Low Temperature Platinum Resistance Thermometry

CONSIDERATIONS OF DESIGN AND CALIBRATION

By C. R. Barber, B.Sc.

Standards Division, National Physical Laboratory, Teddington

The platinum resistance thermometer has long been recognised as the most precise temperature measuring instrument for the temperature range from −182.97°C, the boiling point of oxygen, up to 630.5°C, in which range it is the chosen interpolation instrument of the International Practical Scale of Temperature. In the last decade or so its range of usefulness as a precision instrument has been extended to both higher and lower temperatures by suitably modifying the design of the thermometer.

At low temperatures the resistance-temperature relationship of platinum is by no means ideal, for in common with other metals there is a considerable departure from linearity and many calibration points are required to define the shape of the curve. Curves typical of platinum of very high purity given in Fig. 1 show the relationship between the reduced resistance ($R_T/R_{0°C}$) and the temperature and also the variation of the temperature coefficient of resistance for the temperature range from 10° to 90°K. We see that the resistance of the thermometer has fallen at 60°K to 0.1 of its value at 0°C, to 0.01 at 26°K and to 0.001 at 12°K. The temperature coefficient of resistance, however, does not fall proportionally, and we find that we now have to measure the resistance of the thermometer to only 1 in 6,000 at 20°K to achieve a precision of 0.001°K instead of 4 in 10^6 as at 0°C. The precise shape of the resistance-temperature curve is critically dependent on the purity of the platinum. Despite these limitations platinum still appears to be the best choice for the purpose, since it can be obtained in a very pure condition and much

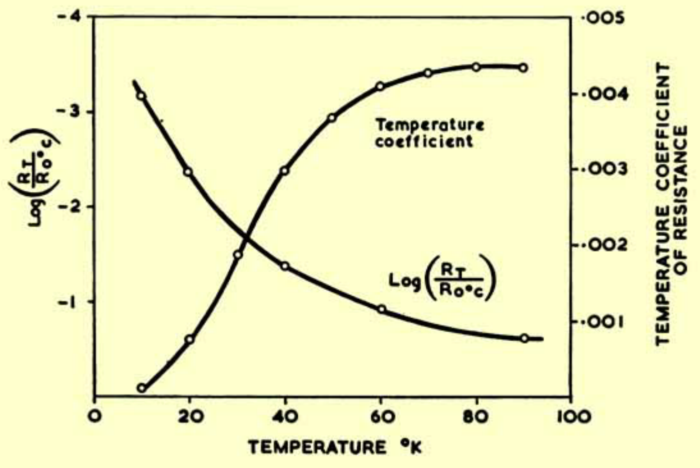

Fig. 1 The resistance-temperature characteristics of pure platinum

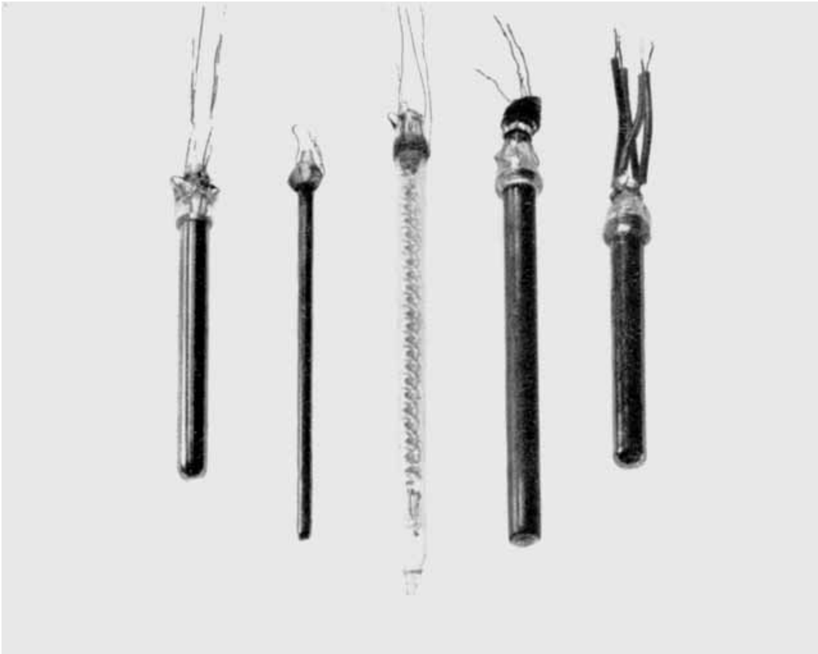

Fig. 2 A group of capsule-type platinum resistance thermometers designed for use at low temperatures. On the left, one of British manufacture; next, one developed at the National Physical Laboratory; in the centre, a thermometer made in the USSR; fourth from the left, one constructed at the Pennsylvania State University, and on the extreme right one of American manufacture

experience has already been gained in the production of uniformly high-purity wire suitable for resistance thermometer construction.

The design of a resistance thermometer for low temperatures is governed by the following considerations. It is obviously an advantage to make the thermometer small but the limit is here set by the minimum diameter of wire that can be used without excessive self-heating by the measuring current. It is common practice for standard thermometers to use wire in the range from 0.07 to 0.1 mm in diameter. It is necessary to suppress conduction of heat into the thermometer by way of leads and stem, otherwise the thermometer may not reach the temperature of the surroundings, for thermal capacities are small and thermal conductivities large at lower temperatures. The method of construction therefore permits total immersion and good thermal contact with the surroundings. In some measurements the platinum sheath of the thermometer is actually joined to the apparatus by a low-melting point solder. The leads of fine wire are brought to the same temperature as the thermometer before being joined to it.

A group of capsule-type platinum thermometers, as they are sometimes known, is shown in Fig. 2. The one on the extreme left of the group is of British manufacture and the one on the extreme right is manufactured in USA. They are contained in thin-walled platinum sheaths about 5 mm in diameter and 45 to 50 mm long, and are filled with a low pressure of helium. The thermometer in the centre of the group was made in the USSR; it has a glass sheath and the coil is mounted on a twisted glass strip.

A type which has recently been used successfully at the National Physical Laboratory is the second from the left in the photograph. The sheath is only 2.5 mm in diameter and 70 mm long. The remaining thermometer is somewhat larger than the others and was constructed at the Pennsylvania State University.

Properly constructed platinum thermometers are extremely stable when cycled between room temperature and the lowest temperatures, the $R_{0°C}$ values remaining constant to within the equivalent of 0.001°C for long periods. In fact any changes that take place are more likely to be due to mechanical rather than to thermal shocks. We can probably say that from the point of view of the physical dimensions, robustness and stability, the capsule-type platinum resistance thermometer is ideally suited to low temperature measurement but the greatest difficulty in its use is to provide it with an accurate calibration.

At certain of the national standardising laboratories, namely, the National Physical Laboratory in this country, the National Bureau of Standards in the USA and the Physico-technical Radio-technical Measurements Institute in the USSR, low temperature scales have been established over the range from 10° to 90°K and these are recorded in terms of groups of platinum resistance thermometers of the types abovementioned. It is possible from these to derive accurate calibrations by comparison at many temperatures over the range. It would be very advantageous, however, to be able to define the practical scale of temperature in terms of the platinum thermometer using only a few fixed points of calibration, just as we do already in the regions defined by the International Practical Scale of Temperature.

There is no simple function relating resistance and temperature in the low temperature range and the only way of dealing with the problem is to use a standard table of resistance (or some function of resistance) and temperature, based on a typical thermometer or group of thermometers, and to derive the calibration of a particular thermometer by difference from this table using a few calibration points. A method suggested by the application of Matthiessen's rule over the range from 20° to 90°K is to use a standard table of Z functions, where $Z = \frac{R_T - R_{H_2}}{R_{O_2} - R_{H_2}}$ and R_T, R_{H_2} and R_{O_2} are the resistances of the thermometer at temperature T and at the boiling points of hydrogen and oxygen respectively. By limiting the thermometers to those having α-coefficients greater than 3.92×10^{-3} it is probable that such a table would give a calibration accurate in all cases to ±0.02°K and it would only be necessary to calibrate the thermometer at the boiling points of hydrogen and oxygen. To obtain calibrations with smaller errors of interpolation it is clear that more calibration points must be used, and suggestions have been made for using quadratic and cubic equations for the departures from the Z function table, using one and two additional fixed points.

A method recently considered by the author which appears to have good possibilities—because it is generally simpler than others and moreover covers a wider range—is as follows. The particular thermometer is calibrated at the triple point of equilibrium hydrogen (13.82°K), the boiling point of equilibrium hydrogen (20.27°K), the triple point of nitrogen (63.15°K) and the boiling point of oxygen (90.18°K). A curve of difference from a standard table of reduced resistance $\left(\frac{R_T}{R_{0°C}}\right)$ and temperature is then plotted. With thermometers having α-coefficients greater than 3.925×10^{-3} it is found that the calibration is given to within ± 0.005°K over the whole range 14° to 90°K. The particular calibration points are chosen because they are comparatively simple to realise.

The capsule-type platinum resistance thermometer is thus capable of giving very high accuracy of temperature measurement down to 14°K and may well eventually be the means of defining an extension of the International Practical Scale of Temperature. The problem is under consideration by the International Committee of Weights and Measures through its Advisory Committee on Thermometry.