

12. Carbon-Glass Resistance Thermometers

Lawless (1972) suggested that carbon-glass thermometers be used instead of the classical carbon thermometer because of the latter's instability. Some thermometers also exist that use plastic instead of glass [Besley (1983)], but they are not commonly available and so are not discussed here.

12.1 Fabrication

A porous glass is prepared by removing the boron-rich phase from a borosilicate alkaline glass to leave a material having the appearance of silicate spheres of about 30 nm diameter, randomly distributed and separated by 3 to 4 nm pores. The spaces are then partially filled with high-purity carbon to form amorphous fibres. The resulting material is cut in pieces of about 5 x 2 x 1 mm on which are deposited electrodes of Nichrome-gold to which copper leads are attached. The pieces are heated at 100 °C for 24 h to desorb gases and water vapour and are then sealed in platinum capsules under an atmosphere of helium. The amorphous nature of the carbon gives the advantage that the specimens have no piezoresistance, so there is no problem of mounting without constraint as there is for a germanium resistor; this shortens the response time.

The thermal capacity of these elements [Lawless (1981)] varies with temperature much like that of the silica substrate but it is more important at very low temperatures. Between 2 and 30 K, the quantity CT^{-3} (where C is the heat capacity) passes through a maximum near 10 K of $50 \times 10^{-4} \text{ J kg}^{-1} \text{ K}^{-4}$, for example, for a specimen having a resistivity of $9 \text{ } \Omega\text{cm}$ at 4.2 K.

The carbon also plays a small role in the thermal conductivity. For the same specimen as above, the order of magnitude is $5 \times 10^{-2} \text{ Wm}^{-1}\text{K}^{-1}$.

12.2 Resistance- Temperature Characteristics; Sensitivity; Calibration

The resistivity of these thermometers is small; those available commercially have a resistivity of 10 to 25 Ωcm at 4.2 K, decreasing to 0.7 Ωcm at 300 K.

The resistance of carbon-glass thermometers decreases exponentially and slowly with increasing temperature so that the useful range of a given specimen is easily 1.5 K to 350 K (Fig. 12.1). Typical values of resistance are 2100 Ω at 4.2 K, 34 Ω at 77 K, and 17 Ω at 300 K.

Few measurements have been made using alternating current but the thermometers seem to be perfectly ohmic.

The carbon-glass thermometer sensitivity is compared with that of germanium and carbon thermometers in Fig, 11.2.

The sensitivity is a monotonic function of temperature, which permits calibration of thermometers using a semi-empirical equation of the form $R = k_1 T^{-3/2} e^{-k_2/T} + k_3 T^{-k_4} e^{-k_5/T}$, and so avoiding interpolation with polynomials of high degree. On the one hand this reduces the number of calibration points necessary, and on the other the same formula is valid over a large temperature range within the measurement precision. For example, between 4.2 K and 30 K, a calibration has been obtained [Swartz et al. (1976)] with a standard deviation of 0.43 mK with the following formula:

$$R = k_1 T^{-3/2} e^{-k_2/T} + k_3 T^{-k_4} e^{-k_5/T} \quad (12.1)$$

$$k_1 = 7231.956; \quad k_2 = 10.76346; \quad k_3 = 727.7906$$

$$k_4 = 0.4644607; \quad k_5 = 6672207$$

The carbon-glass elements are not interchangeable but for specimens i and j coming from the same batch it is possible to relate the calibration of one to the other by using the relation: $R_i = aR_j^b$, where a and b are temperature-independent constants and b is near unity. The accuracy of this procedure is not yet truly established; its use has led to a standard deviation with respect to a classical calibration of 4×10^{-3} in $\ln R$.

12.3 Stability

Carbon-glass is not as stable as germanium. The behaviour of carbon-glass thermometers when thermally cycled is not identical from one specimen to another. Between room temperature and 4.2 K, instabilities have ranged from tenths of millikelvins to many dozens of millikelvins [Besley (1979)]. This suggests that the instabilities have a variety of causes, such as structural defects and diffusion of impurities due to the passage of electrical current. There appears to be no improvement of stability through aging the specimens. The thermometer resistance does not suffer from drift or abrupt jumps. The reproducibility suffices for most applications; for the most part it is of the order of 0.5 mK at 4.2 K, 10 mK at 20 K, and 60 mK at 77 K.

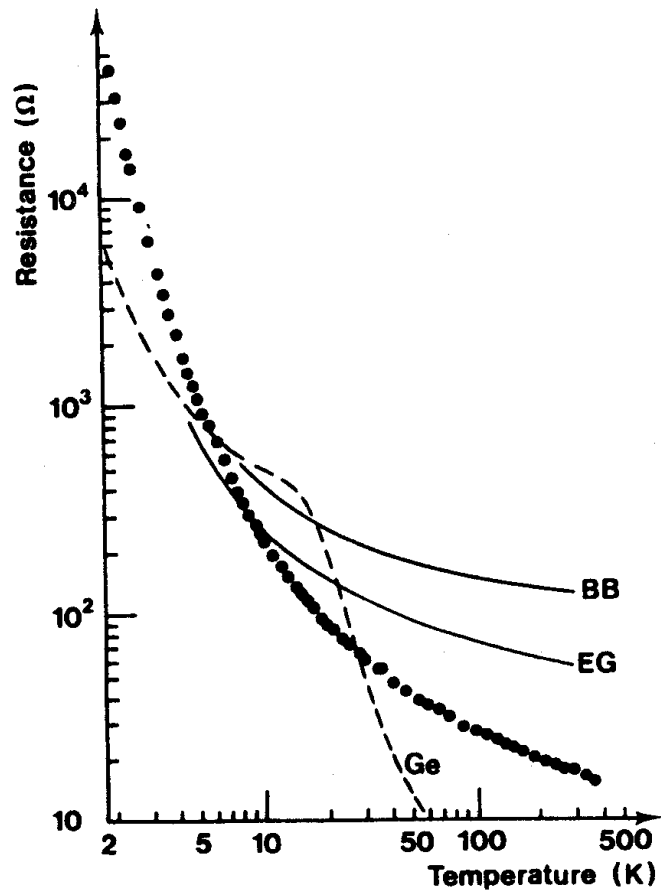


Fig. 12.1: Resistance-temperature characteristic of typical carbon-glass thermometer (solid circles) compared with that of germanium (broken curve) and two Allen-Bradley carbon thermometers (BB: 1/8 W; EG: 1/2 W) [Lawless (1972)].

Although less stable than germanium, carbon-glass thermometers are also less sensitive to a magnetic field, although in magnetic fields higher than 5 to 8 teslas capacitive thermometers are preferable (see Chapter 19).