THERMOPHYSICAL MEASUREMENTS

THERMOMETER WORKING STANDARD FOR TEMPERATURES BELOW 0.5 K

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We describe standard resistance thermometers made of a rhodium—iron alloy designed for operation in the temperature range 0.02-2 K. The sensitive element of the thermometer is filled with liquid helium-4 or helium-3, which improves the heat exchange by several orders of magnitude. This makes it possible to significantly increase the measuring current and to use conventional technology for precise measurement of resistance.

We know that at temperatures below 14 K, wire-wound resistance thermometers made of rhodium—iron alloy have a readout reproducibility which is better by an order of magnitude than all other thermometers, usually greater than 0.3 mK in the best models. This is due to the high chemical stability of the wire material and its much higher mechanical rigidity than platinum in the annealed state, as a result of which the thermometer with an unsupported coil proves to be quite stable. It is specifically such thermometers which can be used to maintain the temperature scale in the state primary temperature standard.

In [1] it is shown that the sensitivity of thermometers made of rhodium—iron alloy manufactured by different companies, including at the All-Union Scientific-Research Institute of Physicotechnical and Radiotechnical Measurements, increases with a reduction in temperature down to 30 mK or below. However, application of such thermometers below 0.5 K encounters significant difficulties, which are due to the sharp reduction in heat exchange between the coil of the thermometer (heated by the measuring current) and its case, leading to thermal contact with the object whose temperature is being measured. The reason for the decrease in heat exchange is obvious, and involves the drop in pressure of the heat-exchange helium below 1 Pa, after which heat transfer may occur only along the wire of the sensitive element.

The thermal conductivity of rhodium—iron alloy is low, on the order of 0.05 W/(K·m) at 0.1 K; the wire has a small diameter (0.03-0.05 mm) and long length (0.5-1.0 m). Accordingly, for a thermometer having resistance of 100 Ω at room temperature, according to the data in [1] the measuring current at 0.1 K for obtaining 1 mK overheating should be 1-3 μA. The power produced by such a current is equal to about 5·10^{-12} W, and for a sensitivity of about 1 Ω/K this corresponds to a voltage sensitivity of 1-3 μV/K. From this, in order to obtain even the often insufficient resolution of 1 mK, the measuring circuit should have a sensitivity significantly higher than 1 nV. To this we should add the difficulties in measurements at constant current connected with taking into account the thermal emf, which even in a good setup is rarely less than 50 nV.

Schuster [1, 2] solved this problem by developing a computer-controlled measurement circuit for ac current providing resolution of 0.06 nV with averaging time of 1000 sec. This result makes it possible to use thermometers made of rhodium—iron alloy in any experiments not requiring rapid measurements. However, the circuit design is rather complicated. Furthermore, successful application of the circuit is possible only within a special and very expensive shielded compartment, within which the sensitive part of the measuring equipment is located (communicating with the computer along fiber-optic lines). These circumstances make such a solution out of reach for almost all researchers.

But if, departing from the customary approach, using the same type of thermometer both for practical measurements and for calibration of other temperature-measuring devices, then we can design a good standard thermometer or working standard allowing us to employ widely used technology for precise measurement of resistances. The cost of the changes introduced is an increase in the dimensions and heat capacity of the thermometer and the impossibility of using such an instrument in many experiments (such as for heat capacity measurements).
The basis for the proposed approach is the sharp improvement in heat exchange with the coil of the sensitive element. This may be achieved by filling the case of the thermometer with liquid helium-4 in the superfluid state, the thermal conductivity of which is exceptionally high. We note that in this case there are no additional factors affecting the thermometric properties of the unsupported coil. It is specifically for this reason that we should reject any attempts to improve heat exchange by gluing the coil, deposition of the alloy onto a substrate, etc., which do not allow us to eliminate additional mechanical stresses in the alloy due to the difference in the thermal expansion of the materials and in all known cases lead to a sharp deterioration in the stability of the instrument.