NBS CIRCULAR 600

Calibration of Liquid-in-Glass Thermometers

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards

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UNITED STATES DEPARTMENT OF COMMERCE • Lewis L. Strauss, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

Calibration of Liquid-in-Glass Thermometers

James F. Swindells

National Bureau of Standards Circular 600

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Preface

The liquid-in-glass thermometer is probably the most widely used temperature measuring device in both science and industry. In spite of its fragile nature, its relative simplicity makes this type of thermometer singularly attractive where reliable temperature measurements are required but the highest attainable accuracy is not necessary.

The liquid-in-glass thermometer is not an entirely foolproof instrument, however. If the user is to realize the accuracy of which his thermometer is capable, and to recognize its inherent limitations as well, he must have, in addition to its calibration, some knowledge of the behavior to be expected of such a thermometer. It is the purpose of this Circular to emphasize the important features of good practice in the design and use of liquid-in-glass thermometers, and to describe the techniques used by the National Bureau of Standards in their calibration. This information is intended to be of value not only to those who wish to submit thermometers to the Bureau for calibration, but also to manufacturers, to other standards laboratories, and to those who wish to calibrate their own instruments.

A. V. Astin, *Director.*

Contents

Calibration of Liquid-in-Glass Thermometers

James F. Swindells

This Circular contains information of general interest to both manufacturers and users of liquid-in-glass thermometers, as well as those who wish to calibrate thermometers or submit them to the National Bureau of Standards for calibration. Important elements of thermometer design are discussed, and eligibility requirements for certificates or reports of tests are given. Factors affecting the use of common types of liquid-in-glass thermometers are included together with tables of tolerances and reasonably attainable accuracies. The calculation of corrections for the temperature of the emergent stem is given in detail for various types of thermometers and conditions of use. The Circular also describes the techniques and equipment used in the calibration procedures and provides instructions for applicants requesting thermometer calibration services.

1. Introduction

It is the responsibility of the National Bureau of Standards to establish, maintain, and assume custody of the Nation's standards of physical measurement. One important activity under this responsibility is the accurate reproduction of the International Temperature Scale as a basis for the uniform measurement of temperature throughout the scientific and industrial activities of the United States. To this end the Bureau accepts for calibration with reference to this scale selected types of temperature-measuring instruments [1][1] for use as reference or working standards where precise-temperature measurements are required. Less precise types of instruments are not accepted, nor are the more routine calibrations performed in cases where such work can be done in qualified commercial testing laboratories or elsewhere. It is the purpose of this Circular to describe the practices employed at the Bureau in the calibration of acceptable types of liquid-in-glass thermometers. The information is intended for those who wish to submit thermometers for calibration or who have occasion to use thermometers calibrated at the Bureau. Important features of good practice in the use of liquid-in-glass thermometers are emphasized to assure the realization of the accuracy of which the thermometers are capable, as well as to point out their inherent limitations.

In this Circular, which supersedes the fourth edition of Circular 8, much of the material formerly deleted in the third and fourth editions of Circular 8 has been retained. It appears that much of this information is of continuing interest to both manufacturers and users and is most useful when collected in one publication. Consistent with the purpose of this Circular, however, only material relating to liquid-in-glass thermometry is included.

2. Temperature Scales and Standards

The calibration of a thermometer consists of comparing its indications with known temperatures on an accepted scale of temperature. The Kelvin Scale is recognized as the absolute thermodynamic scale to which all temperatures should be ultimately referable. In 1954 the Tenth General Conference on Weights and Measures defined this scale by means of a single fixed point, the triple point of water, to which was assigned the temperature 273.16° K, exactly. Because of the difficulties encountered in the realization of the Kelvin Scale, however, a practical working scale, the International Temperature Scale, was first adopted in 1927 and later revised in 1948. This Scale was intended to have close correspondence with the Kelvin Scale and to provide scientific and industrial laboratories throughout the world with a common basis for stating temperatures. Calibrations of thermometers at the Bureau are therefore made with reference to temperatures on the International Temperature Scale.

In the range of temperatures covered by liquid-in-glass thermometry, the International Temperature Scale is defined by four fixed points, the normal boiling points of oxygen at −182.970° C, water at 100° C, sulfur at 444.600° C, and the normal freezing point of water (ice point) at 0° C. It is recommended that the ice point be taken as the temperature exactly 0.01° C below the temperature of the triple point of water. This makes 0° C correspond to 273.15° K. Temperatures in the range 0° to 630.5° C, other than the fixed points, are defined on the International Temperature Scale in terms of a standard platinum resistance thermometer calibrated at the ice (or triple point), steam, and sulfur points.[2] The oxygen point is added as a fourth calibration point when the standard resistance thermometer is used below 0° C. For international uniformity the name of the scale was changed in 1948 from "centigrade" to "Celsius." In the range from −182.97° to 630.5° C no significant change in the values of temperature was effected as compared with the 1927 scale.

Thermometers graduated on the Fahrenheit scale are calibrated with reference to the Inter-

[1] Figures in brackets indicate the literature references at the end of this Circular.

[2] Because of the uncertain nature of the sulfur point, it is probable that action by the International Conference on Weights and Measures in 1960 will result in the use of the freezing point of zinc, with an assigned temperature close to 419.505° C, as a defined fixed point on the ITS.

national Temperature Scale using the conversion formula,

$$t_{°F}=\frac{9}{5}\,t_{°C}+32°\,F.$$

When the highest accuracy is required in a calibration, the thermometer indications are compared directly with temperatures obtained with a standard resistance thermometer. If lesser accuracy is adequate, one of a series of mercury-in-glass standards is used, except below 0°C, where the calibration is always made directly with a resistance thermometer regardless of the accuracy required. The series of mercury-in-glass thermometers which serve as standards for total-immersion comparisons is shown below.

Range	Smallest graduation	Auxiliary scale
°C	*°C*	*°C*
0 to 50	0. 1	------
0 to 100	0. 2	------
50 to 100	0. 1	at 0
100 to 200	0. 2	at 0
200 to 300	0. 5	at 0
300 to 500	1. 0	at 0

These standards are calibrated with reference to the International Temperature Scale through comparisons with a standard resistance thermometer.

Partial-immersion standards, known as "like standards," are maintained for the calibration of accepted designs of partial-immersion thermometers. These standards are calibrated for stem-temperature conditions expected to prevail during the calibration of similar thermometers. This use of like standards eliminates the need for many of the precautions necessary when dissimilar thermometers are compared. The procedure permits the direct comparison of the indications of similar thermometers, as long as the bulbs are at the same temperature and the stem temperatures are essentially the same for all of the thermometers under comparison.

For the use of those who may want to set up reproducible fixed points in their own laboratories, the Bureau issues triple-point-of-benzoic-acid cells and freezing-point standards of tin, lead, zinc, aluminum, and copper together with their appropriate measured temperatures. Detailed information on these samples and their procurement is given in NBS Circular 552.

3. Kinds of Thermometers Accepted for Test

Liquid-in-glass thermometers include a wide variety of types, not all of which are accepted for test. In general, considerations of design, intended use, and probable stability of the thermometer indications are the principal factors governing acceptability for test. Thermometers belonging to the large and varied group which may be classed as laboratory or "chemical" thermometers are regularly accepted. These may be of the etched-stem or enclosed-scale (Einschluss) type. Other acceptable types include such special-purpose thermometers as Beckmanns, calorimetrics, and clinicals. Thermometers of the so-called industrial or mechanical types, with special mountings for their various intended uses, can be accepted for test only when their construction permits testing with the equipment available. Ordinary household or meteorological thermometers will not, in general, be accepted unless the scale is graduated on the glass stem itself and the thermometer can be readily detached from its mounting for insertion in a testing bath.

Every thermometer submitted must pass a preliminary examination for details of construction before being finally accepted for test. The examination is made with optical aid (about 10 to 15 ×) for fineness and uniformity of graduation, cleanness of the mercury and capillary bore, and freedom from moisture, gas bubbles, and cracks in the glass. Among other possible defects are omission of gas filling where needed, insufficient annealing, misnumbered graduations, and numerous others. A complete listing of all possible defects is not practicable. When serious defects are found the thermometer is returned untested.

4. Certificates and Reports

A certificate of test issued by the Bureau for a liquid-in-glass thermometer, in addition to giving the results of the test, may be taken as an indication that the thermometer 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.

The test requirements and tolerances outlined in sections 5, 6, and 7 indicate the standard to which a thermometer should conform in order to be eligible for certification.

If a thermometer that is accepted for test 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 not issuing a certificate. 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. There may be some other cases where a thermometer is carefully manufactured, but is designed to meet a particular government or commercial specification which, while adequate for its intended purpose, is in some particular in conflict with the NBS requirements for certification. A report of test will usually serve to enable the user to secure satisfactory and reliable temperature measurements with the thermometer if it is properly used and the reported corrections are applied.

In addition to the results of test, a certificate or report will show the following information: the manufacturer's identification markings and numbers; the agency or firm for which the test was made; the NBS 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 to apply the results of the test to advantage. The authenticity of a certificate is evidenced by an 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 test when 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.

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

(a) Defects of design or workmanship, in general.

(b) Omission, where required, of ice point or other reference point.

(c) Part of graduated scale not usable.

(d) Defects in graduation or numbering, or graduation in unsuitable intervals.

(e) Omission of required marking on partial-immersion thermometers.

(f) Unsuitable glass in bulb.

(g) Inadequate annealing.

(h) Inadequate gas filling.

(i) Scale error in excess of tolerance.

(j) Not tested over entire range of scale.

5. Thermometer Design Requirements

The first requirements for certification are that the thermometer shall be of good design, material, and workmanship and shall be permanently marked with a serial number which will serve to uniquely identify the thermometer with its certificate of calibration. No attempt is made to list specifically all possible defects of design and workmanship, since some latitude for judgment must be reserved to deal with individual cases as they arise. Certain important requirements of general applicability can be singled out, however, and these are described below.

5.1. Materials of Construction

While the cleanliness of the thermometer bulb, bore, and liquid filling have a pronounced effect upon the performance of a finished thermometer, of equal importance is the proper choice of the glass from which the thermometer is manufactured. Particularly, the thermometer bulb must be made of a glass suitable for use in the temperature range for which the thermometer is graduated. In addition, the thermometer must be adequately annealed so that continued use will not greatly change its indications. This is especially important for a thermometer graduated above 300° C or 600° F. The quality of the thermometer glass and the adequacy of the annealing process may be judged in part by the stability of reference-point readings (such as ice points). To be eligible for certification, reference-point readings taken before and after test must not differ by more than the accuracy bounds stated for the particular type of thermometer in the applicable table in section 6.

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 must be gas filled to minimize the distillation of mercury from the top of the column. Gas filling for lower temperatures is optional, but is strongly recommended.

5.2. Scale Design and Workmanship

Thermometers of the plain-stem type shall have the graduation marks etched directly on the stem and so located as to be opposite the enamel back. In thermometers of the enclosed-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 enclosing tube—or if this is not done, a mark should be placed on the outer tube to locate the scale and indicate at any time whether the scale is in its original position. The graduation marks shall be clear cut, straight, of uniform width, and in a plane perpendicular to the axis of the thermometer. The spacing of the gradua-

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UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D. C.

National Bureau of Standards

Certificate

Liquid-in-Glass Thermometer

Tested for
National Bureau of Standards
Division 3, Section 1

Marked
Surety 1495

Range
-5° to +105°C in 0.2°

Thermometer Reading	Correction
- 0.02°C	+0.02°C
20.00	+ .02
40.00	- .02
60.00	+ .02
80.00	+ .04
100.00	+ .06

If the correction is + the true temperature is higher than the indicated temperature; if the correction is — the true temperature is lower than the indicated temperature. To use the corrections properly, reference should be made to the notes marked by asterisks on the reverse side of this sheet.

For the Director

Geneva Williams

Geneva Williams, Physicist
Thermometry Laboratory
Heat Division

Test No. G-25060
Completed: April 9, 1958
JST:dh

FIGURE 1. *Facsimile of face of a thermometer certificate.*

NOTES

* Note A.—The tabulated corrections apply for the condition of total immersion of the bulb and liquid column. If the thermometer is used at partial immersion, apply an emergent stem correction as explained in the accompanying stem correction sheet.

Note B.—The tabulated corrections apply for the condition of total immersion of the bulb and liquid column. Although this thermometer is not ordinarily used in this way, no significant errors should be introduced by neglecting the corrections for emergent stem.

Note C.—The thermometer was tested in a large, closed-top, electrically heated, liquid bath at an immersion of . 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 liquid column to differ markedly from that prevailing in the test, appreciable differences in the indications of the thermometer would result.

Note D.—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) by the same amount.

* Note E.—The tabulated corrections apply provided the ice-point reading, taken after exposure for not less than 3 days to a temperature of about 25° C (77° F) is −0.02°C . If the ice-point reading is found to be higher (or lower) than stated, all other readings will be higher (or lower) by the same amount. 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 F.—The tabulated corrections apply provided the reading when the thermometer is immersed in steam at 100° C (212° F) is If the reading is found to be higher (or lower) than stated, all other readings will be higher (or lower) by the same amount. The temperature of steam is 100° C (212° F) only if the pressure is 760 mm (29.921 inches). If the pressure differs from 760 mm (29.921 inches) allowance must be made for this. If the pressure is higher (or lower) than 760 mm (29.921 inches) the temperature will be higher (or lower) than 100° C (212° F) by approximately 0.037° C per mm difference (1.68° F per inch difference).

Note G.—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 H.—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 to the indications of one of them.

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

Note J.—The tabulated corrections apply for the condition of immersion indicated provided the ice-point reading, taken after heating to for not less than 3 minutes, is . If the ice-point reading, which should be taken within 5 minutes after removal of the thermometer from the heated bath, is found to be higher (or lower) than stated all other readings will be higher (or lower) by the same amount.

Figure 2. *Facsimile of back of a thermometer certificate.*

tions shall be free from significant irregularities which would produce uncertainties in the indications by amounts exceeding the limits otherwise set for the type of thermometer.

The scale shall be graduated either in 1.0-, 0.5-, 0.2-, or 0.1-degree intervals, or in decimal multiples or submultiples of such intervals. Thermometers with scales graduated in 0.25-degree intervals, or in 0.25-degree intervals further subdivided, have occasionally been submitted for test. Such thermometers are sometimes difficult to read and their elimination is desirable. The divisions shall be numbered in such a way that the identification of any graduation is not unnecessarily difficult. Thermometers graduated in 0.1- or 0.2-degree 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-degree intervals, or in decimal multiples or submultiples of 0.5 degree, require three lengths of graduation marks consisting of alternating short and intermediate marks, with every tenth mark distinctly longer than the others, and numbering at every 10th or 20th mark.

The range of scale must not be extended to temperatures for which the particular thermometer glass is unsuited. An example would be 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.

5.3. Dimensional Requirements of Scale

Excessively coarse graduation marks do not represent good design. The optimum line width, however, will depend in some measure upon the use for which a particular thermometer is intended. If the thermometer indications are to be observed precisely, for example to 0.1 division, the width of the graduation marks in the extreme case should not be more than 0.2 of the interval between center lines of the graduations. In cases where the thermometer must be read quickly or in poor light, and less precision is expected, somewhat wider lines may be acceptable.

In addition, the graduation marks must not be too closely spaced. The closest permissible spacing will depend upon the fineness and clearness of the marks. In no case, however, shall the distance between center lines of adjacent graduation marks on an etched-stem thermometer be less than 0.4 mm. The minimum permissible interval between graduation marks for an enclosed-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.

In order that a thermometer scale be usable over its entire range, graduation marks must not be placed too close to any enlargement in the capillary. Insufficient immersion of the mercury in the main bulb or a capillary enlargement, graduation marks placed over parts of the capillary that have been changed by manufacturing operations, or graduations so close to the top of the thermometer that excessive gas pressure results when the mercury is raised to this level, may lead to appreciable errors. The following distances between graduations and the bulb and between graduations and enlargements in the bore are considered as minimum limits for thermometers acceptable for certification:

(a) A 13-mm length of unchanged capillary between the bulb and the lowest graduation, if the graduation is not above 100° C (212° F); a 30-mm length if the graduation is above 100° C (212° F).

(b) A 5-mm length of unchanged capillary between an enlargement and the graduation next below, except at the top of the thermometer.

(c) A 10-mm length of unchanged capillary between an enlargement, other than the bulb, and the graduation next above, if the graduation is not above 100° C (212° F); a 30-mm length if the graduation is above 100° C (212° F).

(d) A 10-mm length of unchanged capillary above the highest graduation, if there is an expansion chamber at the top of the thermometer; a 30-mm length if there is no expansion chamber. For the purposes of this requirement, "an expansion chamber" is interpreted as an enlargement at the top end of the capillary bore which shall have a capacity equivalent to not less than 20 mm of unchanged capillary.

5.4. Reference Point on Scale

To be acceptable for certification, thermometers graduated above 150° C or 300° F, or precision thermometers to be certified to an accuracy better than 0.1° C or 0.2° F, when calibrated for the measurement of actual temperatures rather than temperature differences, must have a reference point at which the thermometer can be conveniently retested from time to time. From these reference-point tests, the effects of changes in bulb volume on the thermometer indications may be followed throughout the life of the thermometer, and the proper corrections applied at any time. If no suitable reference point such as the ice or steam point is included in the range of the main scale, a short auxiliary scale including a fixed point shall be provided. To avoid making the thermometer unduly long, an enlargement in the capillary may be introduced between the auxiliary scale and the main scale. The graduations on an auxiliary scale must extend for a short interval both above and below the reference point. Similarly, when the main scale ends near a temperature to be used as a reference point, the graduations must be continued for a short interval above or below the reference point as the case may be.

Any auxiliary scale must have graduations identical to those of the main scale, both dimensionally and in terms of temperature.

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.

5.5. Marking of Partial-Immersion Thermometers

Partial-immersion thermometers will not be certified unless plainly marked "partial immersion", or its equivalent (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 above the top of the bulb. Special partial-immersion thermometers adapted to instruments which fix definitely the manner of use (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 marked, although even in these cases it is desirable that the thermometers be marked "partial immersion".

6. Common Types of Thermometers and Factors Affecting Their Use

In this section the more common types of high-grade thermometers are mentioned briefly with a discussion of some of the factors affecting their use.

Tolerances allowed by the Bureau in issuing certificates are given in the tables for individual types of thermometers. The values of these tolerances are the same as those given in the fourth edition of Circular 8 (1926). The accuracy bounds shown in the tables may seem broad in some instances, but the definite limitations of liquid-in-glass thermometry become apparent when all factors are considered. For example, if one keeps expanding the scale for more precise reading by reducing the capillary-bore diameter, a practical limit is reached beyond which capillary forces will prevent a smooth advance or retreat of the mercury column. Particularly with a slowly falling temperature, the movement of the mercury meniscus may be found to occur erratically in steps appreciably large in comparison to the graduation interval. If the mercury and glass are clean, no significant sticking of the mercury column should occur if the diameter of the bore of circular cross section is at least 0.1 mm. Excessively elliptical or flattened bores are not recommended. It is evident from the above that increasing the length of a degree on the scale, for practical bulb sizes, improves thermometric performance to a certain point only, beyond which the precision of reading may readily be mistaken for accuracy in temperature measurement.

In addition, other factors such as ice-point changes, unless exactly accounted for, and differences in external pressure may account for inaccuracies much greater than the imprecision with which a scale having 0.1- or 0.2-degree graduations may be read.

6.1. Total-Immersion Thermometers

Thermometers pointed and graduated by the manufacturer to read correct, or nearly correct, temperatures when the bulb and entire liquid index in the stem are exposed to the temperature to be measured are known as "total-immersion" thermometers. While these thermometers are designed for complete immersion of all the mercury, it is not necessary, and in some cases not desirable, that the portion of the stem above the meniscus be immersed. The heating of this portion to high temperatures might cause excessive gas pressures resulting in erroneous readings if not permanent damage to the bulb.

In practice a short length of the mercury column often must be left emergent from the bath (or region) so that the meniscus will be visible when the temperature is being measured. If a large enough temperature difference exists between the bath and its surroundings, an appreciable temperature gradient may be found in the thermometer stem near the surface of the bath for which a correction to the thermometer reading may be required. The condition becomes more serious when a thermometer designed and calibrated for total immersion is intentionally used at partial immersion, that is with a significant portion of the liquid column at a temperature different from that of the bath. The reading will be too low or too high depending upon whether the surrounding temperature is lower or higher than that of the bath. For a total-immersion thermometer so used, an emergent stem correction must be determined and applied in addition to the calibration corrections. The correction may be as large as 20 Celsius degrees (36 Fahrenheit degrees) if the length of emergent liquid column and the difference in temperature between the bath and the space above it are large.

A method for determining this correction is given in section 10.2.

The scale tolerances allowed in awarding certificates to total-immersion thermometers are given in tables 1 and 2. These tolerances are based on the fact that in the manufacture of thermometers certain small errors in pointing and graduation 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.

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TABLE 1. *Tolerances for Celsius total-immersion mercury thermometers*

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
Thermometers not graduated above 150° C				
° *C*				
0 up to 150	1.0 or 0.5	0.5	0.1 to 0.2	0.1
0 up to 150	.2	.4	.02 to .05	.02
0 up to 100	.1	.3	.01 to .03	.01
Thermometers not graduated above 300° C				
0 up to 100	1.0 or 0.5	0.5	0.1 to 0.2	0.1
Above 100 up to 300		1.0	.2 to .3	.1
0 up to 100	.2	0.4	.02 to .05	.02
Above 100 up to 200		.5	.05 to .1	.02
Thermometers graduated above 300° C				
0 up to 300	2.0	2.0	0.2 to 0.5	0.2
Above 300 up to 500		4.0	.5 to 1.	.2
0 up to 300	1.0 or 0.5	2.0	.1 to 0.5	.1
Above 300 up to 500		4.0	.2 to .5	.1

TABLE 2. *Tolerances for Fahrenheit total immersion mercury thermometers*

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
Thermometers not graduated above 300° F				
32 up to 300	2 0	1.0	0.2 to 0.5	0.2
32 up to 300	1.0 or 0.5	1.0	.1 to .2	.1
32 up to 212	.2 or .1	0.5	.02 to .05	.02
Thermometers not graduated above 600° F				
32 up to 212	2 or 1	1.0	0.2 to 0.5	0.2
Above 212 up to 600		2.0	.5	.2
Thermometers graduated above 600° F				
32 up to 600	5	4.0	0.5 to 1.0	0.5
Above 600 up to 950		7.0	1. to 2.0	.5
32 up to 600	2 or 1	3.0	0.2 to 1.0	.2
Above 600 up to 950		6.0	.5 to 1.0	.2

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

Tables 1 and 2 also give suitable values for the subdivisions, the accuracy which may be expected, and the decimal figure to which the calibration corrections are stated for thermometers that have the ranges shown. The word "accuracy" used in these tables refers to the best values attainable in the use of the thermometer when all corrections are applied. The final columns state the magnitudes to which the corrections are given for thermometers calibrated by the Bureau. They are stated to somewhat higher accuracy than can be attained with certainty in calibrating the thermometers. This is done because it is preferable to give the corrections as found, since the results actually obtained are the best that can be deduced for the tests, and any rounding off might introduce an additional uncertainty.

6.2. Partial-Immersion Thermometers

In many instances it is required to measure temperatures under conditions where it is inconvenient or impossible to use a liquid-in-glass thermometer at total immersion. For such uses partial-immersion thermometers are designed with scales graduated to indicate true temperatures when the thermometers are immersed to specified depths. No stem temperature correction is necessary, therefore, when these thermometers are used with the same depth of immersion and emergent-stem temperature for which they are calibrated. Unless otherwise stated, each certificate of calibration issued by the Bureau gives corrections that apply for the temperatures prevailing above the comparison baths. When such a thermometer is to be used with a different stem temperature, the necessary emergent stem correction may be calculated as shown in section 10.3.

The accuracy attained with this type of thermometer will usually be significantly less than that possible with total-immersion thermometers. This is particularly the case when partial-immersion thermometers are used with stem temperatures greatly different than the temperature being measured. An unsteady or irreproducible environment surrounding the emergent stem, together with the inherent difficulty of estimating or measuring the emergent-stem temperature with sufficient accuracy, can contribute markedly to the uncertainty of a given thermometer indication. For this reason tables 3 and 4 show that accuracies expected of partial-immersion thermometers are not so high as those for total-immersion thermometers nor are the calibration corrections stated so closely.

TABLE 3. *Tolerances for Celsius partial-immersion mercury thermometers*

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy [a] in degrees	Corrections stated to
Thermometers not graduated above 150° C				
0 up to 150	1.0 or 0.5	1.0	0.1 to 0.5	0.1
Thermometers not graduated above 300° C				
0 up to 100	1.0	1.0	0.1 to 0.3	0.1
Above 100 up to 300	1.0	1.5	.5 to 1.0	.2
Thermometers graduated above 300° C				
0 up to 300	2.0 or 1.0	2.5	0.5 to 1.0	0.5
Above 300 up to 500		5.0	1.0 to 2.0	.5

[a] The accuracies shown are attainable only if emergent stem temperatures are closely known and accounted for.

Table 4. *Tolerances for Fahrenheit partial-immersion mercury thermometers*

Temperature range in degrees	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
Thermometers not graduated above 300° F				
32 up to 300	2.0 or 1.0	2.0	0.2 to 1.0	0.2
Thermometers not graduated above 600° F				
32 up to 212	2.0 or 1.0	2.0	0.2 to 0.5	0.2
Above 212 up to 600	2.0 or 1.0	3.0	1.0 to 2.0	.5
Thermometers graduated above 600° F				
32 up to 600	5.0 or 2.0	5.0	1.0 to 2.0	1.0
Above 600 up to 950	5.0 or 2.0	10.0	2.0 to 3.0	1.0

6.3. Low-Temperature Thermometers

The lowest temperature to which a mercury-filled thermometer can be used is limited by the freezing point of mercury at about −38.9° C (−38.0° F). This limit may be extended to considerably lower temperatures, however, by alloying thallium with the mercury. The eutectic alloy of 8.5 percent of thallium by weight has a freezing point of −59° C and is used successfully in thermometers for temperatures down to about −56° C. The freezing temperature of the alloy is critically affected in the neighborhood of the eutectic by the amount of thallium present. Small differences in composition, resulting in either too much or too little thallium, have the effect of markedly raising the freezing point of the alloy. It is therefore somewhat difficult to achieve the lowest freezing temperature in practice. In addition, some thermometers with this filling have been found to behave erratically in the range of about two degrees above the freezing point. For these reasons thermometers of this type probably should not be used below −56° C (−68.8° F).

Other low-temperature thermometers are commonly filled with organic liquids. While not considered to be as reliable as mercury-thallium-filled thermometers, they serve to extend the range below −56° C. Some of these liquids are used as low as −200° C (−328° F).

Alcohol, toluene, and pentane have all been used as fluids for low-temperature thermometers. All of these fluids, however, have limitations of one kind or another, but their performance can be improved for some uses by admixing other liquids. Other organic liquids, alone or in mixtures, have been found by some manufacturers to show better characteristics for particular applications.

All of these organic liquids have the disadvantage of wetting the bore of the thermometer tubing which may lead to significant error in the indications of such thermometers if sufficient precautions are not taken. Any liquid that wets the tube will leave a film on the wall as the meniscus falls, the thickness of the film being dependent among other things on the viscosity of the liquid, the interfacial action between the liquid and glass, and the rate at which the thermometer is cooled. Where possible the rate of cooling should be slow with the bulb cooled first. In this way the viscosity of the part of the filling fluid in the thermometer bore is kept as low as possible until the final temperature is reached, thus minimizing the amount of liquid left behind on the wall. Even so, sufficient time should be allowed for drainage from the wall to be essentially completed. Under adverse conditions it may take a very long time, an hour or more, before the effect of drainage is no longer noticeable.

In addition to having good drainage characteristics, a satisfactory low-temperature fluid should be free of water, dirt, or other foreign material which will crystallize or otherwise separate out at temperatures for which the thermometer is graduated. Furthermore, low-temperature thermometers are frequently designed for use up to room temperature or above. In these cases the vapor

Table 5. *Tolerances for low-temperature total-immersion thermometers*

Temperature range in degrees	Type of thermometer	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
Celsius thermometers					
−35 to 0	Mercury	1 or 0.5	0.5	0.1 to 0.2	0.1
−35 to 0	do	.2	.4	.02 to .05	.02
−56 to 0	Mercury-thallium.	.5	.5	.1 to .2	.1
−56 to 0	do	.2	.4	.02 to .05	.02
−200 to 0	Organic liquid.	1.0	.2	.2 to .5	.1
Fahrenheit thermometers					
−35 to 32	Mercury	1 or 0.5	1.0	0.1 to 0.2	0.1
−35 to 32	do	.2	0.5	.05	.02
−69 to 32	Mercury-thallium.	1 or .5	1.0	.1 to .2	.1
−69 to 32	do	.2	0.5	.05	.02
−328 to 32	Organic liquid.	2 or 1.0	3.0	.3 to .5	.2

Table 6. *Tolerances for low-temperature partial-immersion thermometers*

Temperature range in degrees	Type of thermometer	Graduation interval in degrees	Tolerance in degrees	Accuracy in degrees	Corrections stated to
Celsius thermometers					
−35 to 0	Mercury	1.0 or 0.5	0.5	0.2 to 0.3	0.1
−56 to 0	Mercury-thallium.	1.0 or .5	.5	.2 to .3	.1
−90 to 0	Organic liquid.	1.0	3.0	.4 to 1.0	.2
Fahrenheit thermometers					
−35 to 32	Mercury	1.0 or 0.5	1	0.3 to 0.5	0.1
−69 to 32	Mercury-thallium.	1.0 or .5	1	.3 to .5	.1
−130 to 32	Organic liquid.	2 or 1	5	.8 to 2.0	.5

pressure of the filling liquid becomes important. A low vapor pressure is necessary to prevent distillation of the liquid at the higher temperatures. Any dye added to improve the visibility of the thermometer liquid should be chosen for good color fastness with respect to light exposure or chemical action with the thermometer liquid.

Tolerances applicable to low-temperature thermometers are given in tables 5 and 6.

6.4. Beckmann Thermometers

A metastatic or Beckmann thermometer is usually of the enclosed-scale type, so constructed that portions of the mercury may be removed from, or added to, the bulb permitting the same thermometer to be used for differential measurements in various different temperature ranges. The scales are kept short, usually 0 degree to 5 or 6 degrees C, although some so-called micro types have a scale of only about 3 degrees C. The "setting" of such a thermometer refers to the temperature of the bulb when the reading is 0° on the scale. When the setting is changed to allow for use at a higher or lower temperature, the quantity of mercury affected by a temperature change is different. It follows that two equal changes in temperature at different settings cause different indications on the scale. Therefore a "setting factor" must always be used to convert reading differences into true temperature differences whenever the thermometer is used at any setting different from the one at which its scale was calibrated. These setting factors combine corrections for the different changes in volume of different quantities of mercury during equal temperature changes, and the difference between the mercury-in-glass scale and the International Temperature Scale.

Table 7 lists setting factors calculated for thermometers of Jena 16^{III} glass, or its American equivalent, Corning normal. The scale calibrations for Beckmann thermometers as reported by the Bureau are applicable to a setting of 20° C, and the factor is consequently 1.0000 at this temperature. For a setting of any other temperature the observed temperature difference must be multiplied by the appropriate factor from the table. An illustrative example is given below the table.

In a common design of the Beckmann thermometer the large bulb is joined to the fine capillary, backed by the milk-glass scale, by a capillary of much larger diameter. When such an instrument is used at partial immersion this large capillary is a source of some uncertainty, since the temperature of this relatively large quantity of mercury, enclosed in the glass case, cannot be actually measured. When an estimate can be made of the temperature of the emergent stem, however, a correction may be calculated as described in section 10.5.

Tolerance requirements for the certification of Beckmann thermometers are given in table 8.

Table 7. *Setting factors for Beckmann thermometers*

Setting	Factor	Setting	Factor
°C.		°C.	
0	0.9934	55	1.0096
5	.9952	60	1.0107
10	.9969	65	1.0118
15	.9985	70	1.0129
20	1.0000	75	1.0139
25	1.0015	80	1.0148
30	1.0030	85	1.0157
35	1.0044	90	1.0165
40	1.0058	95	1.0172
45	1.0071	100	1.0179
50	1.0084		

As an illustration, suppose the following observations were made:

Setting=25° C. Lower reading=2.058°
Stem temperature=24° Upper reading=5.127°

	Lower	Upper
Observed reading=	2.058	5.127
Correction from certificate=	+0.005	−0.008

Corrected upper reading=	5.119
Corrected lower reading=	2.063
Difference=	3.056
Difference multiplied by setting factor (1.0015)=	3.061
Emergent stem correction (see accompanying-stem correction sheet)=	+.004
Corrected difference=	3.065

Under the heading "Accuracy of interval in degrees" is given the estimated accuracy attainable in the measurement of any interval within the limits of the scale.

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

Table 8. *Tolerances for Beckmann and calorimeter thermometers*

Type of thermometer	Graduation interval in degrees	Allowable change in correction in degrees	Accuracy of interval in degrees	Corrections stated to
Beckmann	0.01° C	0.02 over a 1° interval for setting of 20° C.	0.002 to 0.005	0.001
Bomb calorimeter.	.01° C	0.03 over a 2° interval.	.005 to .01	.002
Do	.02° C	0.03 over a 2° interval.	.005 to .01	.002
Do	.05° F	0.08 over a 5° interval.	.01 to .02	.005
Gas calorimeter.	.1° F	0.15 over a 5° interval.	.02 to .05	.02

6.5. Calorimeter Thermometers

Calorimeter thermometers include a specialized group of etched-stem mercury-in-glass thermometers which are used for accurate differential measurements. Since, in the use of these thermometers, the accuracy at any one temperature is of less importance than the accuracy of the temperature intervals, no reference point is required for certification.

Table 8 gives the scale tolerances required of some typical calorimeter thermometers. No tolerances for scale error are given although it is desirable that the scale corrections be small.

6.6. Clinical Thermometers

Clinical, or medical, thermometers are small maximum-reading thermometers used in measuring body temperatures. In this country they are usually graduated in degrees Fahrenheit, and the range covers about 10 to 16 degrees Fahrenheit, from at least 96° to 106° F. When graduations are in degrees Celsius, the range usually covers 6 to 9 degrees Celsius, from at least 35° to 41° C. The bulb, made of a suitable grade of thermometer glass, has the least volume, that is, the least heat capacity consistent with a reasonably steady motion of the mercury along the very fine capillary of the lens front tubing. A constriction above the bulb formed by collapsing a bubble blown in the capillary permits the expanding mercury to pass when the bulb is being warmed, but is "tight" enough to prevent the retreat of the mercury after the warming ceases. At the same time, the constriction must be "loose" enough so that the mercury can be shaken down by hand or by whirling in a suitable centrifuge.

In order to accurately indicate the temperature of the body, the thermometer must be left in place for a time sufficiently long for all the mercury to reach the body temperature. For most thermometers this requires 3 min or more.

Clinical thermometers submitted to the Bureau are usually tested for compliance with Commercial Standard CS1–52. Thermometers meeting the requirements of this specification are marked NBS followed by a two-digit number indicating tne year in which the test was made. A note explaining the certification is issued with each thermometer certified.

7. Number and Choice of Test Points

In calibrating a thermometer, corrections to its indications must be determined at a number of test points sufficient to give reasonable assurance that the corrections between test points can be reliably obtained by interpolation. In general, if the readings of a thermometer are to to be trusted to one- or two-tenths of the smallest scale division, the interval between test points should not exceed 100 divisions and usually need not be less than 40. 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 considerable confidence as to its correctness. If interpolation 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-degree intervals at a series of points only 1 or 2 degrees apart. In general such requests are declined, since the extra work involved would not improve the accuracy of the calibration. In another case, a request may call for test at only two points on a long scale. 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 the use of the entire scale of the thermometer. In no case will a thermometer be tested at less than two points on the main scale nor will test of at least one reference point be omitted when such a point (or points) is included in the scale.

In general, when a thermometer is to be tested without reference to any special use, the choice of test 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 does 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.

For some special types of thermometers, set procedures have been established with regard to choice of test points. For example, Beckmann thermometers with scales 3 to 6° C long are calibrated every degree and calorimetric thermometers are calibrated every 2° C or 2.5° F.

8. General Calibration Procedures

At the Bureau all liquid-in-glass thermometers are calibrated in terms of the International Temperature Scale as defined by the indications of the standard platinum resistance thermometer. Indications of the thermometer under test may be compared directly with a resistance thermometer, or indirectly through the use of a mercury-in-glass standard, as the situation dictates. Through considerations of accuracy, direct comparisons are made with Beckmann thermometers, calorimeter thermometers, and thermometers graduated in tenths of a degree Fahrenheit. Below 0° C, all calibrations are made directly both for convenience and accuracy. Above 316° C (600° F), the platinum thermometer is used because of its greater stability. All other calibrations are generally made against mercury-in-glass standards (listed in section 2) which have been calibrated directly with a standard resistance thermometer.

When comparing thermometers with liquid-in-glass standards two standards are always used. In this way reading errors are more readily detected and cross checks of the standards are maintained. The comparison procedures are described in simplified form in the following hypothetical test of four thermometers (T1 through T4) which are assumed to have been found free of gross defects such as are discussed in section 5.

Table 9 shows the observations taken in obtaining the corrections applicable to the thermometers at 20°. To simplify the illustration, all of the entries in the table assume perfect thermometer performance and no observer error.

TABLE 9. *Comparison of test thermometers with liquid-in-glass standards*

	S1	T1	T2	T3	T4	S2
Ice-point readings of test thermometers						
Observer A	-----	+0.02	−0.02	+0.02	0.00	------
Observer B	-----	+.02	−.02	+.02	0.00	------
Mean ice points	-----	+.02	−.02	+.02	.00	------
Thermometer comparisons						
Observer A reading left to right	19.87	19.98	19.96	20.02	20.03	19.89
Observer A reading right to left	19.88	19.99	19.97	20.03	20.04	19.89
Observer B reading left to right	19.88	19.99	19.97	20.04	20.05	19.90
Observer B reading right to left	19.89	20.00	19.98	20.04	20.05	19.90
Means	19.88	19.99	19.97	20.03	20.04	19.89$_5$
Ice-point readings of standards						
Observer A	−0.01	-----	-----	-----	-----	−0.08
Observer B	−.01	-----	-----	-----	-----	−.08
Mean ice points	−.01	-----	-----	-----	-----	−.08
Calculations of corrections						
Correction to standards	+0.12	-----	-----	-----	-----	+0.04
Mean temperature, each standard	20.01	-----	-----	-----	-----	20.01$_5$
Mean temperature of all readings	-----	-----	20.01	-----	-----	-----
Corrections to test thermometers	-----	+0.02	+0.04	−0.02	−0.03	-----

The first observations are the ice points of the thermometers under test. These are entered in the upper part of the table. The thermometers are then mounted in the comparison bath between the two standards, and the power to the bath is so adjusted that its temperature is slowly increasing at a steady rate. The data shown in the table are for a temperature rise of 0.001° between each observation. Two observers (A and B) are used, first with one observer reading and the other recording, and next with the observers interchanged. Observer A reads in the order left to right as the thermometers appear in the table and then repeats the observations in the order right to left. Observer B then immediately reads in the same manner. The observations are spaced uniformly in time so that with the bath temperature increasing steadily with time, the mean of the observations with any one thermometer will correspond to the mean temperature of the comparison bath during the observations of all of the thermometers. Immediately after the comparison observations ice points are taken of the two standards. Using these ice-point data together with the known scale corrections for the standards, the temperatures indicated by the standards are calculated and an over-all mean temperature for the observations is obtained. This over-all mean temperature is compared with the mean of the observations with a particular thermometer to obtain a correction to the scale of the thermometer at this point. The thermometer comparisons are then repeated at the next higher test point and so on until corrections are obtained at a sufficient number of points to calibrate the complete scale, as specified in section 7.

Ice-point readings are not usually taken with each test point on the scale. For thermometers not graduated above 300° C or 600° F ice points taken before the first test point on the scale and after the last point will usually suffice. With high-temperature thermometers, however, it is the practice to take an ice point and then test immediately at the highest test point on the scale. After a rest period of 3 days at room temperature a second ice point is taken. If a change in ice point is found that is greater than the expected accuracy of the thermometer, the thermometer is deemed unsuitable for certification and further tests are unnecessary.

The corrections obtained in this manner apply as long as the ice point remains the same as that observed during calibration. Subsequent changes in the ice point will be a result of small changes in the glass which affect the volume of the thermometer bulb. The volume of the capillary stem also changes, but the volume of mercury contained in the stem is so small in comparison to that in the bulb that changes in the stem volume can usually be ignored. As a result, changes in the ice-point reading will be duplicated by similar changes in readings at each point along the scale. Thus, when during use the correction at the ice point is found to be higher (or lower) than that observed at the time of calibration, the other reported corrections to the scale can confidently be taken to be higher (or lower) by the same amount.

9. Testing Equipment

9.1. Ice Bath

Through the use of an ice bath, the ice point may be realized conveniently to better than 0.01° C. A thermos bottle or Dewar flask serves as a container for the ice, the melting of the ice being retarded by the insulating properties of such a vessel. Ice shaved from clear cakes and distilled water are mixed to form a slush. Enough water is used to afford good contact with the thermometers, but not so much as to float the ice. From time to time excess water is syphoned from the bath. Precautions are taken to prevent contamination of the ice and water. A small reading telescope with a magnification of about 10 diameters aids in reading the thermometer indication and reduces errors due to parallax. Gently tapping the thermometer just before reading may prevent the sticking of a falling meniscus. On the other hand too vigorous a tap will occasionally cause the mercury to rebound to an erroneously high reading.

9.2. Steam Bath

The steam point may be realized in a steam-point apparatus or hypsometer either by comparing the thermometers with standards or by the determination of the temperature of the steam from a measurement of the prevailing atmospheric pressure.

The steam bath shown in figure 3, consists of a double-walled steam jacket in which steam from a boiler circulates. The thermometers are suspended in such a manner as to insure free circulation of steam around them. Provision is made for either relieving any excess pressure in the space surrounding the thermometers, or for determining the excess by means of a small differential manometer.

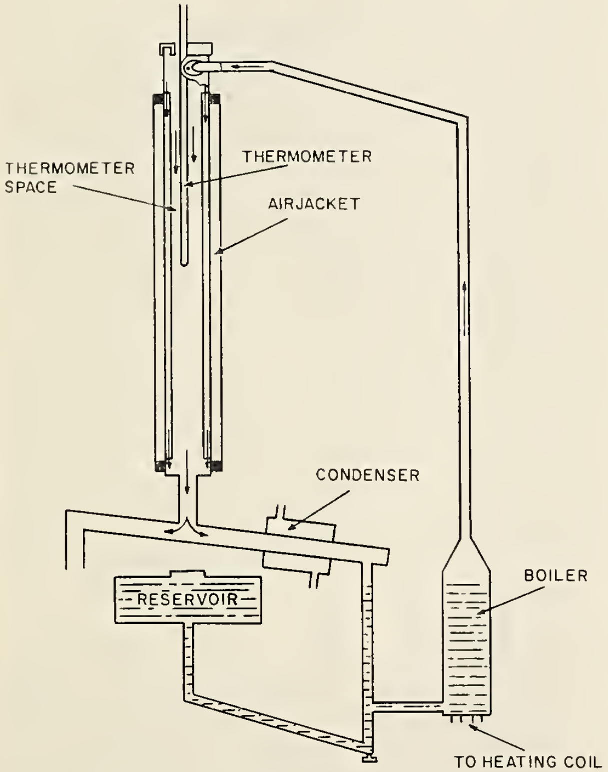

Figure 3. *Schematic drawing of steam bath.*

When the steam bath is used as a fixed-point apparatus a barometer is a necessary accessory since the true temperature of the steam is dependent upon the prevailing pressure. The usual corrections are applied to the barometer reading including any corrections necessary for the value of local acceleration of gravity, for the difference in height of the steam bath and the barometer, and for any excess pressure in the hypsometer. The steam temperature may then be found from the pressure-temperature values given in table 10, reproduced from a paper by Osborne and Meyers [2]. With a good barometer, accurate to 0.1 mm Hg, this procedure is capable of an accuracy of 0.002 to 0.003 degree C. The Fortin type barometer will usually serve for all but the most exacting measurements.

The steam bath is also used as comparison bath, in which case the temperature of the steam is determined at the time of test by means of a previously standardized thermometer. This method is simpler than determining the steam temperature from a barometer reading, and may be preferable, particularly when a resistance thermometer can be used as the standard.

9.3. Comparison Baths

Stirred liquid baths of two designs are used at the Bureau as comparators in which thermometers are calibrated in the range −40 to +500 degrees C. This equipment is of design appropriate to accommodate the thermometers to be tested, to permit stirring adequate for uniform temperature distribution, and to provide for controlled heat input for temperature regulation.

A type suitable for use with media which do not solidify at room temperature is shown in figure 4. This bath [3] is constructed with two tubes of different diameters having connecting passages at the top and bottom. The heating coil, cooling coil for circulating cold water for comparisons below room temperature, and stirrer are located in the smaller tube, the larger tube being left clear for immersion of the thermometers.

The type shown in figure 5 is designed for use at high temperatures with molten tin as the bath liquid. The bath is made with two coaxial tubes of which the inner tube is open at both ends. The stirring propeller is mounted near the bottom of the inner tube leaving the space above the propeller free to receive thermometers which are inserted in reentrant tubes. Heat is supplied by heater coils wound on the outside tube. As is also the case with the bath shown in figure 4, the thermometers are shielded from direct radiation from the hotter parts of the bath.

In both types of baths a 2- or 3-in. thickness of insulation reduces heat loss and thus aids in maintaining a uniform temperature distribution throughout the bath liquid. Each bath is provided with an insulated cover carrying a thermometer holder which can be rotated to bring

Table 10. *(Thermometric) condensation temperature of steam* [2]

[Star (*) indicates change in integer]

P	Pressure in mm mercury (standard)									
	0	1	2	3	4	5	6	7	8	9
	Temperature in degrees of International Scale									
500	88.678	0.730	0.782	0.834	0.886	0.938	0.990	*0.042	*0.093	*0.144
510	89.196	.247	.298	.350	.401	.452	.502	.553	.604	.655
520	0.705	.756	.806	.856	.907	.957	*.007	*.057	*.107	*.157
530	90.206	.256	.306	.355	.405	.454	.503	.553	.602	.651
540	0.700	.749	.798	.846	.895	.944	.992	*.041	*.089	*.138
550	91.186	.234	.282	.330	.378	.426	.474	.521	.569	.617
560	0.664	.712	.759	.806	.854	.901	.948	.995	*.042	*.089
570	92.136	.182	.229	.276	.322	.369	.415	.462	.508	.554
580	0.600	.646	.692	.738	.784	.830	.876	.922	.967	*.013
590	93.058	.104	.149	.195	.240	.285	.330	.375	.420	.465
600	0.5100	.5548	.5996	.6443	.6889	.7335	.7780	.8224	.8668	.9112
610	.9554	.9996	*.0438	*.0879	*.1319	*.1759	*.2198	*.2636	*.3074	*.3511
620	94.3948	.4384	.4820	.5255	.5689	.6123	.6556	.6989	.7421	.7852
630	0.8283	.8713	.9143	.9572	*.0001	*.0429	*.0857	*.1284	*.1710	*.2136
640	95.2562	.2987	.3411	.3834	.4257	.4680	.5102	.5523	.5944	.6365
650	95.6785	.7204	.7623	.8041	.8459	.8876	.9293	.9709	*.0125	*.0539
660	96.0954	.1368	.1782	.2195	.2607	.3019	.3431	.3842	.4252	.4662
670	0.5072	.5480	.5889	.6297	.6704	.7111	.7517	.7923	.8329	.8734
680	.9138	.9542	.9946	*.0349	*.0751	*.1153	*.1555	*.1956	*.2356	*.2756
690	97.3156	.3555	.3954	.4352	.4749	.5146	.5543	.5939	.6335	.6730
700	0.7125	.7519	.7913	.8307	.8700	.9092	.9484	.9876	*.0267	*.0657
710	98.1048	.1437	.1827	.2216	.2604	.2992	.3379	.3766	.4153	.4539
720	0.4925	.5310	.5695	.6079	.6463	.6846	.7229	.7612	.7994	.8376
730	.8757	.9138	.9519	.9899	*.0278	*.0657	*.1036	*.1414	*.1792	*.2170
740	99.2547	.2924	.3300	.3675	.4051	.4426	.4800	.5174	.5548	.5921
750	0.6294	.6667	.7039	.7410	.7781	.8152	.8523	.8893	.9262	.9631
760	100.0000	.0368	.0736	.1104	.1471	.1838	.2204	.2570	.2936	.3301
770	0.3666	.4030	.4394	.4758	.5121	.5484	.5846	.6208	.6570	.6932
780	.7293	.7653	.8013	.8373	.8733	.9092	.9450	.9808	*.0166	*.0524
790	101.0881	.1238	.1594	.1950	.2306	.2661	.3016	.3371	.3725	.4079

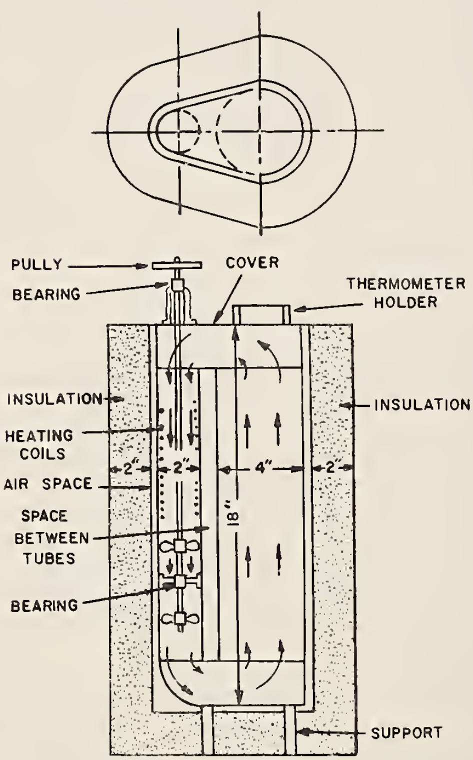

Figure 4. *Stirred bath for use with liquids which do not solidify at room temperature.*

successive thermometers into the field of a vertically adjustable reading telescope.

For calibrations in the range 5 to 99 degrees C, or 40 to 210 degrees F, water is used as the bath liquid. One grade of petroleum oil is used between 99° and 200° C and a second between 200° and 315° C. The oils are chosen with properties such that they are not too viscous for adequate stirring at the lower temperature and at the same time have flash points which are not exceeded at the higher temperatures. The tin bath is used from 315° C up to about 540° C.

Calibrations from 0° to −110° C are made in a cryostat similar in essentials to that described by Scott and Brickwedde [4]. The cryostat, shown in figure 6, consists of an inner Dewar flask, D, which contains the bath, surrounded by liquid nitrogen in the outer Dewar flask, C. The rate of heat transfer between the bath liquid and the liquid nitrogen is controlled by varying the gas pressure between the walls of the inner Dewar flask, which is connected to a vacuum system through the side tube, M. Vigorous stirring of the bath liquid is maintained by the propeller, I, which circulates liquid upwards through the inside of the stirrer tube, P, and down the outside. Excess refrigeration is compensated by thermostatically controlled heat supplied by the heater coil, J, wound outside the stirrer tube.

For temperatures down to −75° C, the bath liquid used is the eutectic mixture of carbon tetrachloride and chloroform (49.4 percent, by weight, of CCl_4 and 50.6 percent of $CHCl_3$), which freezes at about −81° C. For temperatures between −75° and −110° C a five-component mixture is used containing 14.5 percent of chloroform, 25.3 percent of methyl chloride, 33.4 percent of ethyl bromide, 10.4 percent of transdichloroethylene, and 16.4 percent of trichloroethylene. This mixture freezes at about −150° C, but absorbs moisture readily and becomes cloudy at somewhat higher temperatures.

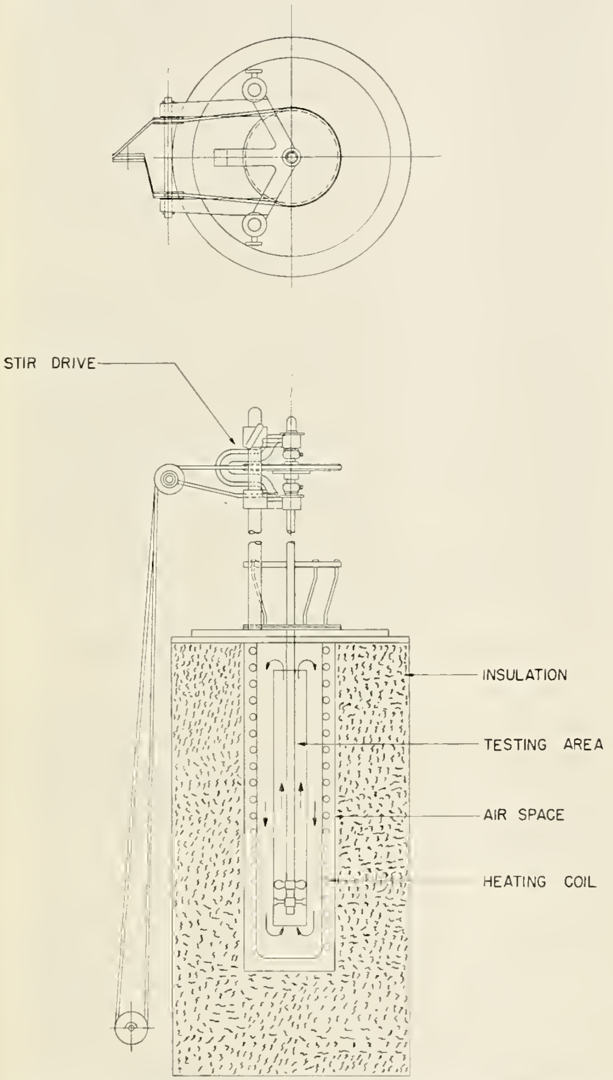

FIGURE 5. *Stirred bath suitable for use with liquids which do solidfy at room temperature.*

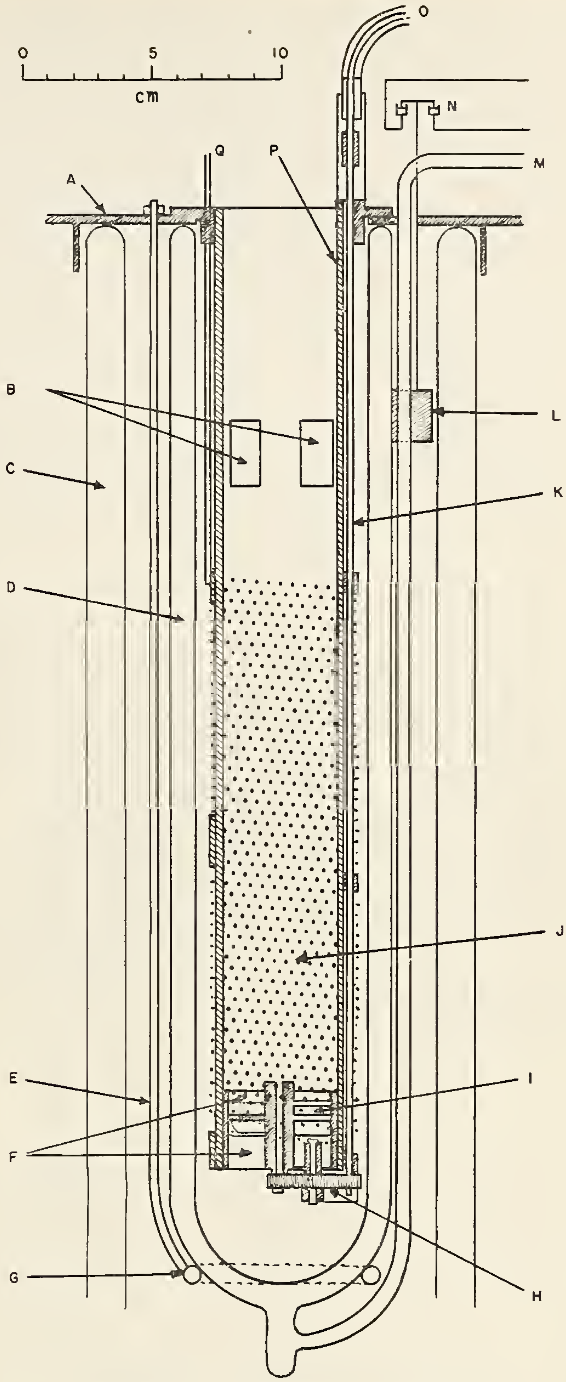

FIGURE 6. *Vertical section of cryostat.*

10. Corrections for Emergent Stem

The proper application of scale corrections as reported in NBS Certificates and Reports presents no difficulties in cases where thermometers are calibrated and used under conditions of total immersion. In such cases the temperature of the thermometer, including the stem up at least to the top of the mercury thread, is definitely specified and may be readily reproduced in use. Instances may occur in use, however, where some part of the mercury column is emergent from the region whose temperature is being measured. In these cases the emergent part of the stem may be in an environment not only in which the temperature is markedly different from that of the thermometer bulb, but in which pronounced temperature gradients may be present. If such a situation exists in the use of a thermometer which has been calibrated at total immersion, a correction may be calculated to account for the difference in temperature between the bulb and the emergent stem. The calculation of this correction requires a reliable estimate of the mean temperature of the emergent stem, which, for the best work, will be made from measurements. But if the stem temperature measurements are not repeated each time the thermometer is used, the accuracy of the correction will depend upon the constancy of the stem temperature over periods of time. For example, if the emergent stem is exposed to the air above a liquid bath, variations in ambient temperature and air circulation will sometimes cause significant variations in the temperature of the emergent stem.

The same situation can occur in the case of partial-immersion thermometers. For this type of thermometer, the reported scale corrections apply only for the indicated depth of immersion and a particular stem temperature. If the thermometer is then used under conditions where the mean stem temperature is different, the reported scale corrections are not applicable, and a stem temperature correction is required.

In the following paragraphs methods for determining stem temperatures and formulas for calculating the corrections are given. For a given known or assumed condition, the use of these formulas will serve to indicate the importance of the stem correction in relation to a desired accuracy, and the corrections can then be applied as necessary.

10.1. Measurement of Emergent-Stem Temperature

The mean temperature of the emergent stem may be measured approximately by means of one or more small auxiliary thermometers suspended near the emergent stem, or more accurately by exposing an exactly similar stem and capillary mercury thread beside the emergent stem and thus measuring its mean temperature [5]. This is conveniently carried out with a faden thermometer ("thread thermometer") in which the expansion of the mercury in a capillary tube (bulb) is measured in a still finer capillary stem.

The methods used at NBS in calibration work are based upon the use of faden thermometers whenever possible. These thermometers have very long bulbs (5 to 20 cm) with wall thicknesses and bore sizes nearly the same as the stem of an ordinary thermometer. They are calibrated to read approximately true temperatures when immersed to the top of the bulb. If a faden thermometer is immersed beside a thermometer to be observed, to such a depth that the top of the faden thermometer bulb is at the same level as the top of the mercury column in the thermometer, the faden thermometer reading will give approximately the mean temperature of the adjacent portion of the thermometer stem and mercury thread. For example, a faden thermometer with a 10-cm bulb will give the mean temperature of the adjacent 10 cm of the thermometer stem. This method of using the faden thermometer is convenient for correcting the readings of a total-immersion thermometer when being used at partial immersion. If the stem temperature of a partial-immersion thermometer is to be measured, one or more faden thermometers are mounted so as to indicate the mean stem temperature between the immersion mark and the top of the mercury column.

In calculating the correction for the emergent stem, it is convenient to express the length of thermometer stem adjacent to the faden bulb in terms of degrees on the thermometer scale. Thus, for a 10-cm faden thermometer, the number of degrees corresponding to 10 cm must be found by measurement of a portion of the thermometer scale. This measurement should be made over the portion of the graduated scale which was adjacent to the faden bulb. This is particularly important with high-temperature thermometers where the length of a degree is generally not the same at all parts of the scale.

10.2. Formula for Total-Immersion Thermometers

When a thermometer, which has been graduated and calibrated for use at total immersion is actually used at partial immersion, the correction for the emergent stem may be calculated by the general formula,

$$\text{stem correction} = Kn(T-t),$$

where

K = differential expansion coefficient of mercury (or other thermometric liquid) in the particular kind of glass of which the thermometer is made,

n = number of thermometer scale degrees adjacent to the faden thermometer,

t = average temperature of n degrees of the thermometer stem (faden thermometer reading),

T = temperature of the thermometer bulb.

The coefficient K is different for different kinds of glass, and even for the same glass, it differs for different temperature intervals, i. e., different values of $(T-t)$. Since, however, most of the change results from the varying coefficient of the mercury, the change in K with temperature for one glass may with some certainty be inferred from the change for another glass.

10.3. Formula for Partial-Immersion Thermometers

The scale corrections for partial-immersion thermometers calibrated at the Bureau are reported for the conditions of immersion to the depth of the immersion mark on the thermometer and unless otherwise requested, for the unspecified stem temperatures resulting from the particular environments prevailing over the comparison baths in the course of the calibration. Frequently, however, thermometers are submitted for calibration with a request for scale corrections which are applicable to a specified mean temperature of the emergent stem. In such cases the emergent stem temperatures are measured during the process of calibration. The calibration observations are then corrected as necessary to account for any differences found between the stem temperatures observed during test and the specified stem temperature for which the scale corrections are to apply. In this case, the magnitude of the stem correction is proportional to the difference between the specified and observed stem temperatures and may be calculated for Celsius mercurial thermometers by means of the relation,

$$\text{stem correction} = 0.00016n(t_{sp} - t_{obs}),$$

where

t_{sp} = specified mean temperature of emergent stem (for which reported scale corrections apply),

t_{obs} = observed mean temperature of emergent stem,

n = number of scale degrees equivalent to the length of emergent stem.

The above relation, of course, may also be used to correct the indications of a partial-immersion thermometer when used under stem-temperature conditions other than specified ones for which the scale corrections apply. In using the formula it should be noted that n applies to the whole length of emergent stem, i. e., from the immersion mark to the top of the mercury column. The ungraduated length between the immersion mark and the first graduation on the scale must therefore be evaluated in terms of scale degrees and included in the value of n.

For purposes of computing the emergent-stem correction, the value of K may be considered as depending on the average of T and t, that is $(T+t)/2$. Values of K as a function of $(T+t)/2$ for two widely used thermometer glasses are given in table 11. If the kind of glass is not known, K may be taken as 0.00016 for Celsius mercury thermometers and 0.00009 for Fahrenheit thermometers.

The calculation of the stem correction may be illustrated by the following example:

Table 11. *Values of K for mercury-in-glass thermometers*

Mean temp. $\frac{T°+t°}{2}$	K for "normal" glass	K for "borosilicate" glass
For Celsius thermometers		
0°	0.000158	0.000164
100	.000158	.000164
150	.000158	.000165
200	.000159	.000167
250	.000161	.000170
300	.000164	.000174
350	----------	.000178
400	----------	.000183
450	----------	.000188
For Fahrenheit thermometers		
0°	0.000088	0.000091
200	.000088	.000091
300	.000088	.000092
400	.000089	.000093
500	.000090	.000095
600	.000092	.000097
700	----------	.000100
800	----------	.000103

Suppose a total-immersion thermometer reads 90° C in a bath when immersed to the 80° C graduation mark on the scale, and a 10-cm faden thermometer placed alongside the thermometer is adjacent to the scale between 60° and 90° C. For this case $n=90-60=30$. If the faden thermometer indicates 80° C, then the stem correction $=0.00016\times30(90-80)=+0.048$, or $+0.05°$ C. Note that when the temperature of the emergent stem is lower than the bath temperature, the sign of the correction is +.

If a faden thermometer were not available in the above example, the emergent-stem temperature could be estimated by suspending a small auxiliary thermometer above the bath adjacent to the main thermometer and with its bulb centered at about the level of the 85° graduation. The reading of the auxiliary thermometer will then approximate the mean temperature of the 10 degrees C (80° to 90° C) emergent from the bath. For this condition $n=10$. If the auxiliary thermometer reads 60° C, the stem correction $=0.00016\times10(90-60)=+0.048$ or $+0.05°$ C. This method, however, will usually not be as reliable as the method using a faden thermometer.

10.4. Formula for Calorimeter Thermometers

The stem correction is often important when thermometers are used for differential temperature measurements, as in calorimetry. In this case, provided the mean temperature of the stem remains constant, the correction may be computed from the following formula, involving the difference of the initial and final readings:

$$\text{stem correction} = Kd(T_1 + T_2 - S - t),$$

where

K=factor for relative expansion of glass and mercury,
T_1 and T_2=the initial and final readings, respectively,
$d=T_2-T_1$,
S=scale reading to which the thermometer is immersed, and
t=mean temperature of the emergent stem.

This correction must be applied (added if +, subtracted if −) to the difference of the readings to give the true difference of temperature.

Example: Suppose the thermometer was immersed to its 20° mark; its initial reading, T_1, was 25° C; its final reading, T_2, was 30° C; and the stem temperature was 20° C. Then the correction is $0.00016\times5(25+30-20-20)=+0.012°$ C. The difference between T_1 and T_2 is 5°. The true difference between the initial and final temperatures was T_2-T_1+correction=5.012° C.

10.5. Formula for Beckmann Thermometers

For a Beckmann thermometer the correction may be readily computed from the following formula, differing only slightly from that for calorimeter thermometers, provided the thermometer is immersed to near the zero on its scale and that the temperature of the stem remains constant:

$$\text{stem correction}=Kd(S+T_1+T_2-t),$$

where

S=setting of the thermometer (section 6.4), and the other symbols have the same meanings as for calorimeter thermometers.

A Beckmann thermometer of the ordinary type should not be used with any part of the lower portion of the stem exposed, as this part may contain 5 to 10 times as much mercury per centimeter as the graduated portion and, if exposed, introduces a large and uncertain error. If it is unavoidable, however, to use such a thermometer with some of the lower portion of the stem emergent from the bath, the necessary correction may be computed from the above formula, provided S in the formula is replaced by $S+m$, where m is the number of degrees the temperature of the thermometer must be lowered to bring the meniscus from the zero mark on its scale to the point of immersion.

If the thermometer is immersed to some point other than its zero mark, as would ordinarily be the case with thermometers having the zero graduation at the top of the scale, the differential stem correction may be calculated from the above formula if S is replaced by $S+m$. The formula is applicable whether the point of immersion is on the scale or below it, provided the points at which readings are made are above the point to which the thermometer is immersed.

11. Lag of Thermometers

Practically all theoretical treatment of the question of thermometer lag is based on the assumption that Newton's law of cooling (i. e., that the rate of change in the reading of the thermometer is proportional to the difference between thermometer temperature and bath temperature) holds for the thermometer. It is an immediate consequence of this law that when a thermometer is immersed in any medium it does not take up the temperature immediately, but approaches it asymptotically. A certain time must elapse before the thermometer reading agrees with the temperature of the medium to 0.1 degree, still longer to 0.01 degree, the temperature remaining constant. If the temperature is varying, the thermometer always indicates, not the true temperature, but what the temperature of the medium was at some previous time. The thermometer readings are thus said to "lag" behind the temperature by an amount which may or may not be negligible, depending upon the rapidity of temperature variation and the construction of the thermometer. A more complete treatment of this subject has been given by Harper [6].

For a thermometer immersed in a bath, the temperature of which is changing uniformly, the lag may be defined as the interval in seconds between the time when the bath reaches a given temperature and the time when the thermometer indicates that temperature. This lag, λ, is dependent upon the dimensions and material of the thermometer bulb, the medium in which it is immersed, and the rate at which this medium is stirred. For instance, the lag when in the air of the room would be perhaps 50 times that of the same thermometer when immersed in a well-stirred water bath.

Since the value of λ for mercurial thermometers is not large, being from 2 to 10 sec in a well-stirred water bath, it is not generally necessary to correct for it. For example, if two thermometers, one having a lag of 3 and another of 8 sec, are read simultaneously in a bath whose temperature is rising at the rate of 0.001 degree in 5 sec, the former will read 0.001 degree higher than the latter, due to the lag. In the intercomparison of thermometers the rate of temperature rise may nearly always be kept so small that this lag correction is negligible.

If a thermometer at a given initial temperature is plunged into a bath at a different temperature, the lag, λ, is the time required for the original difference in temperature between thermometer and bath to be reduced to $1/e$ (that is 1/2.8) of itself. In a length of time 4λ the difference will have become about 1.5 percent and in a length of time 7λ about 0.1 percent of the original difference.

This shows that it is necessary to wait 10 to 45 sec after placing a thermometer in stirred water in order to get a reading correct to within 1 percent of the original difference between bath and thermometer.

When a thermometer is used to measure changes of temperature, as in calorimetry, it has been shown by White [7] that the lag enters into the observations in such a way as to be eliminated from the results in applying the usual radiation corrections. Therefore the lag need not be considered, provided only that the initial and final readings are made when the temperature is varying uniformly. This is not strictly true, however, in the case of some Beckmann thermometers that have no true value of λ, as has been explained in the paper referred to above.

An idea of the magnitude of the lag, λ, of thermometers of various types, when immersed in a well-stirred water bath, may be obtained from table 12.

Table 12. *Lag of thermometers*

Type of thermometer	Lag, λ
	sec
Laboratory thermometer, small bulb	2
Calorimeter thermometer, large bulb	5
Beckmann thermometer, large bulb	9
Inclosed capillary portion of Beckmann thermometer	50+

12. 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.

12.1. Gradual Changes in Glass

There is a gradual change in the volume of a glass thermometer bulb which will continue for years. This change manifests itself by a slow rise in the thermometer indications at all points. With better grades of thermometer glasses the change will not exceed 0.1° C in many years, provided the thermometer has not been heated to temperatures above about 150° C. In addition permanent changes in bulb volumes have sometimes been observed with thermometers which have been repeatedly cycled at low temperatures, for example between −30° and +25° C. Allowance for these changes can readily be made by determining the ice-point reading from time to time, since if the reading at this point is found to be higher (or lower) than at the time of test all readings will be higher (or lower) to the same extent.

12.2. Temporary Changes in Bulb Volume

When a thermometer which has been at room temperature for a long time 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 degrees C in about 3 days. Obviously, this phenomenon has an important bearing on the precision attainable with mercury thermometers and must be taken into consideration in precision thermometry, especially in the interval 0 to 100 degrees 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 degrees) 0.01 of a degree for each 10-degree 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-degree 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.

12.3. Changes in Bulb Volume 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 degrees 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 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.

13. Separated Columns

Many inquiries are received concerning separated mercury columns, particularly after shipment. Since no means of avoiding such occurrences has yet been found, the recourse of stating some directions for joining the mercury is adopted. The mercury may separate somewhat more readily in thermometers which are not pressure-filled, but it can be more easily joined since there is little gas to separate the liquid. The process of joining broken columns consists of one or a series of manipulations which may be effective, and these are briefly described here.

1. The bulb of the thermometer may be cooled in a solution of common salt, ice, and water (or other cooling agent) to bring the mercury down into the bulb. Moderate tapping of the bulb on a paper pad or equally firm object or the application of centrifugal force usually serves to unite the mercury in the bulb. If the salt solution does not provide sufficient cooling, carbon dioxide snow (dry ice) may be used. Since the temperature of dry ice is about −78° C and mercury freezes at about −40° C, it will cause the mercury to solidify. Care must be taken to warm the top of the bulb first so that pressures in the bulb due to the expanding mercury may be relieved. Care should also be taken in handling dry ice as it may cause severe "burns".

2. If there is a contraction chamber above the bulb or an expansion chamber at the top of the thermometer the mercury can sometimes be united by warming the bulb until the column reaches the separated portions in either enlargement. Great care is necessary to avoid filling the expansion chamber completely with mercury, which might produce pressures large enough to burst the bulb. Joining the mercury is more readily accomplished if the quantity in either cavity has first been shattered into droplets by tapping the thermometer laterally against the hand.

3. As a last resort, especially for thermometers having no expansion chambers, small separated portions of the column can sometimes be dispersed by warming, into droplets tiny enough to leave space for the gas to by-pass, and these droplets can then be collected by a rising mercury column.

The procedure for thermometers in which organic liquids are used is similar. Liquids in the stem can more readily be vaporized and may then be drained down the bore. The latter process is aided by cooling the bulb. All of these manipulations require patience, and experience is helpful, but they will yield results if care is used. A convenient method of ascertaining that all the liquid has been joined is a check of the ice point, or some other point on the scale.

14. General Instructions to Applicants for Tests

Tests in accord with the policies of the National Bureau of Standards, and of the types indicated in the fee schedules as published in the "Federal Register", will be undertaken. If need arises for a special test, not listed in the fee schedule but of a similar nature, the Bureau should be consulted. If the required measurements appear feasible, and, in the opinion of the Bureau, sufficiently important to justify the work, such tests will be undertaken for a special fee determined by the nature of the work. In all requests the following procedures and information are pertinent.

14.1. Initial Arrangements

A letter or purchase order, stating the tests desired and referring to the appropriate sections and subsections of the fee schedule, should be sent to the Bureau prior to any shipment. The purpose of this requirement is to determine whether or not the Bureau will undertake the test and to insure correct procedure in reporting, shipping, and billing. In the case of routine or periodic tests, of a type made in the past for the requester, this letter may be sent at the time shipment is made. In general, the purpose of the test and the manner in which the results are to be used should be stated. If the thermometer submitted has been previously calibrated by the Bureau, reference should be made to the former test number. A test number will be assigned by the Bureau to each project, and this test number must be referred to in all subsequent communications.

14.2. Shipping and Packing

Shipping charges, both to and from the Bureau, must be assumed by the applicant. Return shipments are made by the Bureau in accordance with its judgment of the best method of shipping unless specific instructions are received. Such instructions should be supplied at the time that arrangements are being made for the test. If a test number has been assigned prior to the shipment, this number should appear on the shipping container. If a test number has not been assigned at this time, an invoice, purchase order, or letter should be enclosed in the shipment for identification purposes.

All possible care will be taken in handling thermometers at the Bureau, but the risk of damage either in shipment or in testing must be assumed by the applicant. The applicant should consider the nature of the equipment he is shipping and pack it accordingly, with appropriate labeling. Attention is called to the availability of security express in shipping thermometers.

Appreciation is expressed for the use of the following material: (a) Figure 3, which first appeared in the Journal of the Optical Society of America; (b) figure 4, which first appeared in the Proceedings of the American Society for Testing Materials; and (c) section 13, Separated Columns, is from the paper by Johanna Busse, Liquid-in-glass thermometers, which appeared in the book, Temperature, its Measurement and Control in Science and Industry (Reinhold Publishing Corp., New York, N. Y.).

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