PYROMETER TESTING AND HEAT MEASUREMENTS

Department of Commerce and Labor
BUREAU OF STANDARDS
Washington

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CONTENTS.

1. ORGANIZATION OF THE BUREAU.

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approved March 3, 1901, the Office of Standard Weights and Measures of the Treasury Department was, on July 1, 1901, superseded by the Bureau of Standards.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 educational institutions, 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, and 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.

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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.

2. REGULATIONS.

(*a*) Application for Test.—The request for verification of any instrument should state explicitly the points at which test is to be made and the temperature or any other conditions which it is desired should be observed. Whenever possible, the request should be accompanied by the fee as shown in the appended schedules.

(*b*) 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 given to the article.

(*c*) 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 otherwise arranged, articles will be returned by express "collect."

(*d*) 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 should be left at the office of the Bureau and should be accompanied by a written request for the verification.

(*e*) Remittances.—Fees may be remitted by money order or check 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 thereon have been received.

3. GENERAL INSTRUCTIONS.

When pyrometers are submitted for test, it is highly desirable that the request for test be accompanied by a statement giving as far as possible the conditions under which the pyrometer is used (e. g., method of mounting pyrometer, depth of immersion, kind of bath or medium whose temperature is to be measured, how the pyrometer is protected, at what temperature it is used, and whether continuously exposed to these temperatures, etc.). A sketch showing method of use of instrument is often very useful. It is only when accompanied by such information that it is possible to realize approximately the same conditions in the test as in the actual use of the pyrometer, and to make a statement as to the order of accuracy that may be attained. It also enables suggestions to be made as to desirable modifications in the use of the instrument that may lead to more satisfactory results.

4. TEMPERATURE SCALE.

The high-temperature scale of this Bureau is in practical agreement with that of the other national standardizing laboratories (except possibly at the highest temperatures, which are still uncertain) and is reproduced in terms of certain fixed temperatures—freezing and boiling points of some of the chemical elements—which have been determined by various investigators. This scale, however, is by no means finally fixed, especially for the higher temperatures, and is probably not absolutely certain in terms of the indications of the gas thermometer to much better than 5° at 1200° C. The scale used for temperatures above 1200° is based on the radiation laws of the black body.

The provisional scale now in use at the Bureau may be expressed in terms of the following more important fixed points:

		° C.	° F.
Tin	Freezing	232	449.5
Zinc	Freezing	419	786
Sulphur	Boiling	444.7	832.5
Antimony	Freezing	630.5	1167
Gold	Melting	1064	1947
Copper	Freezing	1084	1983
Nickel	Melting	1435	2615
Palladium	Melting	1546	2815
Platinum	Melting	1753	3187

Sn, Pb, Zn, Sb, and Cu must be protected from oxidation. This can be done by using a graphite crucible and protecting the surface of the metal with powdered graphite. Copper saturated with its oxide has a freezing point of 1065° C. The freezing point of lead (327° C) and aluminium (658° C for 99.7 per cent purity) and the boiling point of naphthalene $\left(218.0°\mathrm{C}+\frac{\mathrm{H}-760}{17.1}\right)$ are also frequently used as fixed points in the calibration of pyrometers.

5. THERMOELECTRIC PYROMETERS.

In pyrometers of this type temperatures are measured by the magnitude of the electromotive forces set up between wires of different materials when one junction is exposed to the temperature to be measured and the other junction (or junctions) is kept at some known temperature.

For the measurement of temperatures in the interval 300° to 1600° C, thermocouples, consisting of a wire of an iridium or rhodium alloy of platinum joined to a wire of pure platinum, are generally used. The most common type, known as the Le Chatelier pyrometer, consists of a wire of 10 per cent rhodium alloy with platinum joined to one of pure platinum. For this couple the relation between the electromotive force (E) and the temperature of the hot junction (t), in the interval 300° to 1200°, is quite accurately given by the equation,

$$\mathrm{E}=\mathrm{a}+\mathrm{bt}+\mathrm{ct}^2 \qquad \text{(a)}$$

when the cold junctions are at 0° C. When this equation is extrapolated to higher temperatures it gives low values for the temperature (e. g., 1710° for the melting point of platinum, instead of 1750° or higher as given by recent work). The Holman equation,

$$\mathrm{E}=\mathrm{mt}^{\mathrm{n}}$$

or

$$\log \mathrm{E}=\mathrm{n}\log \mathrm{t}+\mathrm{c} \qquad \text{(b)}$$

expresses the relation between E and t to a sufficient accuracy for nearly every purpose, and agrees with (a) to within about 2° C in the above temperature interval. When extrapolated above 1200° the equation (b) gives temperatures more exactly than does (a).

For the Pt–Ir, Pt thermocouples the electromotive-force-temperature equation is more nearly linear above 300° than for the Pt–Rh, Pt thermocouples, and the E. M. F. is greater for a given temperature, but the iridium couples deteriorate more rapidly than the rhodium couples, owing to the greater evaporation of iridium and its deposit on the platinum wire.

For the measurement of very high temperatures (2000° C) thermocouples of iridium and an alloy of iridium and ruthenium may be used. The wires of this couple are extremely brittle and it is only suited for careful laboratory use.

For the measurement of temperatures below 600° C to that of liquid air (−200° C) or lower, various combinations have been used, such as iron-constantan, copper-constantan, and gold-platinum. The electromotive force-temperature equation varies with the different couples and is usually of the third degree in t or higher.

A number of other types of thermocouple made of cheaper materials than platinum and its alloys, such as Fe, Cr, Mo, W, and Ni, and their alloys, have also been used for temperature measurements to 1200° C or higher. For some of these couples the E. M. F.-temperature relation is very nearly linear. These alloys are more subject to oxidation than the platinum alloys and must be frequently renewed. These couples generally give a much larger E. M. F. for a given temperature than the platinum couples and can therefore be used with a more robust type of indicating or recording galvanometer. Pivot-bearing instruments are, however, now available for use with the platinum couples. Thermocouples made of alloys containing iron or nickel often have critical points within certain temperature regions, where the thermoelectric properties undergo discontinuities. In general, alloys of the baser metals are not suited for work of the highest precision at high temperatures mainly on account of parasite electromotive forces and time changes.

(*a*) *Homogeneity.*—For work of precision it is important that each wire of a thermocouple be of exactly the same chemical composition and physical properties throughout, otherwise the indications of the thermocouple will vary with the depth of immersion in the heated (or cooled) region. When requested, a special test of the homogeneity of the wires will be made, the results being expressed in terms of the electromotive forces generated when successive short lengths of the wire are exposed to a constant high temperature.

(*b*) *Annealing.*—Before calibration and use all high temperature thermocouples should be annealed by heating them throughout their length, preferably by means of an electric current, to a temperature higher than any to which they may subsequently be exposed. This eliminates the electromotive forces developed between the hard and soft portions of the wires. When platinum couples have been contaminated by long-continued use they may often be restored to their original condition by annealing (for an hour or more) at high temperatures (1500° or 1600° C).

(*c*) *Precautions in Use.*—The wires of the couple should be fused together at the hot junction, not tied or twisted, as such connections are liable to develop high resistance or to interrupt the circuit when the wires become oxidized. In general the wires of the thermocouple should be protected from the action of hot furnace gases, silicon, metallic vapors, etc. The cold junctions should be so placed that their fluctuations of temperature are negligible. The electrical resistance of the pyrometer galvanometer should be so high that the errors resulting from the resistance of the leads and the variation of the resistance of the couple with temperature and depth of immersion may be neglected. In work of the highest precision at high temperatures (above 1100° C) contamination of the couples due to the evaporation of rhodium and especially of iridium must be carefully avoided.

A great many of the reported failures of thermocouples to fulfill the practical requirements of technical applications have been traced to neglect of one or the other of these precautions. Re-tests made by this Bureau of platinum, platinum-rhodium couples that have been subjected to long and severe usage in the industries have shown that, after annealing the couples, the new calibrations are in practical agreement with the old.

(*d*) *Calibration.*—Thermocouples are usually calibrated at the Bureau of Standards, after a thorough annealing, by comparisons at four or more temperatures with two standard couples, the couples being immersed for about 25 cm of their length in an electric furnace, and the cold junctions being kept at 0° C.

When a couple is to be used with its cold junction at some temperature other than 0° C, the necessary correction will be indicated in the certificate. For the usual forms of thermocouples made of platinum and its alloys, this correction is approximately + ½ t where t is the centigrade temperature of the cold junctions, and in general this correction lies between + ½ t and + t for practically all types of thermocouple.

(*e*) *Use of a Pyrometer Galvanometer of Low Resistance.*—In many industrial forms of thermoelectric pyrometer, the electrical resistance of the thermocuple wires and accompanying leads is not negligible in comparison with the resistance of the indicating instrument. When this is the case the galvanometer does not in general indicate the true E. M. F. of the thermocouple. If R_1 is the resistance of the thermocouple wires and attached leads, R_2 that of the galvanometer, and E the true E. M. F. of the thermocouple, then the E. M. F. = E_1 as indicated by the pyrometer galvanometer will be $E_1 = E\frac{R_2}{R_1 + R_2}$. E_1 will thus depend[1] also upon the increase in R_1 due to the increase in the resistance of the heated wires and will, therefore, vary with the depth of immersion of the thermocouple in the heated space.

6. ELECTRICAL RESISTANCE THERMOMETERS.

In this method of thermometry the temperature is measured by the variation in the electrical resistance of a metallic wire. For ordinary temperatures up to 300° C and down to the temperature of liquid air, or lower, wires of the pure metals, such as nickel, iron, silver, gold, and copper, may be used. Nickel has a critical region above 300° which causes an irregularity in the temperature-resistance curve. Platinum is the most satisfactory metal for most purposes and can be used throughout the range from the lowest attainable temperatures to 1000° C, or even higher for short periods. As resistances can be compared with extraordinary precision, the resistance thermometer is especially well adapted to the measurement of small changes in temperature and to differential temperature measurements.

If intended for use at high temperatures the platinum coil is generally wound on a mica frame. To eliminate the resistance of the leads, which would vary with depth of immersion and thus give rise to a variable stem correction similar to the emergent stem correction in mercurial thermometers, the thermometer should be constructed with compensating leads or with potential terminals. In thermometers of the former type the compensating leads are inserted in the adjacent arms of a Wheatstone bridge. In thermometers of the potential lead type the drop in potential at the terminals of the coil is measured by comparison with the drop in potential through a standard resistance by means of a potentiometer.

(*a*) *Calibration.*—We may define temperature on the scale of the platinum resistance thermometer as given by—

$$pt = 100\frac{R - R_0}{R_{100} - R_0} \qquad (a)$$

where R is the measured resistance at some unknown temperature, t, and R_{100}, R_0 are the resistances at 100° C and 0° C, respectively. The relation between the platinum temperature pt and the centigrade temperature t from −100° C to 1100° C is very exactly given by Callendar's equation—

$$t - pt = \delta\left(\frac{t}{100} - 1\right)\frac{t}{100}. \qquad (b)$$

The constant δ is characteristic of the kind of metal. For pure platinum $\delta = 1.50$, and it is larger for impure platinum.

[1] For example, if a galvanometer is of 50 ω resistance = R_2, and the leads of 2 ω = R_1, and the true E. M. F., E, is 10 millivolts, the galvanometer will indicate 9.62 millivolts, or in terms of temperature about 4 per cent lower than the true temperature if the couple was calibrated in terms of true E. M. F.

The calibration of a platinum resistance thermometer, which is to be used in the range $-100°$ C to 1000° C, usually consists in measuring its resistance in melting ice (0° C), in steam (100° C), and at one other temperature, usually that of the vapor of boiling sulphur (444.7° C), and computing other temperatures by means of formulæ (a) and (b). The values of R_0, the fundamental interval $(R_{100} - R_0)$, and of δ will be given in the certificate furnished by the Bureau.

The work of many investigators has shown that a platinum resistance thermometer calibrated at these temperatures may be used to reproduce gas scale temperatures throughout the range $-100°$ C to 1100° C with a degree of accuracy equal to that at present attainable in gas thermometry. For example, when such a calibration is extrapolated to the melting point of gold, it gives a value (1062° C) which differs from the true value by an amount which is no greater than the present uncertainty (5°) in our knowledge of this temperature.

If a resistance thermometer is to be used at very low temperatures, the boiling point of liquid oxygen ($-182.5°$ C) may be used to advantage as the third calibration temperature, since the value of δ found from the sulphur boiling point calibration does not hold exactly at these very low temperatures.

Resistance thermometers which are to be used in calorimetric work for the measurement of small temperature changes with high precision will be calibrated at 0°, 100°, and 32.384°, the transition temperature of sodium sulphate.

When the construction of a platinum resistance thermometer does not permit of calibration by the above method of using three fixed temperatures, the instrument will be compared directly with the standards of the Bureau at several temperatures in an electric furnace. This method is not in general capable of so high precision as the previously described one. This is the procedure followed when a resistance thermometer and its direct reading temperature indicator are submitted for test as a single instrument.

7. OPTICAL AND RADIATION PYROMETERS[1].

In *optical pyrometers* the intensity of the light emitted by an incandescent body whose temperature is sought is measured by comparing the intensity of the light which the body emits with that emitted by some standard source, such as a gasoline lamp or an incandescent lamp under specified conditions. Optical pyrometers are therefore essentially, in principle, photometers adapted to meet the varying requirements of shop and laboratory use.

In these pyrometers light of a single color is generally used to get rid of the difficulties in photometry incident to color differences, and also for the reason that the laws connecting the temperature of a body and the intensity of the light emitted are simpler if we deal with a single wave length (color) only.

As illustrations of pyrometers of this type may be cited those of Le Chatelier, Wanner, Féry absorption, Morse, and Holborn-Kurlbaum, the latter instrument differing only in mechanical details from the Morse.

In *radiation pyrometers* the energy of total radiation (i. e., that associated with the long waves which do not affect the eyes as well as the energy of the short light waves) is measured in various ways by the heat effect which it produces, such as by the electric current set up when the radiation heats one or more junctions of two dissimilar metals, the expansion produced by the heating of a compound metal strip, and the change in resistance of a very fine metal ribbon.

[1] Full details of the calibration, precautions in use, and accuracy attainable with optical pyrometers, together with a description of these instruments and a discussion of the laws on which they are based, will be found in "Optical Pyrometry," by C. W. Waidner and G. K. Burgess, Bureau Reprint No. 11, from Bulletin Bureau of Standards, Vol. I, p. 189–254, 1904.

Pyrometers based on the first of these methods have been devised by Féry and by Thwing. Féry has also made use of the second of these methods in constructing a radiation pyrometer.

The radiation emitted by substances depends on the nature of the substance and condition of its surface as well as upon the temperature. The only body whose radiation depends only on its temperature is the *"black body,"* which is approximately realized by a uniformly heated inclosure.

If an optical pyrometer has been calibrated in terms of the radiation from a black body, it will not, therefore, in general give the true temperature of the incandescent body under observation, but nevertheless it will define a consistent temperature scale for any one substance, which in very many cases is all that is necessary in the control of an industrial operation. Where the equivalent black-body temperature is not sufficient, true temperatures may be found by applying a suitable correction, the magnitude of which will depend on the emissive power of the body and on its temperature, or by taking the measurements in such a way that the radiation is very approximately black-body radiation. For example, if the problem at hand is the measurement of the temperature of a furnace or hardening bath, then by inserting a closed-end tube, of suitable material, such as magnesia, porcelain, or tungsten steel, of sufficient length so that the end and some distance along the tube is at the temperature of the furnace or bath, the radiation coming out of this tube is a close approximation to black-body radiation, and the optical pyrometer will then give true temperatures. Again, within many furnaces the conditions approximate fairly close to black-body conditions and the temperatures found by the use of an optical or radiation pyrometer will then differ but little from the true temperature. The readings of optical pyrometers and, to a much greater degree, of radiation pyrometers will be influenced by the presence of flames, vapors, and furnace gases.

The temperature scale defined by the several radiation laws is in agreement with the gas scale throughout the widest range of measurable temperatures, and when these laws are extrapolated to the highest attainable temperatures they are still in satisfactory agreement.

Calibration.—An optical pyrometer may be calibrated by sighting either upon a black body or upon another body whose emissive properties are known. It is, however, necessary to determine the calibration temperatures by some auxiliary means, as a thermocouple; or carrying out the calibration at certain known temperatures, such as the fusing point of gold, palladium, and platinum; or, what is usually the more convenient in the case of industrial instruments, comparing the indications of the pyrometer to be tested with that of a standard instrument, both being sighted upon the same source, which may be a clear furnace, or, in the case of the two instruments using the same colored light, a graphite or metal strip mounted in vacuo and heated electrically. This use of an electrically heated strip permits of a very rapid calibration of sufficient accuracy for industrial and many scientific purposes. With a graphite strip such a calibration may be made up to 1900°–2000° C. With a strip of tungsten such a calibration might be carried several hundred degrees higher.

The calibration formula for those optical pyrometers which are of the photometer type, and in which light of a single color is used, is very simple. The intensity I of a monochromatic light source, approximating a black body, varies with its absolute temperature T (= t + 273° C) as follows:[1]

$$\log I = a - \frac{b}{T}$$

where a and b are constants. Such a pyrometer may, therefore, be calibrated completely by finding its readings at two temperatures only, if its construction is otherwise mechanically

[1] The complete expression for T in terms of I, for a given wave length λ, is known as Wien's law: $I = C_1 \lambda^{-5} \; e^{-\frac{c_2}{\lambda T}}$ where C_1 and c_2 are constants and e is the base of Napierian logarithms.

correct. Often with such pyrometers the monochromatic light is obtained by means of colored glasses which are but approximately monochromatic. In this case the calibration should be carried out at several temperatures, the number depending on the glass used and the accuracy sought.

The relation between the current C through the filament of the lamp of the Morse or Holborn-Kurlbaum type of pyrometer and the temperature t of an approximately black body source is—

$$C = a + bt + ct^2 \qquad (a)$$

where a, b, and c, are constants, so that measurements at three temperatures, at least, are necessary to calibrate such pyrometers. The pyrometer lamps should be aged before calibration for some twenty hours at a temperature of about 1800° C.

In order to extend the range of any optical pyrometer above 1500° C absorption glasses, mirrors, diaphragms, or rotating sectors may be used. It is then necessary to determine the absorption coefficient[1] for the screen used, by the measurement of one or more known temperatures with and without the screen interposed.

The indications of total radiation pyrometers, such as the Féry thermoelectric telescope, obey approximately the law—

$$E = k\,(T^4 - T_o^4) \qquad (b)$$

where E is the energy received by the instrument at a temperature T_o from a black-body source whose temperature is T, and k is a constant. For the measurement of high temperatures, T_o^4 may usually be neglected in comparison with T^4. The industrial forms of these instruments usually give readings departing somewhat from equation (b), so that it is necessary to calibrate them empirically at several points over the range for which they are intended to be used. A relatively large area is usually required upon which to sight these pyrometers. These instruments may be used with recording galvanometers and thus give a permanent record of temperatures.

8. EXPANSION AND OTHER PYROMETERS.

Mercury thermometers reading to about 550° C (1000° F) are obtainable, in which the stem above the mercury column is filled with an inert gas under great pressure. To avoid troublesome changes of zero, the thermometer bulbs should be made of very hard glass and the instrument thoroughly annealed before testing.

For the measurement of temperatures to about 1400° F, pyrometers based on the relative expansion of metals, or of a metal and graphite, are widely used. These instruments should be tested from time to time to correct for changes in zero.

This Bureau will also receive for test other types of pyrometer, such as specific heat, expansion, transpiration, and viscosity pyrometers.

(*a*) *Recording Instruments.*—With the exception of the optical, practically all forms of pyrometer can be used in connection with some form of suitable recording instrument. This Bureau will receive for test temperature recorders if submitted with the pyrometer with which they are to be used. The test of a recorder includes the determination of several temperatures on its scale for the pyrometer submitted with it, a measurement of the time rate of the recorder, and a statement of the general adaptability of the instrument for its intended use.

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[1] The coefficient of absorption K is given by the formula: $\log K = \frac{c_2 \log e}{\lambda}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$ where T_1 and T_2 are the absolute temperatures of the black-body source, as given with and without the screen, respectively.

9. HEAT MEASUREMENTS.

Testing of the various kinds of calorimetric and flash-point apparatus and viscosimeters is also undertaken by the Bureau, as well as the determinations in certain cases of the thermal properties of fuels, oils, and other substances. Samples of metals, alloys, and salts may be submitted for the determination of their melting points, and such substances will also be accepted for test of the presence of critical points by taking their cooling curves. The Bureau will soon be prepared to make thermal tests on refractory materials, such as fire brick and cements.

When of scientific or technical interest, special investigations in heat measurements and allied subjects, involving more elaborate experimental facilities and completeness than the ordinary tests, may be undertaken.

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.

Persons interested in pyrometric problems are welcome to visit the laboratories of the Bureau, where many of the leading types of pyrometer way be seen in operation.

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.

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

10. PUBLICATIONS IN THERMOMETRY, PYROMETRY, AND HEAT MEASUREMENTS.

The following papers, embodying the investigations in thermometry, pyrometry, and heat measurements carried out at the Bureau have been published. They are issued in pamphlet form and will be sent upon request. They may be designated by the numbers which precede the titles in the list. A complete list of the technical publications of the Bureau, with brief abstracts of contents, will also be sent upon application.

8. On the Temperature of the Arc (Sept. 1, 1904), 16 pp.....*C. W. Waidner* and *G. K. Burgess.*
11. Optical Pyrometry (Sept. 15, 1904), 61 pp.....*C. W. Waidner* and *G. K. Burgess.*
13. The Testing of Clinical Thermometers (Nov. 1, 1905), 15 pp.....*C. W. Waidner* and *L. A. Fischer.*
24. Radiation from Platinum at High Temperatures (Aug. 15, 1905), 3 pp.....*G. K. Burgess.*
32. Heat Treatment of High-Temperature Mercurial Thermometers (Apr. 15, 1906), 36 pp. *H. C. Dickinson.*
40. Preliminary Measurements on Temperature and Selective Radiation of Incandescent Lamps (Sept. 30, 1906), 11 pp.....*C. W. Waidner* and *G. K. Burgess.*
55. Radiation from and Melting Points of Palladium and Platinum (Mar. 4, 1907), 46 pp. *C. W. Waidner* and *G. K. Burgess.*
57. On the Establishment of the Thermodynamic Scale of Temperature by Means of the Constant-Pressure Gas Thermometer (Feb. 4, 1907), 57 pp.....*E. Buckingham.*
62. Melting Points of the Iron-Group Elements by a New Radiation Method (Apr. 5, 1907), 11 pp. *G. K. Burgess.*
68. Calorimetric Resistance Thermometers and the Transition Temperature of Sodium Sulphate (June 21, 1907), 21 pp.....*H. C. Dickinson* and *E. F. Mueller.*
69. On the Standard Scale of Temperature in the Interval 0° to 100° C. (May 3, 1907), 66 pp. *C. W. Waidner* and *H. C. Dickinson.*
99. On Methods of Obtaining Cooling Curves (Aug. 3, 1908).....*G. K. Burgess.*

Specific Heat of some Calcium Chloride Solutions (In preparation).....*H. C. Dickinson* and *E. F. Mueller.*

11. TABLE OF FEES.

High-range Mercurial Thermometers.

Mercurial thermometers will be tested in accordance with requirements and schedules published in Bureau Circular No. 8.

Schedule 36.—Thermocouples.

(*a*) Temperature-E. M. F. test of thermocouple alone	$7.50
(*b*) Test of thermocouple with pyrometer galvanometer (5 points on temperature scale)	10.00
(*c*) Additional points on temperature scale of galvanometer, each	1.50
(*d*) Examination of homogeneity of wires of thermocouple	5.00

Tests of the E. M. F. scales of instruments suitable for use as pyrometer-galvanometers, and of potentiometers for use with thermocouples, will be carried out in accordance with requirements and schedules governing electrical apparatus. (Bureau Circular No. 6.)

For tests above 1500° C or for unusual forms of thermocouple special fees will be charged.

Schedule 37.—Electrical Resistance Thermometers.

(*a*) Test of a resistance thermometer at three temperatures	$10.00
(*b*) Test of a resistance thermometer with its temperature indicator, per point tested, $2, but minimum fee	10.00

The testing of resistance coils of temperature indicators will be carried out in accordance with the requirements and schedules governing electrical apparatus. (Bureau Circular No. 6.)

Schedule 38.—Optical and Total Radiation Pyrometers.

(*a*) Test of an optical pyrometer to 1500° C. (Types: Le Chatelier, Morse, Wanner, Féry absorption, etc.)	$15.00
(*b*) Calibration of absorption glass for extending range to highest temperatures	10.00
(*c*) Test of total radiation pyrometer to 1400° C. (Types: Féry, Thwing, etc.)	20.00

Special furnaces will soon be installed for the testing of these instruments at higher temperatures.

Schedule 39.—Miscellaneous Heat Tests.

(*a*) Test of a recording instrument for thermoelectric, resistance, or radiation pyrometer (including test of the accompanying pyrometer)	$25.00
(*b*) Test of a combustion calorimeter (type of Mahler, Berthelot, Parr, Junkers, Boys, etc.), including a determination of the water equivalent and the corrections to the accompanying thermometers	25.00
(*c*) Determination of the heat value of fuels for the United States, State, County, and Municipal Governments, and in special cases for corporations and individuals	10.00
(*d*) Determination of the melting point of a metal, alloy, or salt, for substances melting below 1100° C	10.00
(*e*) Determination of the cooling curve of a steel or alloy, for the location of critical points	15.00
(*f*) Test of flash point apparatus, including accompanying thermometers	10.00
(*g*) Test of viscosimeter, including accompanying thermometers	10.00

In special cases, tests of the viscosity, setting point, and flash point of oils will be undertaken, for which the following fees will be charged:

(*h*) Viscosity at two temperatures in Engler apparatus	$4.00
(*i*) Flash point in Abel-Pensky or Pensky-Martens apparatus	2.00
(*j*) Setting point	3.00

When, in special cases, tests and inspections are undertaken outside the Bureau, special fees will be charged. For pyrometer and other tests not mentioned in the above schedules, the fee will depend on the nature of the test and the accuracy required.

12. DISCOUNTS AND REMISSION OF FEES.

When three or more instruments or materials of the same class or kind, requiring the same test on each, are submitted together, a discount of 25 per cent from the fees in the above schedules will be allowed.

For educational and scientific institutions and societies, a discount of 50 per cent will be allowed on all tests.

S. W. STRATTON,
Director.

Approved:
OSCAR S. STRAUS,
Secretary.

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