TESTING OF THERMOMETERS

Department of Commerce and Labor
BUREAU OF STANDARDS
Washington

BUREAU CIRCULAR NO. 8

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By an act of Congress approved March 3, 1901, the Office of Standard Weights and Measures of the Treasury Department was, on July 1, 1901, superseded by the Bureau of Standards. The Bureau was transferred to the Department of Commerce and Labor July 1, 1903, by the act establishing that Department.

The functions of the Bureau of Standards are as follows: The custody of the standards; the comparison of the standards used in scientific investigations, engineering, manufacturing, commerce, and education, with the standards adopted or recognized by the Government; the construction, when necessary, of standards, their multiples and subdivisions; the testing and calibration of standard measuring apparatus; the solution of problems which arise in connection with standards; the determination of physical constants and the properties of materials. The Bureau will also furnish such information concerning standards, methods of measurement, physical constants, and the properties of materials as may be at its disposal. It is authorized to exercise its functions for the Government of the United States, for State or municipal governments within the United States, for scientific societies, educational institutions, firms, corporations, or individuals engaged in manufacturing or other pursuits requiring the use of standards or standard measuring instruments.

For all comparisons, calibrations, tests or investigations, except those performed for the Government of the United States or State governments, reasonable fees will be charged.

INTRODUCTION.

This circular has been enlarged beyond the scope of a table of fees in order to answer as far as possible the inquiries that are addressed to this Bureau from time to time concerning temperature measurements, methods of using thermometers, specifications for and construction of thermometers to meet special problems, regulations governing their acceptance for test, etc. Some of the important thermometric properties of different kinds of glass, and their proper treatment, together with the essential requirements of a reliable thermometer, are emphasized in the hope of bringing about an improvement in the product, which is often not constructed according to the best practice of the present day.

Thermometers of glass filled with mercury, alcohol, toluene, petroleum-ether, pentane, or other suitable thermometric liquid, whose construction satisfies the requirements herein specified, will be accepted for comparison with the standard thermometers of this Bureau. Primary standard mercurial thermometers will be accepted for calibration and determination of pressure coefficients and fundamental interval.

NOTE.—Special circulars on Testing of Clinical Thermometers (No. 5) and on Pyrometer Testing and Heat Measurements (No. 7) have been issued by the Bureau.

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REGULATIONS GOVERNING APPLICATIONS FOR TEST.

Application for Test.—The request for verification of any instrument should state explicitly the nature of the test to be made—for example, the temperatures at which thermometers are to be tested, the depth of immersion during the test, or any other conditions which the applicant wishes to have observed. Whenever possible, the request should be accompanied by the fee shown in the appended schedules.

Identification Marks.—Instruments and the packages in which they are shipped should both be plainly marked to facilitate identification, preferably with the name of the manufacturer or shipper, and a special reference number should be given to the article.

Packing.—The greatest care should be exercised in packing thermometers. They should be wrapped in some soft material which will lessen the effect of jars but will not permit any appreciable movement of the thermometers in the surrounding casing or box, which should be placed inside another box from which it is separated on all sides by excelsior or other suitable packing. Proper packing is emphasized because an unduly large percentage of the thermometers shipped to the Bureau for test are broken when received.

Shipping Directions.—Instruments should be securely packed in cases or packages which may be used in returning them to the owner. Tops of cases should be screwed down whenever possible. Transportation charges are payable by the party desiring the test, and should be prepaid. Unless other arrangements are made, articles will be returned by express "collect."

Address.—Articles should be addressed simply, "Bureau of Standards, Department of Commerce and Labor, Washington, D. C." Delays incident to other forms of address will thus be avoided.

Articles delivered in person or by messenger must be left at the office of the Bureau and must be accompanied by a written request for the verification.

Remittances.—Fees should be sent with the request for test in accordance with the schedules of fees following, and should be remitted by United States postal money order or by express money order drawn to the order of the "Bureau of Standards."

Delays in forwarding fees will involve corresponding delay in the completion of tests, as the articles are not returned until all fees due on them have been received.

TEST REQUIREMENTS.

In general, thermometers showing defective construction will not be received for test, but when such thermometers are tested attention will be called to the defects in the certificate of test.

Attention is directed below to a few of the essential requirements for a reliable thermometer.

1. The graduations must be ruled either directly on the stem, which is always preferable, or on a scale securely and firmly fastened to the stem. In the latter case a fiducial mark must be found on the stem coinciding with a mark on the scale, so that any relative displacement can be controlled.

2. The divisions of the stem should be numbered at such frequent intervals and in such a way that the identification of any graduation mark is not unnecessarily difficult. The bore and the spacing of the graduations should be uniform and free from such irregularities as would produce uncertainties in the indications by amounts exceeding the limits otherwise set by the type of thermometer.

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3. The width of lines should in no case exceed 0.2 of the smallest scale divisions, and should preferably be less than 0.1 where the corrections are desired to 0.1 of the smallest scale division. If the width or the form of the graduations introduces too great uncertainty in the scale readings, the corrections will be given only to the smallest scale division.

4. The thermometer should have a few graduations beyond the extreme points or temperatures that are to be tested.

5. All standard hypsometric and calorimetric thermometers should have a pear-shaped reservoir at the upper extremity of the capillary tube. This auxiliary reservoir is also highly desirable in most of the other types of thermometers, as it makes possible the calibration of the stem, allows the removal of air from the mercury column, and diminishes danger of breakage due to overheating.

6. Every thermometer submitted for test must pass a preliminary examination for details of construction, such as, for example, fineness and uniformity of graduation and uniformity of caliber, cleanliness of the mercury and capillary tube and freedom from moisture, air bubbles, cracks in the glass, etc. Tests are also made on the change of the zero after repeated heatings and on the amount of the zero depression, as a check on the reliability of the indications and the properties of the glass of which the thermometer is constructed. If these experiments show that the thermometer has not been sufficiently aged by a suitable process of annealing, or that it is constructed of glass having an unduly large hysteresis effect, certification may be refused.

If in this preliminary test a thermometer shows evidence of insufficient annealing, it will, *if accepted for test*, be first thoroughly annealed, for which an additional charge will be made.

If a thermometer has not been annealed, its zero reading (freezing point) will be permanently raised each time it is heated. In high temperature mercurial thermometers this total change may exceed 25° C. This difficulty may be obviated, when the better grades of thermometric glass are used, by annealing the thermometer at a temperature of 450° C. or over for a period of at least seventy-five hours.* It is desirable that this annealing be carried out by the maker before the final graduation of the thermometer. There is a slow rise of the zero which goes on for years, even if the thermometer is maintained at a constant temperature; but with thermometers of suitable glass that have been properly annealed this change is very small, and should not exceed 0.1° C. in some years, for thermometers that are used at ordinary temperatures. The importance of proper annealing is emphasized because a large number of the high-temperature thermometers received for test are defective in this respect.

The depression† of the zero after the thermometer is heated to 100° C. (212° F.) should not exceed 0.1° C. (0.2° F.). The amount of this "zero depression" for some of the most widely used thermometric glasses is given in the following table:

Zero depression in thermometers made of different kinds of glass.

Kind of glass.	Dep. of zero after 100° C.
Jena 59^{III}	0.02° C.
Jena 16^{III}	0.05° to 0.07°.
Verre dur	0.07° to 0.10°.
English crystal	0.18° about.

*The results of investigations on the annealing of mercurial thermometers, carried out by this Bureau, are printed in Bulletin of the Bureau of Standards, Vol. 2, No. 2, and in Reprint No. 32.

† Difference in ice-point reading before and immediately after thermometer is heated to 100° C. (212° F.).

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Thermometers made of the better grades of thermometric glass, after heating, assume their final condition of equilibrium in a few minutes, while those made of glasses having large zero depression take an hour or more. Further, in the former the recovery of the zero is much more rapid, taking but a few days, while with the latter it requires months.*

7. It is highly desirable that all thermometers should have on their scales the freezing point (0° C. or 32° F.) or the boiling point (100° C. or 212° F.), preferably the former, so that the changes in the glass referred to above can be followed and the proper correction applied. This construction is essential in all precision and laboratory thermometers for use at ordinary temperatures when a precision of 0.1° or better is desired, in limited-scale thermometers such as clinical standards, and in all high-temperature thermometers in which the changes may amount to many degrees.

8. Thermometers showing careless workmanship or having any defects of construction that are likely to lead to significant uncertainties in the use of the instrument will not be certified. The Bureau of Standards reserves the right in every instance to decide as to the acceptance of the instrument for test.

GENERAL CONDITIONS OF TEST.

The exact conditions prevailing during the test, for which the table of corrections applies, will be stated in the certificate. In general, however, the corrections will be given for the condition corresponding to what is termed "total immersion," i. e., when the mercury in the bulb and in the stem are both at the temperature of the bath in which the thermometer is immersed. If a thermometer is used under any other conditions, the certificate issued with it will give the necessary data for applying the "stem correction."

If desired, the corrections will be determined for the thermometer immersed to the depth at which it is to be used, provided that the Bureau's comparators admit of it. When the thermometers are of such length and form that they can not be readily adapted to the Bureau's comparators, and require for their test the construction of special apparatus, an additional charge will be made.

The number of points at which tests will be made and the order of accuracy of the corrections will depend upon the intended use of the thermometer, its graduation, the fineness of the lines, the kind of glass of which it is made, etc. The order of accuracy of the corrections will, in general, be stated in the certificate.

It is always desirable that a statement should accompany the thermometer when it is sent in for test, giving the order of accuracy desired, the portion of the scale which it is desired to know with the greatest accuracy, and the conditions under which the thermometer is to be used (i. e., depth of immersion, usual room temperature, etc.). If this information accompanies the transmitting letter, the necessary data will be at hand to determine the number and distribution of the points at which tests should be made.

If desired, the corrections will be given to one-tenth the smallest interval of graduation, provided that this interval is not too short (not less than 0.4 or 0.5 mm.), and that the graduations are sufficiently fine and uniform and the construction and behavior of the thermometer warrant this order of accuracy.

In general it may be stated that if the readings of a thermometer are to be trusted to one-tenth of the smallest scale division, the interval between test points should not exceed

* Further details of experiments on the effects of annealing, as well as on the physical and chemical properties of various glasses, and references to the original papers, will be found in Guillaume's Thermométrie de Précision, Hovestadt's Jenaer Glas, and in the Thermometric Researches of the Physikalisch-Technische Reichsanstalt.

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50 divisions. For ordinary thermometers graduated in 1° or 2° intervals, when the corrections are given only to the nearest degree, test points 100° apart are often sufficiently near together.

METHODS OF USING PRECISION THERMOMETERS.

Owing to the imperfect elastic properties of glass, which manifest themselves in the depression of the zero, with its slow recovery, varying widely for different glasses, the indications of a thermometer will depend on its previous treatment, i. e., if a given temperature were measured with the same thermometer, first after it had been for a long time at room temperature, and second soon after it had been at 100° C., the indications would differ from one another by amounts depending on the quality of the glass—a half degree or more for some of the inferior glasses, and only a few hundredths for the better glasses. Pernet* has shown that these effects of imperfect elasticity can be eliminated and the indications of a thermometer rendered independent of its previous treatment by determining immediately after each temperature measurement the zero corresponding to that temperature and using as the fundamental interval the distance between the 100° C. point and the zero determined immediately after. When the corrections are desired to a high order of accuracy, 0.01° or 0.02°, this procedure is always followed.

For the ordinary ranges of temperature (0° C. to 100° C.) the comparisons are carried out in a comparator which has been briefly described in the Physical Review for July, 1904, page 52.

In making observations with precision thermometers it is important that the temperature should not be falling, for the meniscus in any thermometer usually falls in steps of greater or less length and of no uniformity. Often one thermometer will indicate an absolutely constant temperature, while another beside it will show that the temperature has fallen a hundredth of a degree or more. The only safe way is to take all observations with a rising meniscus. A slowly varying temperature also tends to reduce errors of observation, since it requires readings in different positions relative to the scale, preventing the repetition of the same error of estimation.

Another important source of error in the use of thermometers arises from parallax. When a thermometer is made without an opaque backing this error may be eliminated by taking readings first with the divisions before and then with the divisions behind the mercury, without varying the line of sight, and taking the mean of the two readings. For thermometers with opaque backs this result may be attained by taking care that the reflection of the scale can be seen in the mercury thread and adjusting so that the line of the scale nearest the meniscus exactly hides its own image. The line of sight will then be normal to the stem at this point.

Further details of the method of using a thermometer to obtain results of the highest precision are given in references previously cited (see footnotes).

CORRECTIONS FOR EMERGENT STEM.

If a thermometer is used under conditions other than those corresponding to total immersion, as explained under "General conditions of test," which is the case when the stem emerges from the bath or medium whose temperature is to be measured, the emergent stem and contained mercury may be at a temperature very different from that of the bath. When a thermometer is used in this way, it is necessary to apply a correction for emergent

* Pernet, Trav. et Mém. du Bur. Int. des Poids et Mésures, t. 1.

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stem. This so-called "stem correction" is very large if the number of degrees emergent and the difference of temperature between the bath and the space above it are large. It may amount to more than 20° C. for measurements made with a mercury thermometer at 400° C. (750° F.).

The amount of this stem correction may be computed approximately by means of the following formula:

$$\text{Stem correction} = 0.00015 \times n \times (T - t) \text{ C}^\circ.$$

$$\text{Stem correction} = 0.000085 \times n \times (T - t) \text{ F}^\circ.$$

Where n = number of degrees emergent from the bath;
T = temperature of the bath;
t = mean temperature of the emergent stem.

The mean temperature, t, of the emergent column may be approximately measured by means of a small auxiliary thermometer suspended near it, or by surrounding the stem with a small water jacket, and taking the temperature of the water with the auxiliary thermometer, or, more accurately, in the way suggested by Guillaume, who exposes a capillary mercury thread beside the stem and thus measures its mean temperature by the expansion of the mercury thread. This is even more conveniently carried out by the Fadenthermometer of Mahlke,* in which the expansion of the mercury in the long capillary (bulb) is measured by means of a still finer capillary stem.

TEMPERATURE SCALE.

It is well known that the scale of temperature defined by any thermometer consisting of a glass envelope filled with a liquid is dependent upon the composition and treatment of the glass. Even samples of glass from the same pot show differences in this respect. Mercury thermometers, although capable of very great precision when properly constructed and used with due precautions, are therefore not suited to establish the standard scale of temperature.

The temperature scale which has come into almost world-wide use in the interval —35° C. to +100° C. is the hydrogen scale of the International Bureau of Weights and Measures, as defined by the following resolution of the International Committee on Weights and Measures, adopted October 15, 1887: "The International Committee on Weights and Measures adopts as the standard thermometric scale for the international service of weights and measures, the centigrade scale of the hydrogen thermometer, having as fixed points the temperature of melting ice (0°) and of the vapor of distilled water boiling (100°) at standard atmospheric pressure; the hydrogen being taken at an initial manometric pressure of 1 meter of mercury, that is to say, $\frac{1000}{760} = 1.3158$ times the standard atmospheric pressure."

On this scale of temperature, therefore, 1 degree centigrade is measured by $\frac{1}{100}$ of the change in pressure, between the two fixed points, of the confined mass of hydrogen gas, whose volume is kept constant, and whose initial pressure (at 0° C.) is equivalent to 1 meter of mercury (at 0° C., lat. 45°, sea level).

For temperatures in the interval —35° C. to +100° C., the standard scale of temperature adopted by this Bureau is the international hydrogen scale, defined by the mean indications of a number of primary standard mercurial thermometers, constructed by Baudin and by Tonnelot, which have been carefully studied and compared at various times with the standards of the International Bureau.

* Mahlke, ZS. f. Instrk., **13**, p. 58, 1893; Wied. Ann., **53**, p. 987, 1894.

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As hydrogen gas is not well adapted for use at high temperatures, on account of its great chemical activity and the ease with which it diffuses through the walls of the containing envelope, the standard scale of temperature used in the interval 100° C. to 550° C. (and higher in pyrometric work) is that defined by the nitrogen-gas thermometer. This scale is fixed by the mean indications of a number of platinum resistance thermometers.

In the interval —35° C. to —200° C., or lower, the standard scale is fixed by the mean indications of a number of platinum resistance thermometers that are referred to the scale of the hydrogen-gas thermometer by calibration at three known temperatures (steam, ice, boiling point of oxygen).

PRIMARY STANDARD THERMOMETERS.

By the term primary standard thermometer is meant a thermometer that defines within itself a scale of temperature. These thermometers must therefore have on their scale the two fixed points 0° C. and 100° C. Experience has shown that the length of one degree which best satisfies the requirements for primary standards in the interval 0° C. to 100° C. is about 6 or 7 mm (not less than 5 mm); for the higher temperatures the length of the degree may be less. In order not to unduly increase the length of the thermometer the scale of a primary standard need include only the region in which it is intended for use, e. g., 0° C. to 50° C., 100° C. to 200° C., etc. It must, however, be so constructed, by suitable auxiliary reservoirs in the stem, that it contains the two fixed points, and, further, that the volume of any part of the stem can be referred to the fundamental volume between the 0° C. and 100° C. marks. Types of construction of primary standard thermometers are shown in the following illustration:

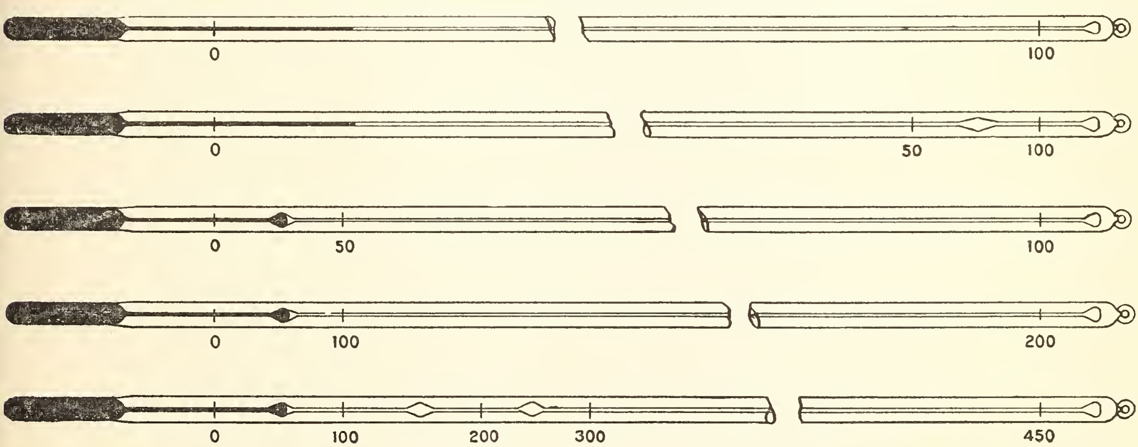

Fig. 1.—Primary Standard Thermometers.

If a number of such thermometers were made of the same specimen of glass, subjected to the same treatment, they should agree well among themselves, and they would serve to fix a definite scale of temperature for that particular kind of glass; and if the scale defined by this glass had previously been compared with that defined by the gas thermometer, it would then be possible to express the indications of the mercury in glass thermometer as temperatures on the scale of the standard gas thermometer. The scales defined by a number of the best thermometric glasses (verre dur, Jena 16^{III}, Jena 59^{III}) have been compared, either directly or indirectly, with the hydrogen scale of the International

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Bureau, so that the indications of primary standard thermometers made of these glasses can be used to measure temperatures on the international hydrogen scale.

As stated above, primary standards made from the same specimen of glass should be in agreement among themselves, but in order that this might be the case it would be necessary that the thermometers be perfect in every respect, which can not, of course, be realized in practice. They must therefore be constructed in such a way that the necessary corrections may be readily determined and applied. One of the two fixed points is determined in a mixture of pure ice and distilled water (0° C.) and the other in the vapor of pure water boiling under standard atmospheric pressure (100° C.). In a perfect thermometer the interval between these points would be divided into 100 parts of equal volume. In the practical construction of thermometers this is approximately done by *calibrating the tube* by sliding mercury threads along the capillary and observing their lengths in various positions. By this method good laboratory and commercial thermometers can be constructed that may be depended upon to a few hundredths of a degree. For primary standards, however, this method of construction is not permissible, for here the correction for variation in caliber must be known to a far higher degree of accuracy and must be determined by the most careful calibration of the tube. The amount of work involved in the calibration is very greatly increased if the divisions are irregularly spaced. The tube of which the thermometer is made must be carefully selected by a preliminary calibration and must be *very uniform* in cross section. The greatest difference in the calibration corrections must not exceed 0.2° C. or 0.3° C. at most. After the positions of the fixed points are determined, the space between must be divided into *parts of equal length*. For this puropse a dividing engine should be used whose screw has been very carefully studied for progressive and periodic errors. As the length of a degree is generally about 5 to 7 mm in primary standards, the accidental errors of ruling should be kept within a few thousandths of a millimeter. The graduation marks on the stem must be very fine and clear, and their thickness must not be greater than 0.1 of the smallest scale interval and should, preferably, be much less.

The indications of thermometers will also be influenced by variations of pressure on the outside of the bulb due to variations of atmospheric pressure and of the pressure of the medium in which the bulb is immersed, and by the pressure from within due to the mercury column of the thermometer itself and to capillary forces. For this reason it is necessary to determine the *external and internal pressure coefficients* so that the indications of the thermometer can be reduced to standard conditions, i. e., to an external pressure of 760 mm and an internal pressure of zero (really the somewhat variable pressure of the mercury meniscus) corresponding to the horizontal position of the thermometer.

Further, as it is not possible for the maker to locate without error the fixed points, these must be determined with the greatest care, in the manner already indicated, by observing the reading of the thermometer in steam, and the corresponding barometric pressure; and immediately after, before any recovery of the zero shall have taken place, the reading in ice. This gives the value in degrees of the interval between the fixed points, called the *fundamental interval* of the thermometer, and therefore the value of one division in degrees. The fundamental interval should not be in error by more than 0.1° C.

The stem of the thermometer must be transparent, so that the errors of parallax can be avoided by taking the mean of the readings with the scale before and the scale behind the mercury column; for this reason the use of the enamel-back stem is not permissible in primary standard thermometers.

As the amount of work involved in the study of a primary standard thermometer is very great, and the order of accuracy aimed at is a few thousandths of a degree, the

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requirements that have been discussed, which are based on the elaborate and painstaking researches carried out at the International Bureau of Weights and Measures and at the Physikalisch-Technische Reichsanstalt, are essential to the acceptance of such thermometers for test as primary standards.

As an illustration of the methods of reduction of the readings of a primary standard the following example has been added:

Thermometers Baudin 15555 and Tonnelot 4334 were read in a vertical position in a well-stirred water bath. The bulbs were 60 cm below the surface, and the reduced barometric pressure was 768 mm. The zeros as given below were determined immediately after the preceding temperature measurement.

Reduction of readings and determination of zero in primary standard thermometers.

Baudin 15555.		Tonnelot 4334.	
Observed reading	43.435°	Observed reading	43.491°
Calibration correction	+.021°	Calibration correction	—.081°
External pressure correction	—.006°	External pressure correction	—.005°
Internal pressure correction	+.069°	Internal pressure correction	+.048°
Zero correction	—.069°	Zero correction	+.025°
	43.450°		43.478°
Fundamental interval correction	—.009°	Fundamental interval correction	—.035°
Temperature on the scale of mercury thermometer	43.441°	Temperature on the scale of mercury thermometer	43.443°
Correction to hydrogen scale	—.107°	Correction to hydrogen scale	—.107°
Temperature on hydrogen scale	**43.334°**	Temperature on hydrogen scale	**43.336°**
Observed zero	+.061°	Observed zero	=—.033°
Calibration correction	.000°	Calibration correction	.000°
External pressure correction	.000°	External pressure correction	.000°
Internal pressure correction	+.008°	Internal pressure correction	+.008°
Reduced zero	+.069°	Reduced zero	—.025°

Fees—Schedule 31—Primary standard thermometers.

(*a*) Calibration with use of single mercury thread	$5.00
(*b*) Calibration by the Neumann-Thiesen method into 5 intervals, and subcalibration of each interval for every 2°	20.00
(*c*) Determination of the internal and external pressure coefficients	5.00
(*d*) Determination of the fundamental interval	5.00

LOW-TEMPERATURE THERMOMETERS.

For the measurement of temperatures below —30° C. there are available alcohol, toluene, petroleum-ether, and pentane liquid in glass thermometers, copper-constantan thermocouples, and electrical resistance thermometers.

The lower range of the alcohol thermometer is about —70° C., of the toluene about —90° C., and of the petroleum-ether and pentane thermometers about —200° C.

Chappuis* made a careful investigation of the alcohol and toluene thermometers. The presence in the alcohol of water, which can hardly be eliminated, produces a marked

* Chappuis: ZS. f. Instrk., **14**, p. 141; 1894.

influence on its coefficient of expansion. Thus a number of thermometers made up of different samples of alcohol designated as chemically pure were found to differ among themselves by 1° C. With thermometers filled with different samples of toluene, the greatest difference did not exceed 0.04° C.

The necessary data for graduating toluene thermometers will be found in the paper just referred to.* If the scale of a toluene thermometer were continued down in degrees of equal volume, as in a mercury thermometer, its readings would differ very considerably from true gas-scale temperatures; in the actual construction of these thermometers this is allowed for by making the degree intervals shorter as they go down the stem; the thermometer can then be made to read true (gas scale) temperatures with great accuracy. The same method of construction may be followed in alcohol thermometers.

The amount by which the temperature registered by the toluene thermometer, if the scale were continued down in degrees whose volume was one one-hundredth of the volume between the 0° C. and 100° C. marks, would depart from the true temperature on the scale of the hydrogen-gas thermometer, is given in the following table:

Temperature.	Toluene.	Temperature.	Toluene.	Temperature.	Toluene.
—10° C.	— 8.54° C.	—30° C.	—25.10° C.	—70° C.	—56.63° C.
—20°	—16.90°	—50°	—41.08°		

Kohlrausch† and Holborn‡ have investigated the behavior of petroleum-ether thermometers at temperatures as low as —190° C. Complex mixtures of petroleum-ether distilled at temperatures between 20° C. and 33° C. are used in these thermometers. The coefficients of expansion of these liquids and the necessary details of construction of these thermometers will be found in the papers referred to. The coefficient of expansion is very variable, the length of a degree at —150° C. being only about 0.8 that at +25° C. When these thermometers are used with the necessary precautions their indications are consistent to 1° C. or better at —190° C.

Rothe § has made a careful study of pentane thermometers and his paper gives all the necessary data for their construction. His experiments show that their indications are consistent to 0.02° C. at —190° C.

An important precaution in the use of these low-temperature thermometers, especially in the lower portions of their ranges, is slow cooling. The bulb must be cooled down first, then the stem; otherwise the meniscus becomes stiff and tears off from the walls, leaving drops of liquid behind.

HIGH-TEMPERATURE THERMOMETERS.

In mercury thermometers for use above 275° C. (525° F.) the space above the mercury must contain a dry inert gas (N or CO_2) under pressure, to prevent boiling of the mercury. Two methods of construction are in use for this purpose. In one a very small bulb or length of capillary is found at the top, the whole space being filled at atmospheric pressure when the mercury is at a suitable point in the stem, and as the mercury rises the confined

* Chappuis: ZS. f. Instrk., **14**, p. 141; 1894.
† Kohlrausch, Wied. Ann., **60**, p. 463; 1897.
‡ Holborn, Ann. d. Phys., **6**, p. 255; 1901.
§ Rothe, ZS. f. Instrk., **22**, p. 192; 1902; **24**, p. 47; 1904.

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gas is compressed and the pressure increased sufficiently to prevent boiling. In the other the bulb at the top is large in comparison with the volume of the capillary stem, and the space is filled under an initial pressure great enough to prevent boiling at the highest temperature on the scale. This pressure is about 20 atmospheres for thermometers intended for use at a temperature of 550° C. (1,000° F.).

Thermometers for use above 425° C. (775° F.) and up to about 550° C. (1,000° F.) are now generally made of the hard Jena 59^{III} borosilicate glass or of special grades of combustion tubing. Many industrial thermometers are constructed in complicated forms, with protecting tubes, air jackets, or other devices, to permit of the use of soft enamel-back glass for the stems in connection with hard-glass bulbs. In many cases this gives the advantage of a very legible scale, which may justify the complication. However, on account of simplicity of construction and higher accuracy, the use of a uniform hard glass throughout is often desirable.

Thermometers made with fused quartz in place of glass, and filled above the mercury with an inert gas under a pressure of about 60 atmospheres, are now available, and extend the upper limit of mercurial thermometry by 150° C. or more (to about 700° C.).

LABORATORY AND SPECIAL THERMOMETERS.

Under this head may be broadly grouped most of the thermometers of the usual types, including secondary and working standards whose order of accuracy is 0.01° or better, and ordinary thermometers whose order of accuracy is 1° or 2°. Illustrations of special thermometers are maxima and minima thermometers, calorimetric, hysometric, deep-sea, and other thermometers used for special purposes.

Fees—Schedule 32—Laboratory and special thermometers.

(*a*)	Determinations of the corrections in the interval — 30° to + 100° C. to an order of accuracy of 0.01° or 0.02°, or as accurately as the construction of the thermometer warrants, for each point tested	$0.20
(*b*)	Same as above, in lots of 6 or over	.10
(*c*)	Determination of corrections to nearest 0.1° or 0.2°, for each point tested	.15
(*d*)	Same as above, in lots of 12 or over	.075
(*e*)	Determination of the corrections to within 0.1° C. or 0.2° C. from 100° C. up to about 250° C., and somewhat less accurately at higher temperatures, for each point tested	.50
(*f*)	Determination of corrections in the interval 100° C. to 550° C., to within 1° or 2°, for each point tested	.30
(*g*)	Same as above, in lots of 6 or over	.20
(*h*)	Determination of corrections in alcohol, toluene, petroleum-ether, and pentane thermometers, below — 30° C., for each point tested	1.00

INDUSTRIAL THERMOMETERS.

Under this head are classed thermometers of special construction adapted to the requirements of the industries, such as flue gas, steam tank, angle stem, distilling, and other thermometers.

Fees—Schedule 33—Industrial thermometers.

The fees for testing thermometers of this class will depend on the range and construction of the instrument. When the thermometer is adapted for testing with the ordinary facilities, the fees will be about the same as those given in Schedule 32.

HOUSEHOLD THERMOMETERS AND THERMOGRAPHS.

This class includes thermometers used to indicate or record the temperature in rooms, hospitals, office buildings, etc.

Fees—Schedule 34—Household thermometers.

(*a*) For each point of the scale tested	$0.15
(*b*) In lots of 12 or more, for each point tested	.05

These fees apply only when the thermometers can be readily tested in the ordinary comparators. When special facilities are required an extra fee will be charged if the thermometer is accepted for test.

Recording thermographs for the ordinary ranges of temperature may be submitted for test at the following rates:

Fees—Schedule 34—Thermographs.

(*c*) Determination of the corrections at two temperatures	$2.00
(*d*) Same as above, in lots of 3 or more, each	1.25
(*e*) For testing each additional temperature	.50

CLINICAL THERMOMETERS.

Clinical thermometers of the usual form of construction may be submitted for test at the rates specified in the following table. When the construction entails extra work, as in thermometers with metallic caps that have to be removed for engraving, or thermometers of such size that they will not fit the ordinary holders, an extra fee will be charged.

Fees—Schedule 35—Clinical thermometers.

(*a*) In lots up to 8, each	$0.25
(*b*) Any number between 8 and 12, total fee	2.00
(*c*) In lots of 1 dozen or over, and less than 4½ dozen, per dozen	2.00
(*d*) Any number between 4½ and 6 dozen, total fee	9.00
(*e*) In lots of 6 dozen or over, per dozen	1.50

ELECTRICAL RESISTANCE THERMOMETERS.

These thermometers are based on the variation of the electrical resistance of a metal (preferably platinum) with the temperature. When properly constructed and used with due precautions, the platinum thermometer is an instrument of great accuracy for the measurement of temperature from the lowest attainable up to about 1,000° C. (1,800° F.).

The complete standardization of a platinum thermometer includes a determination of its constants from measurements of its electrical resistance at three known temperatures—melting ice, steam, and sulphur vapor. Where the platinum thermometer is to be used for measurements of temperatures below —100° C. (—150° F.), the boiling point of liquid oxygen will be used instead of the sulphur point.

The fees are given in the schedule below:

Fees—Schedule 37—Electrical resistance thermometers.

(*a*) Complete standardization of a platinum resistance thermometer for precision work	$7.50
(*b*) The standardization of platinum or other resistance thermometers used in the industries, not requiring the highest precision	3.50
(*c*) The standardization of the resistance boxes or potentiometers used in connection with resistance thermometers will be carried out in accordance with the requirements and schedules governing the testing of resistances (Bureau Circular No. 6).	

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FORM OF CERTIFICATE.

The certificate furnished by the Bureau of Standards will contain the following data:

(*a*) Description or identification marks of article or instrument.
(*b*) Bureau of Standards test number.
(*c*) Name of party for whom instrument is compared.
(*d*) Temperature and other conditions of the test.
(*e*) Table of corrected values or of desired corrections.
(*f*) Date of certification.
(*g*) Seal of the Bureau and signature of the Director.
(*h*) Special remarks when necessary.

An identification mark will be engraved upon every instrument tested by the Bureau.

It is the desire of the Bureau to cooperate with manufacturers, scientists, and others in bringing about more satisfactory conditions relative to weights, measures, measuring instruments, and thermal constants, and to place at the disposal of those interested such information relative to these subjects as may be in its possession.

It is also desired to aid in the solution of specific scientific problems arising in technical or scientific work, coming within the scope of the Bureau, and to this end correspondence is invited.

All communications should be addressed, "Bureau of Standards, Department of Commerce and Labor, Washington, D. C."

S. W. Stratton,
Director.

Approved:
Lawrence O. Murray,
Acting Secretary.

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