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THE INTERNATIONAL TEMPERATURE SCALE

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In 1911, the directors of the national laboratories of Germany, Great Britain, and the United States agreed to undertake the unification of the temperature scales in use in their respective countries. This endeavor was approved formally in 1913 by the Fifth General Conference of Weights and Measures, and in 1921 the Sixth General Conference voted to expand the field of activities of the International Committee and International Bureau by including physical constants, such as standard temperatures, and the coordination of results obtained in other institutions. This action was duly ratified by the several governments adhering to the conference.

Finally, in 1927, the Seventh General Conference, representing 31 nations, on the recommendation of the three laboratories above mentioned, which had consulted with the Leiden Cryogenic Laboratory as to low temperatures, adopted unanimously the following resolution, proposed by the International Committee of Weights and Measures:

Le Comité, reconnaissant l'importance pratique de la représentation d'une échelle thermométrique internationale, recommande à la Conférence d'accepter, à titre provisoire, les repères de température, les formules d'interpolation et les méthodes de mesure proposés d'un commun accord par les trois laboratoires nationaux d'Allemagne, des États-Unis d'Amérique, et de Grande-Bretagne.

Le Comité recommande aussi que le texte annexé soit maintenu à l'étude dans le programme des Conférences spéciales de Thermométrie qui seront tenues sous ses auspices.

The English text is as follows:

TEXT CONCERNING THE ADOPTION OF AN INTERNATIONAL TEMPERATURE SCALE SUBMITTED FOR DISCUSSION BY THE BUREAU OF STANDARDS, NATIONAL PHYSICAL LABORATORY, AND PHYSIKALISCH-TECHNISCHE REICHSANSTALT

INTRODUCTION

The experience of the Bureau of Standards, as of the National Physical Laboratory and of the Reichsanstalt, has for many years past indicated the necessity, for industrial purposes, of international agreement on a scale of temperatures ranging from that of liquid oxygen to that of luminous incandescent bodies. As a result of discussion extending over a considerable period, agreement has been reached by the three laboratories, subject to possible minor drafting amendments on the attached specification for a practical scale, as affording a satisfactory basis on which uniformity in certification of temperature measurements for industrial purposes may be maintained.

It is to be understood that this proposal does not purport to replace the absolute temperature scale which it is recommended should be adopted, on principle, by the International Conference on Weights and Measures. It is intended merely to represent this scale in a practical manner with sufficient accuracy to serve the every day needs of the laboratories for the purpose of industrial certifications, and is to be regarded as susceptible of revision and amendment as improved and more accurate methods of measurement are evolved.

It is anticipated that this scale will shortly be adopted by the three laboratories for the purposes indicated, and the attached draft is presented to the conference for consideration, with the recommendation that it should be officially adopted, with such amendments, if any, as may be agreed on, as the best practical realization at the present time of the ideal thermometric scale.

Part I. DEFINITION OF THE INTERNATIONAL TEMPERATURE SCALE

1. The Thermodynamic Centigrade Scale, on which the temperature of melting ice, and the temperature of condensing water vapor, both under the pressure of one standard atmosphere, are numbered 0° and 100°, respectively, is recognized as the fundamental scale to which all temperature measurements should ultimately be referable.

2. The experimental difficulties incident to the practical realization of the thermodynamic scale have made it expedient to adopt for international use a practical scale designated as the International Temperature Scale. This scale conforms with the thermodynamic scale as closely as is possible with present knowledge, and is designed to be definite, conveniently and accurately reproducible, and to provide means for uniquely determining any temperature within the range of the scale, thus promoting uniformity in numerical statements of temperature.

3. Temperatures on the international scale will ordinarily be designated as "°C.," but may be designated as "° C.(Int.)" if it is desired to emphasize the fact that this scale is being used.

4. The International Temperature Scale is based upon a number of fixed and reproducible equilibrium temperatures to which numerical values are assigned, and upon the indications of interpolation instruments calibrated according to a specified procedure at the fixed temperatures.

5. The basic fixed points and the numerical values assigned to them for the pressure of one standard atmosphere are given in the following table, together with formulas which represent the temperature (t_p) as a function of vapor pressure (p) over the range 680 to 780 mm of mercury.

6. Basic fixed points of the International Temperature Scale—

	°*C.*
(*a*) Temperature of equilibrium between liquid and gaseous oxygen at the pressure of one standard atmosphere (oxygen point)	−182.97

$$t_p = t_{760} + 0.0126\ (p-760) - 0.0000065\ (p-760)^2$$

(*b*) Temperature of equilibrium between ice and air-saturated water at normal atmospheric pressure (ice point)	0.000
(*c*) Temperature of equilibrium between liquid water and its vapor at the pressure of one standard atmosphere (steam point)	100.000

$$t_p = t_{760} + +0.0367\ (p-760) - 0.000023\ (p-760)^2$$

(*d*) Temperature of equilibrium between liquid sulphur and its vapor at the pressure of one standard atmosphere (sulphur point)	444.60

$$t_p = t_{760} + 0.0909\ (p-760) - 0.000048\ (p-760)^2$$

	°C
(*e*) Temperature of equilibrium between solid silver and liquid silver at normal atmospheric pressure (silver point)	960.5
(*f*) Temperature of equilibrium between solid gold and liquid gold at normal atmospheric pressure (gold point)	1,063

Standard atmospheric pressure is defined as the pressure due to a column of mercury 760 mm high, having a mass of 13.5951 g/cm³, subject to a gravitational acceleration of 980.665 cm/sec.² and is equal to 1,013,250 dynes/cm².

It is an essential feature of a practical scale of temperature that definite numerical values shall be assigned to such fixed points as are chosen. It should be noted, however, that the last decimal place given for each of the values in the table is significant only as regards the degree of reproducibility of that fixed point on the International Temperature Scale. It is not to be understood that the values are necessarily known on the Thermodynamic Centigrade Scale to the corresponding degree of accuracy.

7. The means available for interpolation lead to a division of the scale into four parts.

(*a*) From the ice point to 660° C. the temperature t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_o\ (1 + A_t + Bt^2)$$

The constants R_o, A, and B of this formula are to be determined by calibration at the ice, steam, and sulphur points, respectively.

The purity and physical condition of the platinum of which the thermometer is made should be such that the ratio R_t/R_o shall not be less than 1.390 for $t=100°$ and 2.645 for $t=444.6°$.

(*b*) From $-190°$ to the ice point, the temperature t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_o\ [1 + At + Bt^2 + C\ (t-100)\ t^3]$$

The constants R_o, A, and B are to be determined as specified above, and the additional constant C is determined by calibration at the oxygen point.

The standard thermometer for use below 0° C. must, in addition, have a ratio R_t/R_o less than 0.250 for $t=-183°$.

(*c*) From 660° C. to the gold point, the temperature t is deduced from the electromotive force e of a standard platinum *v*. platinum-rhodium thermocouple, one junction of which is kept at a constant temperature of 0° C. while the other is at the temperature t defined by the formula

$$e = a + bt + ct^2$$

The constants a, b, and c are to be determined by calibration at the freezing point of antimony, and at the silver and gold points.

(*d*) Above the gold point the temperature t is determined by means of the ratio of the intensity J_2 of monochromatic visible radiation of wave length λ cm, emitted by a black body at the temperature t_2, to the intensity J_1 of radiation of the same wave length emitted by a black body at the gold point, by means of the formula

$$\log_e \frac{J_2}{J_1} = \frac{c_2}{\lambda} \left[\frac{1}{1{,}336} - \frac{1}{(t+273)}\right]$$

The constant c_2 is taken as 1.432 cm degrees. The equation is valid if $\lambda(t+273)$ s less than 0.3 cm degrees.

Part II.—RECOMMENDED EXPERIMENTAL PROCEDURE

1. OXYGEN

The temperature of equilibrium of liquid and gaseous oxygen has been best realized experimentally by the static method, the oxygen vapor-pressure thermometer being compared with the thermometer to be standardized in a suitable low temperature bath.

2. ICE

The temperature of melting ice is realized experimentally as the temperature at which pure, finely divided ice is in equilibrium with pure, air-saturated water under standard atmospheric pressure. The effect of increased pressure is to lower the freezing point to the extent of 0.007° C. per atmosphere.

3. STEAM

The temperature of condensing water vapor is realized experimentally by the use of a hypsometer so constructed as to avoid superheat of the vapor around the thermometer, or contamination with air or other impurities. If the desired conditions have been attained, the observed temperature should be independent of the rate of heat supply to the boiler, except as this may affect the pressure within the hypsometer, and of the length of time the hypsometer has been in operation.

4. SULPHUR

For the purpose of standardizing resistance thermometers, the temperature of condensing sulphur vapor is realized by adherence to the following specifications relating to boiling apparatus, purity of sulphur, radiation shield, and procedure.

The boiling-tube is of glass, fused silica, or similar material, and has an internal diameter of not less than 4 nor more than 6 cm. The vapor column must be sufficiently long that the bottom of the radiation shield is not less than 6 cm below the top of the heat insulating material surrounding the tube. Electric heating is preferable, although gas may be used, but the source of heat and all good conducting material in contact with it must terminate at least 4 cm below the free surface of the liquid sulphur. Above the source of heat the tube is surrounded with insulating material. Any device used to close the end of the tube must allow a free opening for equalization of pressure.

The sulphur should contain not over 0.02 per cent of impurities. Selenium is the impurity most likely to be present in quantities sufficient to affect the temperature of the boiling point.

The radiation shield is cylindrical and open at the lower end, and is provided with a conical portion at the top, to fit closely to the protecting tube of the thermometer. The cylindrical part is 1.5 to 2.5 cm larger in diameter than the protecting tube of the thermometer and at least 1 cm smaller in diameter than the inside of the boiling tube. The cylinder should extend at least 1.5 cm beyond each end of the thermometer coil. There should be ample opening at the top of the cylindrical and below the conical portion to permit free circulation of vapor. The inner surface of the shield should be a poor reflector. The shield may be made of sheet metal, graphite, etc.

In standardizing a thermometer the sulphur is heated to boiling and the heating so regulated that the condensation line is at least 1 cm above the top of the insulating material. The thermometer with its radiation shield is inserted in the vapor, and when the line of condensation again reaches its former level simultaneous observations of resistance and barometric pressure are made. In all cases care should be taken to prove that the temperature is independent of vertical displacements of the thermometer and shield.

5. SILVER AND GOLD

For standardizing a thermocouple, the metal to be used at its freezing point is contained in a crucible of pure graphite, refractory porcelain, or other material which will not react with the metal so as to contaminate it to an appreciable extent.

Silver must be protected from access of oxygen while heated.

The crucible and metal are placed in an electric furnace capable of heating the contents to a uniform temperature.

The metal is melted and brought to a uniform temperature a few degrees above its melting point, then allowed to cool slowly with the thermocouple immersed in it as described in the next paragraph.

The thermocouple, mounted in a porcelain tube with porcelain insulators separating the two wires, is immersed in the molten metal through a hole in the center of the crucible cover. The depth of immersion should be such that during the period of freezing the thermocouple can be lowered or raised at least 1 cm from its normal position without altering the indicated emf by as much as 1 microvolt. During freezing, the emf should remain constant within 1 microvolt for a period of at least five minutes.

As an alternative to displacing the couple, as a means of testing the absence of the influence of external conditions upon the observed temperature, both freezing and melting points may be observed and if these do not differ by more than 2 microvolts, the observed freezing point may be considered satisfactory.

6. THE STANDARD PLATINUM RESISTANCE THERMOMETER

The diameter of the wire should not be smaller than 0.05 or larger than 0.2 mm.

The platinum wire of the thermometer must be so mounted as to be subject to the minimum of mechanical constraint, so that dimensional changes accompanying changes of temperature may result in a minimum of mechanical strain being imposed upon the platinum.

The design of the thermometer should be such that the portion, the resistance of which is measured, shall consist only of platinum, and shall be at the uniform temperature which is to be measured. This may be accomplished by either of the accepted systems of current and potential, or compensating leads.

After completion, the thermometer should be annealed at a temperature of at least 660°.

7. THE STANDARD THERMOCOUPLE

The platinum of the standard couple shall be of such purity that the ratio R_t/R_o is initially not less than 1.390 for $t=100°$. The alloy is to consist of 90 per cent platinum with 10 per cent rhodium. The completed thermocouple must develop an electromotive force, when one junction is at 0° and the other at the freezing point of gold, not less than 10,200 nor more than 10,400 international microvolts. The diameter of the wires used for standard thermocouples should lie between the values 0.35 and 0.65 mm.

The freezing point of antimony, specified for the standardization of the thermocouple, lies within the range of 0° to 660° where the international scale is fixed by the indications of the standard resistance thermometer, and the numerical value of this temperature is therefore to be determined with the resistance thermometer. In the appendix the result of such determinations is given as 630.5°, but the temperature of any particular lot of antimony which is to be used for standardizing the thermocouple is to be determined with a standard resistance thermometer.

The procedure to be followed in using the freezing point of antimony as a fixed temperature is substantially the same as that specified for silver. Antimony has a marked tendency to undercool before freezing. The undercooling will not be excessive if the metal is heated only a few degrees above its melting point and if the liquid metal is stirred. During freezing the temperature should remain constant within 0.1° for a period of at least five minutes.

8. SECONDARY POINTS

In addition to the basic fixed points, the temperatures of a number of other points are available and may be used in the calibration of secondary temperature measuring instruments. These points and their temperatures on the international scale are listed below. The temperatures given are those corresponding to a pressure of one standard atmosphere. The formulas for the variation of vapor pressure with temperature are valid for the range from 680 to 780 mm.

	°C.
Temperature of equilibrium between solid and gaseous carbon dioxide	−78.5

$$t_p = t_{760} + 0.1443\ (t_p + 273.2)\ \log_{10}\ (p/760)$$

Temperature of freezing mercury	−38.87
Temperature of transition of sodium sulphate	32.38
Temperature of condensing napthalene vapor	217.96

$$t_p = t_{760} + 0.208\ (t_p + 273.2)\ \log_{10}\ (p/760)$$

Temperature of freezing tin	231.85
Temperature of condensing benzophenone vapor	305.9

$$t_p = t_{760} + 0.194\ (t_p + 273.2)\ \log_{10}\ (p/760)$$

Temperature of freezing cadmium	320.9
Temperature of freezing lead	327.3
Temperature of freezing zinc	419.45
Temperature of freezing antimony	630.5
Temperature of freezing copper in a reducing atmosphere	1,083
Temperature of freezing palladium	1,555
Temperature of melting tungsten	3,400

The Bureau of Standards, therefore, in common with the other national laboratories, will use until further notice in its scientific work and for the calibration of instruments, the standard temperatures, interpolation formulas, and methods of measurement as laid down above by the General Conference of Weights and Measures on October 4, 1927. It is recommended that scientific workers elsewhere conform to the International Temperature Scale as above set forth.

It is expected that international thermometric conferences will be called, as occasion requires, by the International Committee on Weights and Measures, so that this temperature scale may be revised as the need arises.

WASHINGTON, September 12, 1928.