The Use of Rhodium-Platinum for Precise Low-Temperature Resistors

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The resistive properties of three rhodium-platinum alloys have been measured in the temperature range 2 to 300 K. Resistors of high stability and low temperature coefficient of resistance at liquid helium temperatures have been made with these rhodium-platinum alloys.

As part of its responsibility to maintain the standards on which the units of physical measurement are based, the Australian National Measurement Laboratory has developed a voltage standard based on the a.c. Josephson Effect (1, 2). This experiment makes use of the unique properties of superconductors, and requires operation at temperatures in the liquid helium range, that is at 4.2K or lower.

The experiment can be improved in precision and convenience of operation by incorporating as many components of the measuring apparatus as possible in the liquid helium environment. These improvements can only be realised if the components themselves, such as resistors, are sufficiently stable and reproducible in value at these extremely low temperatures. Conventional alloys used for stable resistors at room temperature, such as Evanohm and manganin, become highly temperature dependent when cooled to helium temperatures. It was therefore decided to investigate the electrical properties of a number of alloys at low temperatures, in order to evaluate their likely performance as part of an improved voltage standard.

Properties of Rhodium-Platinum

The availability of rhodium-platinum wires with well-specified composition, together with their mechanical strength and freedom from chemical corrosion, made them candidates for evaluation in the construction of stable resistors. A further point in their favour was that the annealing procedures established in work with platinum resistance thermometers could be adopted to minimise the unpredictable effects of trace magnetic impurities.

As there was virtually no published information on the low-temperature resistivity of rhodium-platinum, initial measurements of three alloys, 10, 13 and 30 per cent rhodium by weight, were carried out at temperatures between 2K and 300K. The results for annealed wires are summarised in Figure 1

Resistivity and Resistivity Ratio for Rhodium-Platinum Alloys at 293, 77 and 4.2K

Alloy Composition, per cent	Resistivity, μohm-cm			Resistivity Ratio	
	293K	77K	4.2K	293/77	293/4.2
10 Rhodium-90 Platinum	18.8	11.9	10.1	1.584	1.864
13 Rhodium-87 Platinum	20.3	12.8	11.7	1.583	1.734
30 Rhodium-70 Platinum	18.9	13.3	12.3	1.421	1.542

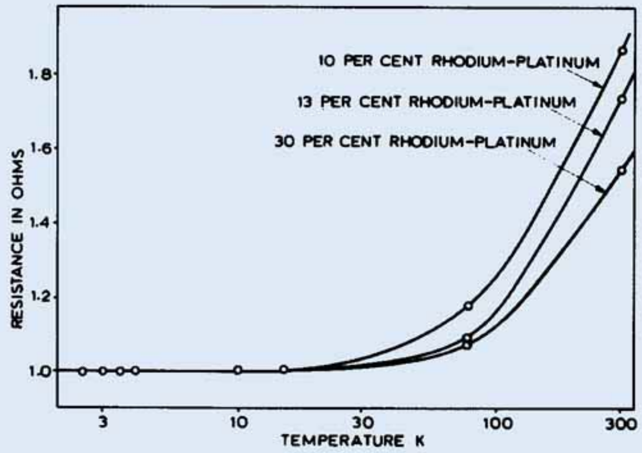

Fig. 1 The temperature dependence of resistors constructed from annealed rhodium-platinum wires, in the range 2 to 300K

and the Table. The resistivities have an uncertainty of ±5 per cent, owing to experimental variability in measurements of the wire diameter. The resistivity ratios, which do not depend on the wire dimensions, have ±0.5 per cent uncertainty.

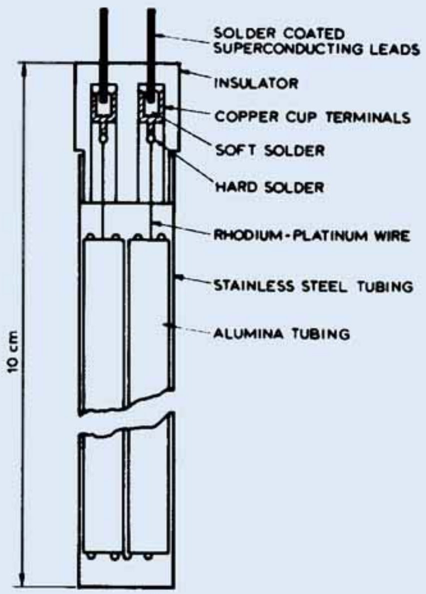

Fig. 2 Resistors were constructed from rhodium-platinum wire loosely wound on alumina tubing, and enclosed in stainless steel tubing

Construction of Resistors

Rhodium-platinum wires, ranging in diameter from 0.1 to 0.3 mm, were used to construct a number of resistors measuring between 0.5 and 10 ohms at room temperature. The wires were loosely wound through multi-bore alumina ceramic tubing and subsequently annealed at 900°C in air for 2 hours. A 3.5 mm diameter copper cup (3) was hard-soldered to each end of the wire, to provide well-defined terminations for the attachment of solder-coated superconducting leads. The details of construction are illustrated in Figure 2.

Low-Temperature Behaviour of the Resistors

The resistors in all cases had a small positive temperature coefficient of resistance at 4.2K, ranging in value from 4 to 6 parts per million (ppm) per degree K, and there was generally a minimum in the resistance-temperature curve at a lower temperature. Detailed measurements on a 30 per cent rhodium-platinum resistor showed the minimum occurring at 2.1K, see Figure 3. As can be seen, this desirable feature was not present in unannealed wires.

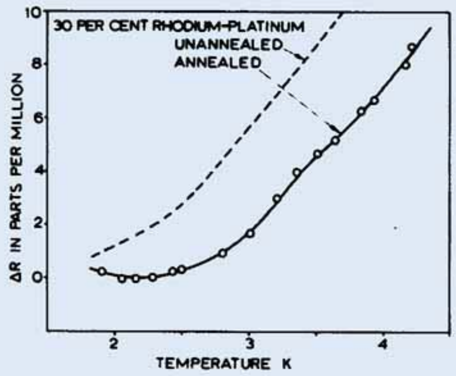

Fig. 3 The change in resistance, ΔR, of a 30 per cent rhodium-platinum resistor, in the annealed and unannealed condition, was determined in the temperature range 1.9 to 4.2K

The stability of resistors from run to run was good. The values of two resistors subjected to many temperature cycles between 2K and 300K changed by less than 4 ppm over a period of 18 months.

Linked with the requirement of low temperature coefficient of resistance is that of load coefficient. If a resistor is to be operated over a range of currents, the temperature rise due to self-heating must not cause the resistor to change significantly from its calibrated value. The load coefficient, which expresses the resistance change in parts per million per watt of power dissipated in the resistor, can be minimised (i) by operating near the resistance-temperature minimum, and also (ii) by promoting the removal of heat from the resistance wire. Liquid helium becomes superfluid below 2.17K, ensuring highly effective cooling of the wire, and when the superfluid state exists at the resistance minimum, as in the example shown in Figure 3, the load coefficient can in principle be very small—of the order of 1 part per million per watt. Resistors tested under working conditions showed no measurable change, within ± 0.01 ppm, at currents up to 20 mA.

Conclusion

Rhodium-platinum wire-wound resistors of relatively simple construction offer a high degree of stability for precise electrical measurements in liquid helium at temperatures close to 2K. Further work will be directed to reducing the overall dimensions of the resistors, and extending the temperature range of the resistance minimum towards 4.2K.

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References

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