

Bureau File Reference:
III-1 Test No.Ttt 44701

TESTED FOR
Bureau of Standards,
Division O-4

THERMOMETER SCALE: -8 to +103°C in 0.2°

RESULTS OF TEST

READING OF THERMOMETER	TEMPERATURE	CORRECTION TO READING
-0.02°C	0.00°	+0.02°
20.00	20.02	+ .02
40.00	40.04	+ .04
60.00	59.94	- .06
80.00	80.04	+ .04
100.00	100.06	+ .06

DEPARTMENT OF COMMERCE ☆ BUREAU OF STANDARDS ☆

Washington, D. C.
AUG - 3, 1926

GEORGE K. BURGESS,
Director.

Form 186 C

(OVER)

Fig. 1.—*Facsimile of face of a thermometer certificate*

NOTES

*CAUTION.—The correct use of this certificate requires that the user shall read and apply those notes designated below by asterisks (*). The tabulated results are those obtained in the test, the probable accuracy is indicated in the Tables in Bureau of Standards Circular No. C8, current edition.

* NOTE A.—The tabulated corrections apply for the condition of total immersion. If not so used, apply a stem correction as explained in the accompanying stem correction sheet.

NOTE B.—The thermometer was tested in a large, closed top, electrically heated, liquid bath, being "immersed" The temperature of the room was about 25° C. (77° F.). If the thermometer is used under conditions which would cause the average temperature of the emergent mercury column to differ markedly from that prevailing in the test, appreciable differences in the indications of the themometer would result. (See Bureau of Standards Scientific Paper entitled "Thermometry.")

NOTE C.—The tabulated corrections apply provided the ice-point reading is . If the ice-point reading is found to be higher (or lower) than stated, all other readings will be higher (or lower) to the same extent.

* NOTE D.—The tabulated corrections apply provided the ice-point reading, taken after exposure for not less than 3 days to a temperature of about 20° C. (or 70° F.) is -0.03° . If the ice-point reading is found to be higher (or lower) than stated, all other readings will be higher (or lower) to the same extent. If the thermometer is used at a given temperature shortly after being heated to a higher temperature, an error of 0.01° or less, for each 10° difference between the two temperatures, may be introduced. The tabulated corrections apply if the thermometer is used in its upright position; if used in a horizontal position, the indications may be a few hundredths of a degree higher.

NOTE E.—The thermometer, before testing, was heated to the temperature of the highest test point. The application of the tabular corrections to the readings of the thermometer will give true temperature differences, provided the thermometer is used in its upright position, and is heated previously (within an hour before using) to the highest temperature to be measured.

NOTE F.—The thermometer was tested for use in differential measurements, such as the measurement of temperature differences in a flow calorimeter. The two thermometers used in a flow calorimeter should be compared occasionally in stirred water at some convenient temperature and if their indications, after application of the tabular corrections, are found to differ, an additional correction equal to the difference, should be applied, with the proper sign, to the indications of one of them.

NOTE G.—The tabulated corrections apply for a "setting" of 20° C. Setting factors for use with other settings are given on the accompanying sheet.

NOTE H.—The tabulated corrections apply for the conditions of immersion indicated, provided the ice-point reading, taken after heating to is If the ice-point reading is found to be higher (or lower) than stated, all other readings will be higher (or lower) to the same extent.

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FIG. 2.—*Facsimile of back of a thermometer certificate*

Some of the reasons why a thermometer may not be certified are given in detail in the two following sections but are briefly summarized below:

1. Defects of design, in general.
2. Omission, where required, of ice point or other reference point.
3. Part of graduated scale not usable.
4. Defective type of graduation, or graduation in unsuitable intervals, such as 1/4°.
5. Omission of required marking on partial immersion thermometers.
6. Defective material or workmanship, in general.
7. Unsuitable glass in bulb.
8. Insufficient annealing.
9. Insufficient or unsuitable gas filling.
10. Defects in graduation or numbering.
11. Scale error at one or more points exceeds tolerance (Tables 1 to 4).
12. Change of correction over a given interval exceeds tolerance. (Tolerance is 5 per cent of interval on laboratory thermometers, and for differential thermometers is given in Table 5.)
13. Test requested at an insufficient number of points.

VI. TEST REQUIREMENTS

The essential requirements for certification other than those concerning accuracy are that the thermometer shall be of suitable design and of "good material and workmanship." Among the requirements are:

1. Design.—The design of the thermometer must be right. It is impossible to make a list of all defects in design, but some general provision is necessary to include special cases which arise from time to time. Some of the important features of design are described below (pars. 2 to 5, inclusive).

2. Reference Point on Scale.—Thermometers graduated above 150° C. or 300° F., and precision thermometers to be certified for measurement of actual temperatures rather than temperature differences, to an accuracy better than 0.1° C. or 0.2° F., should have on their scales the ice or steam point, or in special cases some other point at which the thermomenter can be tested conveniently in order that changes in the volumes of the bulb can be determined from time to time and the proper corrections applied. The graduations should extend both above and below the fixed point and should not terminate just at the fixed point. The scale need include only the interval within which the thermometer is to be used and a short portion *above* and *below* the reference point, and to avoid making the thermometer unduly long, an enlargement or chamber in the

capillary may be introduced between the two graduated portions. High-temperature thermometers may be made with a short graduated scale at 20 or 25° C. (68 or 77° F.) instead of at the ice point. Such thermometers can be conveniently tested by comparison with another thermometer, and are less liable to suffer from separation of the mercury column in shipment, than those having an auxiliary scale at 0° C. with a chamber in the capillary immediately above.

Reference points are not required on thermometers certified for differential measurements (calorimetric, gas calorimetric, etc.), nor on thermometers not graduated above 150° C. or 300° F., if these are not to be certified to an accuracy better than 0.1° C. or 0.2° F.

3. The thermometer must be usable over the entire range for which it is graduated. Failure to comply with this requirement may lead to large errors; as, for example, when the scale extends too close to an enlargement in the capillary or too near the bulb. In other cases—such, for example, as that of a thermometer of borosilicate glass graduated to 1,000° F.—an attempt to use the instrument at that temperature would ruin it in a short time.

4. Graduation.—Laboratory thermometers of the plain stem type should have the graduation marks etched directly on the stem and so located as to be opposite the enamel back. In thermometers of the inclosed scale (Einschluss) type, the graduated scale must be securely fastened to prevent relative displacement between scale and capillary—for example, by fusing the scale to the inclosing tube—or if this is not done a mark should be placed on the outer tube in such a location as to indicate the position of the scale, thus making it possible to determine whether the scale is in its original position.

The scale should be graduated either in 1, 0.5, 0.2, or 0.1° intervals, or in decimal multiples or submultiples of such intervals. Occasionally thermometers graduated in 1/4° intervals or in 1/4° intervals further subdivided, are submitted for test. Such thermometers are so difficult to read that their complete elimination is desirable and they are not eligible for certification.

Graduation marks should not be too closely spaced. The closest permissible spacing will depend upon the fineness and clearness of the graduation marks. However, in no case should the interval between graduation marks on an engraved stem thermometer be less than 0.4 mm. The minimum permissible interval between graduation marks for an inclosed scale thermometer is 0.3 mm if the lines are ruled on a milk-glass scale; for other scales the minimum is 0.4 mm. The minimum in no case represents good design, and well-designed thermometers will have graduation intervals considerably larger than the specified minimum.

Thermometers graduated in 0.1 or 0.2° intervals or decimal multiples or submultiples of these should have every fifth mark longer than the intermediate ones and should be numbered at every tenth mark. Thermometers graduated in 0.5° intervals, or in decimal multiples or submultiples of 0.5° require three lengths of graduation marks consisting of alternating short and intermediate marks, with every tenth mark distinctily longer than the others, and numbering at every tenth or twentieth mark.

5. Marking of Partial Immersion Thermometers.—Partial immersion thermometers of the ordinary laboratory type will not be certified unless plainly marked "partial immersion" or its equivalent (as, for example, "76 mm immersion") and unless a conspicuous line is engraved on the stem to indicate the depth to which the thermometer is to be immersed. This mark must not in any case be less than 13 mm (½ inch) above the top of the bulb. Special partial immersion thermometers adapted to instruments which fix definitely the manner of use (as, for example, viscometers and flash-point testers in which the thermometer is held in a ferrule or other mounting fitting the instrument) need not be specially marked, although even in this case it is desirable that the thermometers be marked "partial immersion."

6. Good Material and Workmanship in General.—It has already been stated that it is impossible to list all defects of design, and the same is true of material and workmanship. Some of the defects which may make a thermometer unfit for test, or make it ineligible for certification, according to circumstances, are dirty mercury, dirt or moisture in the capillary, omission of gas filling where needed, and numerous others. Some of the essential requirements under the general heading of good material and workmanship are described below (pars. 7 to 10, inclusive).

7. Glass.—The bulb must be made of a suitable thermometer bulb glass, such as Corning normal, Corning borosilicate, or special Jena glasses.

8. Annealing.—High temperature thermometers, especially those graduated above 300° C. or 600° F., should be suitably annealed, so that continued heating will not greatly change their indications.

9. Gas Filling.—All high-temperature thermometers should be filled with a dry inert gas under sufficient pressure to prevent separation of the mercury at any temperature for which the scale is graduated. Total immersion thermometers graduated above 150° C. or 300° F. should be gas filled to minimize the distillation of mercury from the top of the column. Gas filling of thermometers for lower temperatures is optional.

10. Graduation and Numbering.—The graduation marks should be clear cut, straight, of uniform width, and should be perpendicular to the axis of the thermometer. The width of the graduation marks should not, in the extreme case, be more than 0.2 of

the interval between graduations. The spacing of the graduations should be free from significant irregularities which would produce uncertainties in the indications by amounts exceeding the limits otherwise set by the type of thermometer. The divisions should be numbered in such a way that the identification of any graduation is not unnecessarily difficult.

VII. TOLERANCES

Tolerances for Ordinary Laboratory Thermometers.—In Tables 1, 2, 3, and 4 are given the tolerances allowed by the bureau in awarding certificates. These tables are identical with those given in the third edition of this circular, issued in 1921. The figures are applicable to the ordinary high grades of mercury in glass laboratory thermometers. The tolerances for partial immersion thermometers are larger than those established for total immersion thermometers.

The tables of tolerances for partial immersion thermometers are based on the assumption that the entire stem above the ice point graduation (0° C., 32° F.), is emergent from the bath. This represents approximately the conditions for which partial immersion thermometers are generally made. If the length of the emergent stem is less than indicated above, the manufacturers should have no difficulty in keeping the errors well within these tolerances.

The tolerances for total immersion thermometers are based on the fact that in the manufacture of thermometers certain small errors in pointing and graduating are inevitable, and also that the indications of thermometers are subject to variations due to the inherent properties of the glass. The tolerances must be sufficiently rigid to insure to the user a satisfactory high-grade thermometer and at the same time must not be so rigid as to cause undue manufacturing difficulties.

The tolerances in the tables may appear somewhat large, but it has been the experience of the bureau that some manufacturers are meeting with difficulty in complying with them. It is hoped that ultimately conditions will be such as to permit reducing these tolerances.

By comparing the tables of tolerances for total and for partial immersion thermometers it will be seen that somewhat larger tolerances are permissible in the latter type and also that the certified corrections, resulting from an ordinary test, are reliable to a lower order of accuracy. This signifies that total immersion thermometers, when used under suitable conditions, are capable of higher accuracy than partial immersion thermometers. On the other hand, where a total immersion thermometer is used at partial immersion, a partial immersion thermometer would usually yield equally accurate results and in many cases would prove to be the more accurate of the two.

TABLE 1.—*Tolerances for centigrade mercurial total immersion laboratory thermometers*

[For interpretation of column headings see "Explanation of the tables," p. 14]

THERMOMETERS FOR LOW TEMPERATURES

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
−35 to 0	1 or 0.5	0.5	0.1 –0.2	0.1
−35 to 0	.2	.4	.02– .05	.02
THERMOMETERS NOT GRADUATED ABOVE 150°				
0 up to 150	1 or 0.5	0.5	0.1 –0.2	0.1
0 up to 150	.2	.4	.02– .05	.02
0 up to 100	.1	.3	.01– .03	.01
THERMOMETERS NOT GRADUATED ABOVE 300°				
0 up to 100	1 or 0.5	0.5	0.1 –0.2	0.1
Above 100 up to 300	1 or 0.5	1.0	.2 – .3	.1
0 up to 100	.2	.4	.02– .05	.02
Above 100 up to 200	.2	.5	.05– .1	.02
THERMOMETERS GRADUATED ABOVE 300°				
0 up to 300	2	2	0.2–0.5	0.2
Above 300 up to 500	2	4	.5–1.0	.2
0 up to 300	1 or 0.5	2	.1– .5	.1
Above 300 up to 500	1 or 0.5	4	.2– .5	.1

TABLE 2.—*Tolerances for Fahrenheit mercurial total immersion laboratory thermometers*

THERMOMETERS FOR LOW TEMPERATURES

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
−35 to 32	1 or 0.5	1	0.1–0.2	0.1
−35 to 32	.2	.5	.05	.02
THERMOMETERS NOT GRADUATED ABOVE 300°				
32 up to 300	2	1	0.2 –0.5	0.2
32 up to 300	1 or 0.5	1	.1 – .2	.1
32 up to 212	.2 or 0.1	.5	.02– .05	.02
THERMOMETERS NOT GRADUATED ABOVE 600°				
32 up to 212	2 or 1	1	0.2–0.5	0.2
Above 212 up to 600	2 or 1	2	.5	.2
THERMOMETERS GRADUATED ABOVE 600°				
32 up to 600	5	4	0.5–1.0	0.5
Above 600 up to 950	5	7	1 –2	.5
32 up to 600	2 or 1	3	.2–1.0	.2
Above 600 up to 950	2 or 1	6	.5–1.0	.2

TABLE 3.—*Tolerances for centigrade mercurial partial immersion laboratory thermometers*

[For interpretation of column headings see "Explanation of the tables," p. 14]

THERMOMETERS FOR LOW TEMPERATURES

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
—35 to 0	1 or 0.5	0.5	0.2–0.3	0.1
THERMOMETERS NOT GRADUATED ABOVE 150°				
0 up to 150	1 or 0.5	1.0	0.1–0.5	0.1
THERMOMETERS NOT GRADUATED ABOVE 300°				
0 up to 100	1	1.0	0.1–0.3	0.1
Above 100 up to 300	1	1.5	.5–1.0	.2
THERMOMETERS GRADUATED ABOVE 300°				
0 up to 300	2 or 1	2.5	0.5–1	0.5
Above 300 up to 500		5	1 –2	.5

TABLE 4.—*Tolerances for Fahrenheit mercurial partial immersion laboratory thermometers*

THERMOMETERS FOR LOW TEMPERATURE

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
—35 to 32	1	1	0.3–0.5	0.1
THERMOMETERS NOT GRADUATED ABOVE 300°				
32 up to 300	2 or 1	2	0.2–1.0	0.2
THERMOMETERS NOT GRADUATED ABOVE 600°				
32 up to 212	2 or 1	2	0.2–0.5	0.2
Above 212 up to 600	2 or 1	3	1 –2	.5
THERMOMETERS GRADUATED ABOVE 600°				
32 up to 600	5 or 2	5.0	1–2	1
Above 600 up to 950		10	2–3	1

In addition to the requirements shown in the above tables, the error in any temperature interval must not exceed 5 per cent of the nominal value of the interval. The obvious intent of this requirement is to eliminate thermometers having large corrections of alternating signs.

Explanation of the Tables.—The following explanations should be read carefully before attempting to interpret the tables. The headings "Temperature range in degrees" and "Graduation interval in degrees" require no further explanation. The "Tolerance in degrees" is the maximum correction, whether plus or minus, which a thermometer of the kind described may have if it is to be eligible for certification.

Under the heading "Accuracy in degrees" is given the order of accuracy to which corrections obtained as the result of an ordinary test are, in general, dependable. The figures given under this heading mean that for the conditions stated in the certificate or report the application of the corrections to the observed indications of the thermometer should give results, expressed on the standard scale of temperature, which are correct within the limits stated in this column for the thermometer and temperature under consideration.

Under the heading "Corrections stated to" are given the figures which show to what extent the certified corrections are, in general, rounded off. It will be noted that, as a rule, corrections are given to a somewhat higher order of accuracy than can be attained with certainty in testing the thermometer. This is done because, as a rule, it is preferable to give the corrections as found, since the result actually obtained is the best that can be deduced from any given test, and any considerable rounding off necessarily introduces an additional uncertainty.

Tolerances for Calorimetric and Differential Thermometers.—In calorimetric or differential thermometers the accuracy at any one temperature is of less importance than the accuracy of the temperature intervals. Table 5 gives the tolerances for the temperature intervals of some typical differential thermometers.

Table 5.—*Tolerances for calorimetric and differential thermometers*

Number of degrees included on scale	Graduation interval in degrees	Allowable change in correction in degrees	Accuracy of interval in degrees	Corrections stated to
20–45° F	0.05	0.08 over a 5° interval	0.01 –0.02	0.01
10–20° C	.02	0.03 over a 2° interval	.005– .01	.002
5–6° C (Beckmann type)	.01	0.01 over a 0.5° interval for setting of 20°	.002– .005	.001

No tolerances for scale error are given in the table although it is desirable that the scale error be small.

Under the heading "Accuracy of interval in degrees" is given the probable accuracy with which the thermometer can be used to measure the short interval between adjacent test points, or in the case of a Beckmann thermometer the estimated accuracy attainable in the measurement of any interval within the limits of the scale. The columns headed "Corrections stated to" shows to what fraction of a degree the corrections are given in certificates or reports.

Thermometers designed for use in laboratory measurements are ordinarily read to 0.1° of the smallest graduation interval; for example, the reading of a thermometer graduated in 0.1° divisions would be estimated to the nearest 0.01°. There are many cases, however, where thermometers designed for industrial use or routine testing are intended to be read only to the nearest whole division or perhaps half division, or where the instrument is not usable to a greater accuracy.

Tables 1 to 5 show, in general, the highest accuracy which may be expected for the various temperature ranges, and, in general, thermometers will not be certified to an accuracy higher than indicated in the tables, even though subdivision of the scale is carried further than there indicated. For example, a partial immersion centigrade thermometer graduated from 0 to 100° even though it were graduated in 0.2 or 0.1° intervals, would be certified only to the nearest 0.1° because certification to 0.01° would be quite meaningless.

VIII. NOTES ON THERMOMETRY

The following brief notes on the characteristic behavior of mercury-in-glass thermometers are added to aid the user in understanding the behavior of such thermometers and in a better utilization of the information that is contained in the certificates or reports of tests.

Secular Changes in Glass.—There is a slow secular change in the volume of the bulb which goes on for years. This manifests itself by a slow rise in the indications at all points. With the better grades of thermometric glasses this change will not exceed 0.1° C. in many years, provided the thermometer has not been heated to temperatures above 150° C. The allowance for this change can readily be made by determining the ice-point reading or other reference point from time to time, since if the reading at this point is found to be higher than at the time of test all other readings will be higher to the same extent.

Temporary Changes in Volume of Bulb.—When a thermometer which has been for a long time at room temperature is heated to a higher temperature, the glass quickly expands to its final equilibrium condition corresponding to the higher temperature. When cooled to the original temperature, the glass does not completely return to its original volume for a long time (months or even years), although if the bulb is made of suitable glass and has not been heated above 100° C. the original volume will be recovered within the equivalent of 0.01 or 0.02° in about three days. Obviously, this phenomenon has an important bearing on the precision attainable with mercurial thermometers and must be taken into consideration in precision thermometry, especially in the interval 0 to 100° C. Thus, if a thermometer is used to measure a given temperature, it will read lower than it otherwise would if it has a short time previously been exposed to a higher temperature. With the better grades of thermometric glasses the error resulting from this hysteresis will not exceed (in the interval 0 to 100° C.) 0.01° for each 10° difference between the temperature being measured and the higher temperature to which the thermometer has recently been exposed and with the best glasses only a few thousandths of a degree for each 10° difference. The errors due to this hysteresis become somewhat erratic at temperatures much above 100° C. For the reasons briefly set forth above it is customary, in precision thermometry, to determine the ice point immediately after each temperature measurement.

Changes in Volume of Bulb Due to Annealing.—Another change to which the indications of thermometers are subject is the annealing change at high temperatures. If the glass has not been properly annealed, it will slowly and progressively contract when exposed to high temperatures (above 300° C.), thus causing the indications of the thermometer to rise progressively. These annealing changes may amount to 30 or 40° C., and hence thorough annealing of a high-temperature thermometer is very important. No amount of annealing will make the ice-point reading of a thermometer absolutely constant if the thermometer is exposed for a long period to high temperatures (450° C. or thereabouts). For well-annealed thermometers such changes will be small and can be readily allowed for by occasional determinations of the fixed-point reading and application of the necessary additional corrections. In the use of high-temperature thermometers care must be taken not to overheat them. When the glass becomes "soft," the high internal gas pressure enlarges the bulb and thus causes a lowering in the indications of the thermometer.

IX. TIME REQUIRED TO COMPLETE TESTS

The time required to complete the test of a group of thermometers from preliminary examination to shipment, is from one to four weeks. If testing could be begun as soon as thermometers were received, the sender might expect to receive his thermometers and certificates in three to six weeks from the date of his request for test. The time will usually be longer, as work on incoming tests can not be begun until work already on hand has been disposed of.

In order to reduce delay, thermometers are now shipped as soon as the laboratory work is completed. At the same time the bill covering test fees is sent out. Certificates and reports are mailed on receipt of fees.

X. BREAKAGE OF THERMOMETERS

A not inconsiderable number of thermometers are received broken, either on account of improper packing or rough treatment in transportation, or both. Some are broken in return shipment. A small percentage of thermometers (less than 1 per cent) are broken in the various testing operations in the laboratory.

There is no legal way in which the bureau can make reimbursement for breakages of this kind. It is therefore a matter of necessity, and not of choice, that the bureau makes those who send apparatus for test assume all the risks involved. Damages to apparatus, even in cases where the bureau would be pleased to assume them, can not be made good out of fees received for testing, since such fees are not expendable by the bureau but are converted directly into the Treasury. Under the circumstances, all that the bureau can do is to make every effort to reduce such breakage to the absolute minimum under the conditions under which the work has to be done.

XI. GENERAL INSTRUCTIONS TO APPLICANTS FOR TESTS

Application for Test.—The request for test should be made in writing, addressed to "Bureau of Standards, Washington, D. C.," and should enumerate the articles submitted for test, giving sufficient information to identify each article or group of similar articles.

When apparatus is sent simply for test, without definite instructions, the bureau will decide upon the nature of the test. Any special information which may be of value in making this decision, such as the use for which the thermometers are intended, should be clearly stated in the request for test.

All packages should bear the shipper's name and address and, preferably, a list of the contents. Each separate article or group of articles should be plainly marked to facilitate identification.

Packing and Shipping.—Thermometers are subject to breakage in packing and shipment in three ways:

(*a*) Thermometers may break from sliding or shaking in their individual cases. This can be avoided by wrapping each thermometer carefully in soft paper before placing it in its case and having sufficient soft packing, as paper or cotton wool, at each end of the case, so that the thermometer can not slip endwise.

(*b*) Thermometers are sometimes broken by the bending of the individual cases due to uneven packing outside of them. This can be avoided by using metal or wooden cases in place of paper cases, and even with paper cases, by care in distributing the packing material.

(*c*) Thermometers may be broken by jars and blows on the outside of the packing case, due to careless handling. The danger of such breakage can be minimized by surrounding the individual thermometer case or cases with a sufficient amount—say, 2 or 3 inches—of excelsior or similar elastic material on all sides and at the ends within a strong but light wooden box. The marking on the outside of this box should call attention to the necessity for careful handling.

Proper packing is emphasized because an unduly large percentage of the thermometers shipped to the bureau for test are received broken.

Shipment in both directions is at the applicant's risk. Transportation charges on apparatus forwarded to the bureau for test must be prepaid. Unless otherwise arranged, articles will be returned or forwarded by express "collect."

Apparatus submitted for test, as well as all correspondence, should be addressed simply "Bureau of Standards, Washington, D. C." Apparatus delivered in person or by messenger should be accompanied by a written request for test.

Remittances.—Payment of test fee should be made promptly upon receipt of bill, as certificates or reports are not mailed until the fees due thereon have been paid. Remittances may be made by money order or check drawn to the order of the "Bureau of Standards."

Fees.—Fee schedules for tests described in this circular are printed separately. These schedules are subject to change from time to time. Copies of the current schedules may be obtained from the bureau on request.

Washington, March 11, 1926.