so small that it could not be measured with any accuracy; consequently, no absolute temperature measurements could be done above the Curie point with the help of a-c heating. Below the maximum of χ' the χ'' increase rapidly, so here measurements could be made with the χ'' thermometer. But, in addition, the remanence below the Curie point is so small for both salts that it could not be used as a thermometric parameter. Thus, of three thermometric parameters used in the case of chromium alum, only the χ'' could be used, and this is the one giving the results with the lowest accuracy. With copper potassium sulfate, temperatures down to 0.0045° K were measured; in the case of manganese ammonium sulfate, the lowest temperatures were only of the order of 0.09° K.

Measurements were made with iron ammonium alum, and this salt behaved more like chromium alum. Its χ'' has reasonable values both above and below the Curie point, and also its remanence can be used as a thermometric parameter. It was found that the Curie point is at $T = 0.032°$ K, and the lowest temperature obtained with this salt was about 0.01° K.

Some measurements were made with a chromium potassium alum, which was strongly diluted with aluminum potassium alum (21.3 aluminum ions for each chromium ion). No maximum was found in susceptibility, but perhaps it occurs at a lower temperature than could be reached with the Leiden magnet. The values found for χ'' were of a suitable order of magnitude, so that caloric measurements could be made using the T^* thermometer. The lowest temperature found in these experiments was 0.0014° K, or twice as low as with ordinary chromium alum. Recently a double demagnetization was performed at Oxford with a similar salt. From the extrapolation of the Leiden measurements it could be estimated that the lowest temperature was of the order of 0.001° K.

Bibliography

CASIMIR, H. B. G. *Magnetism and Very Low Temperatures.* Cambridge: Cambridge Physical Tracts (1940).

DE KLERK, D. Thesis, Univ. Leiden (1948).

DE KLERK, D., STEENLAND, M. J., and GORTER, G. J. *Physica*, **15**, 649 (1949).

KURTI, N. *J. phys.*, **12**, 281 (1951).

SIMON, F. E., *et al. Low Temperature Physics.* London: Pergamon Press, 30 (1952).

STEENLAND, M. J. *Nederland. Tijdschr. Natuurk.*, **17**, 311 (1951).

VAN VLECK, J. H. *Ann. Inst. Henri Poincaré*, **10**, 57 (1947).

The Present Status of Temperature Scales

H. F. Stimson

National Bureau of Standards, Washington, D. C.

THE THERMODYNAMIC TEMPERATURE SCALE known as the Kelvin scale, which was based upon a hundred-degree interval between the ice and steam points, was proposed in a paper by Joule and Kelvin in 1854 (*1*). This scale has been recognized as the fundamental temperature scale to which all accurate temperature measurements should ultimately be referred. In principle the Kelvin scale could be realized rather simply with a gas thermometer if the thermometer were ideal and contained an ideal gas; but since neither the thermometer nor the gas is ideal, corrections must be made for their imperfections.

A gas thermometer for accurate temperature measurements requires apparatus and skill such as are found in only a few laboratories specializing on thermometric researches. It was evident that, for uniformity and precise measurement of temperature, a practical scale was needed which could be used for expressing temperatures on the same basis in laboratories all over the world. Since reproducible temperature measurements are as basic in scientific work as are the measurements of mass, length, and time, the logical body to recommend this scale was the International Committee on Weights and Measures. In 1927, as a result of discussions and correspondence extending over nearly two decades, the national laboratories of Germany, the United States, and Great Britain agreed on a definition of an International Temperature Scale. The international committee recommended it to the 7th General Conference on Weights and Measures, then representing 33 nations, and it was adopted. The international committee also recommended in a resolution that studies be made of the official text of the International Temperature Scale in a program of special conferences on thermometry held under its auspices. This also has been done. In 1937 the international committee set up an advisory committee on thermometry and calorimetry, which met in 1939, 1948, and 1952 to discuss ways to improve the International Temperature Scale.

The International Temperature Scale was adopted in 1927 with the understanding that it should not replace the thermodynamic scale but should represent the latter in a practical manner with sufficient accuracy to serve the everyday needs of scientific and industrial laboratories. At that time the scale was the best practical realization of the thermodynamic temperature scale.

The present International Temperature Scale, revised and adopted in 1948 (*2*), is based on six fixed and reproducible equilibrium temperatures to which numerical values have been assigned, and upon the indications of interpolation instruments calibrated at the fixed points according to a specified procedure. Three of the fixed points are boiling points, and the others are freezing points. All are under a pressure of one standard atmosphere. The two fundamental fixed points, on which the unit of temperature is based, are the ice point at 0° C, which is the temperature of equilibrium between ice and air-saturated water, and the boiling point of water at 100° C, which is the temperature of equilibrium between liquid water and its vapor. The others are called primary fixed points and are the boiling point of oxygen at −182.970° C, the boiling point of sulfur at 444.600° C, the freezing point of silver at 960.8° C, and the freezing point of gold at 1063.0° C. The last decimal places for the primary fixed points merely represent the degree of reproducibility of those points.

The means available for interpolating temperatures led to the division of the scale into four parts, using three different instruments for interpolation. The first is from 0° C to the freezing point of antimony at about 630.5° C, using a standard platinum resistance thermometer and a quadratic equation for relating temperature to resistance. The second part is from the lower limit of the scale at the oxygen point at −182.970° C to 0° C, also using a standard resistance thermometer but with a quartic equation. The third part of the scale is from the freezing point of antimony to the gold point at 1063.0° C, using a standard thermocouple of platinum and platinum-rhodium, and a quadratic formula to relate temperature to the electromotive force when one junction of the thermocouple is at the temperature being measured and the other junction is at 0° C. The fourth part of the scale is above the gold point at 1063.0° C, using a narrow-band radiation pyrometer and the Planck radiation formula with the constant C_2 equal to 1.438 cm degrees.

As the demand increased for greater precision in temperature measurements more attention had to be given to the procedures for realizing the fixed points on the scale, and to the reproducibility of the instruments for interpolating temperatures between the fixed points. The technique for realizing the ice point, for example, had to be refined to give the accuracy that is often demanded. During the past two decades the technique for using the triple point of water for a fixed point had been developed to the extent that it appeared to be more reproducible than the ice point. In 1948 a resolution was proposed by the advisory committee, recommended by the international committee and adopted at the general conference, stating that 0°C should be defined as the temperature 0.0100° below the triple point of pure water.

The boiling points of oxygen, water, and sulfur were realized in 1927 in baths open to the atmosphere, and formulas were included in the definitions of the scale to obtain the actual boiling temperatures when the equilibrium pressures were in the range from 680 to 780 mm Hg. Experience has shown that fluctuations in barometric pressure are great enough to limit the attainable accuracy of measurements, so now it is recommended that the boiling liquids be in closed systems where the pressure is controlled close to 1 atmosphere.

The revision of the International Temperature Scale in 1948 left the defined temperatures of the 1927 scale substantially unchanged. Only two of the revisions in the definition of the scale resulted in appreciable changes in the values assigned to measured temperatures. The change in the value assigned to the silver point from 960.5° C to 960.8° C changed the temperatures measured with the standard thermocouple. The adoption of a higher value for the radiation constant C_2 and the change to the thermodynamically rigorous Planck radiation formula changed the values of all temperatures above the gold point, 1063°C.

Other important modifications, which caused little or no alteration in the measured values of temperatures, but served to make the scale more definite and reproducible were (*a*) the termination of the lower part of the scale at the oxygen point, −182.970° C, instead of −190° C; (*b*) the division of the scale at the freezing point of antimony (about 630.5° C) instead of at 660° C; (*c*) the requirements for higher purity of the platinum of the standard resistance thermometer and standard thermocouple, and for smaller permissible limits for the electromotive force of the standard thermocouple at the gold point.

The present lower limit of the International Temperature Scale at the oxygen point leaves a region below this temperature of more than 90°, where there is no international scale at the present time. Instead, there are several scales in use based upon reference instruments in different laboratories, but no scale has been defined so that it can be set up without reference to these actual instruments or without fundamental measurements that utilize a gas thermometer. At temperatures below the oxygen point the boiling point of hydrogen near 20° K may be used as a primary fixed point. At still lower temperatures the boiling point of helium near 4.2° K, and perhaps its lambda point near 2.2° K, may be used. It seems probable that platinum resistance thermometers can be employed for interpolating temperatures down to the hydrogen region, when the proper specifications can be worked out and agreed upon to relate temperature to the resistance of thermometers having some specified purity of platinum. Below the hydrogen region, where the sensitivity of the platinum resistance thermometer becomes very low, it is not easy to choose the instrument for interpolation. These and other problems relating to the extension of the International Temperature Scale were discussed at the meeting of the advisory committee at Paris in June 1952.

As Lord Kelvin defined the thermodynamic temperature scale in 1854, it is a centigrade scale because the fundamental interval between the ice and steam points is 100 degrees. The temperature of the ice point on this scale depends on the results of experiments, and different laboratories use their own preferred value. Lord Kelvin did say, however, that, when the value of the ice point was known with sufficient accuracy, the scale could be defined in terms of the value assigned to the ice point rather than by assigning 100° to the difference between the ice and steam points. He also said "the former is far preferable in the abstract, and must be adopted ultimately." This proposal was made again by W. F. Giauque in 1939 (*3*). In 1948 the advisory committee passed a resolution concerning this scale and the international committee, after changing the wording slightly, recommended it to the general conference, which adopted it. The revised wording of this resolution is: "The advisory committee recognizes the principle of an absolute thermodynamic scale requiring only one fixed point, which would now be the triple point of pure water, for which the absolute temperature will be chosen later. The introduction of this new scale in no way affects the International Temperature Scale, which continues to be the recommended practical scale" (*4*). It is expected that a value for the triple point of water will be chosen for this scale in 1954.

Since the value chosen for the triple point of water probably will not be exactly the same as the true value on the centigrade Kelvin scale, which would be obtained by perfect experiments, it follows that the new absolute thermodynamic scale will not be exactly the same as the centigrade Kelvin scale. This means that the size of the degree on the two will not be identical, and the steam point at 1 atmosphere will not be exactly 100° above the ice point, as would be desirable for its relation to the International Temperature Scale. The value for the triple point of water, therefore, should be the best possible at the time of choosing. If the value is chosen within 0.01° of the true value on the centigrade Kelvin scale, it would probably be some years before the difference at the steam point could be definitely determined. The second sentence of the resolution, however, permits the steam point on the International Temperature Scale to be kept at 100° C as long as this scale continues to be the accepted practical one for expressing temperatures.

It is now believed that the value assigned to the primary fixed point at the sulfur point is lower than the value on the thermodynamic scale by over a tenth of a degree, and the value assigned to the primary fixed point at the oxygen point is higher than the value on the thermodynamic scale by a few hundredths of a degree. This raises the question of whether it is better to change these values in the relatively near future or better to keep the present values for a long time and apply corrections, as best known, in the few instances when the highest accuracy attainable is necessary. Inasmuch as frequent changes produce confusion, it seems better to keep the present values for the practical scale.

During the General Conference on Weights and Measures in 1948 a name was proposed almost spontaneously to replace the name "centigrade" that scientists have been using. This came about as a result of a question in the French language whether the term centigrade or centesimal should be used. The term "Celsius" was proposed in their place and adopted two days later at the last session of the conference (*5*). In defense of this decision it may be noted that the term has been in general use in Germany and some other countries for many years. No new symbol is required since "C" has been used in the past. Furthermore, this scale had been the only one that did not honor some man who had made fundamental advances in the field of thermometry. The use of this new name is not compulsory, of course, and neither is the use of the International Temperature Scale, but in the interest of international uniformity they are recommended. Should confusion arise, it can be avoided by designating temperatures as degrees Celsius (centigrade) until the term Celsius has come into such common usage that it can stand alone. This may take a generation or more.

No mention of Fahrenheit, Reaumur, or Rankin scales has been made in the proceedings of the general conferences, but it is assumed that the former simple relations to the Celsius (centigrade) scale still hold.

References

1. Joule, J. P., and Kelvin, W. T. *Phil. Trans. Roy. Soc.*, **144**, 321 (1854).
2. *J. Research Natl. Bur. Standards*, **42**, 209 (1949).
3. Giauque, W. F. *Nature*, **143**, 623 (1939).
4. *Compt. rend. 9ème conf. gén. poids mesures*, 55 (1948).
5. *Ibid.*, 64.