Bimetallic Thermometers

If two strips of metals A and B with different thermal-expansion coefficients α_A and α_B but at the same temperature (Fig. 8.3*a*) are firmly bonded together, a temperature change causes a differential expansion and the strip, if unrestrained, will deflect into a uniform circular arc. Analysis[3] gives the relation

$$\rho = \frac{t\{3(1+m)^2 + (1+mn)[m^2 + 1/(mn)]\}}{6(\alpha_A - \alpha_B)(T_2 - T_1)(1+m)^2} \tag{8.3}$$

where $\rho \triangleq$ radius of curvature
$t \triangleq$ total strip thickness, $0.0005 \text{ in} < t < 0.125 \text{ in}$ in practice
$n \triangleq$ elastic modulus ratio, E_B/E_A
$m \triangleq$ thickness ratio, t_B/t_A
$T_2 - T_1 \triangleq$ temperature rise

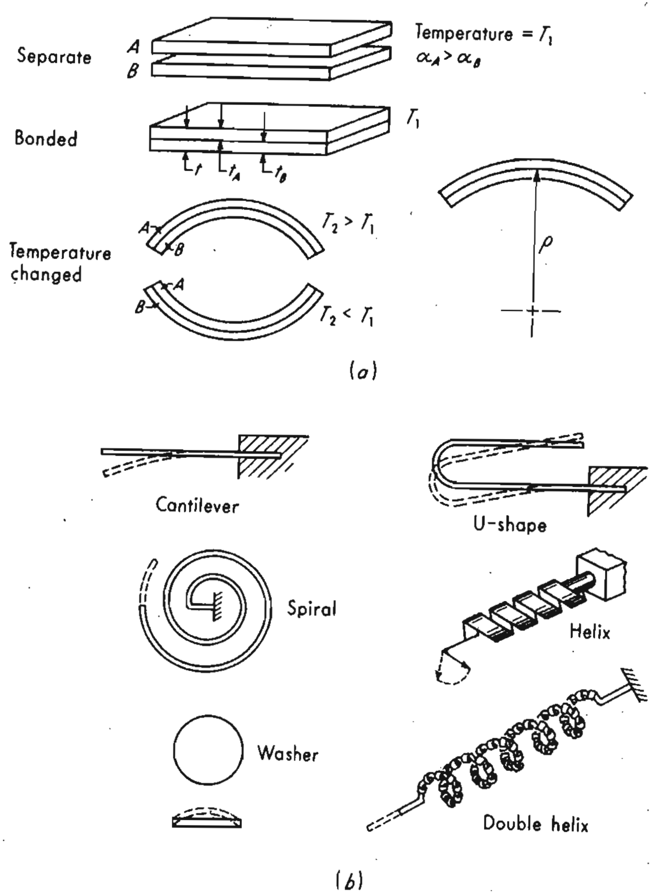
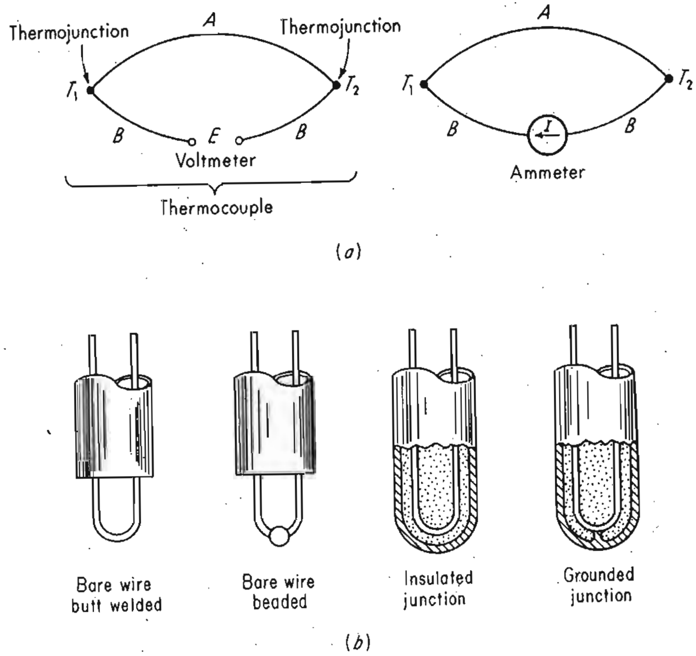


Figure 8.3 Bimetallic sensors.

In most practical cases, $t_B/t_A \approx 1$ and $n + 1/n \approx 2$, giving

$$\rho \approx \frac{2t}{3(\alpha_A - \alpha_B)(T_2 - T_1)} \tag{8.4}$$



Basic thermocouple and junction types.

Thermodynamic approaches are based on the two experimentally observed reversible energy-conversion processes, the Peltier and Thomson effects, and neither require nor give any explanation of the basic atomic mechanisms. The total emf produced is made up of a part due to the Peltier effect, which is localized at each junction, and a (usually much smaller) part caused by the Thomson effect, which is distributed along each conductor between the junctions. The Peltier emf's are assumed proportional to the junction temperature, while the Thomson emf's are proportional to the difference between the squares of the junction temperatures. For the total voltage, the equation takes the form

$$E = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2) \tag{8.6}$$

Copper/constantan thermocouples, for example, give

$$E = 62.1(T_1 - T_2) - 0.045(T_1^2 - T_2^2) \tag{8.7}$$

where $E \triangleq$ total voltage, μV
$T_1, T_2 \triangleq$ absolute junction temperatures, K

Unfortunately, the assumptions made in the analyses leading to Eq. (8.6) are not exactly satisfied in practice; thus equations such as (8.7) *cannot* usually be used to predict accurately temperatures from measured voltages. Rather, a given thermocouple material must be calibrated over the complete range of temperatures in which it is to be used. In this calibration only the overall voltage is of interest, and the separate contributions of Peltier and Thomson effects are not determined. Temperature measurement by thermoelectric means is thus based entirely on empirical calibrations and the application of so-called thermoelectric "laws" which experience has shown to hold. These laws, quoted below, are adequate for analysis of most practical thermocouple circuits. In those cases where the circuit configuration does not lend itself to direct application of these laws, alternative approaches[2] are available.

The laws of thermocouple behavior may be stated as follows:

1. The thermal emf of a thermocouple with junctions at T_1 and T_2 is totally unaffected by temperature elsewhere in the circuit if the two metals used are each homogeneous (Fig. 8.9*a*).

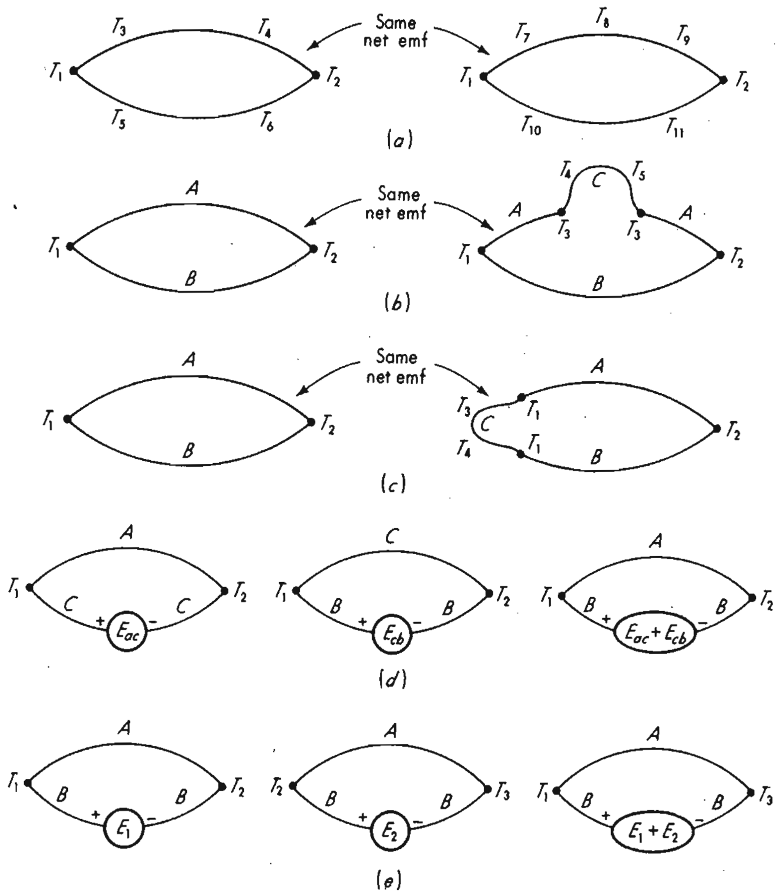
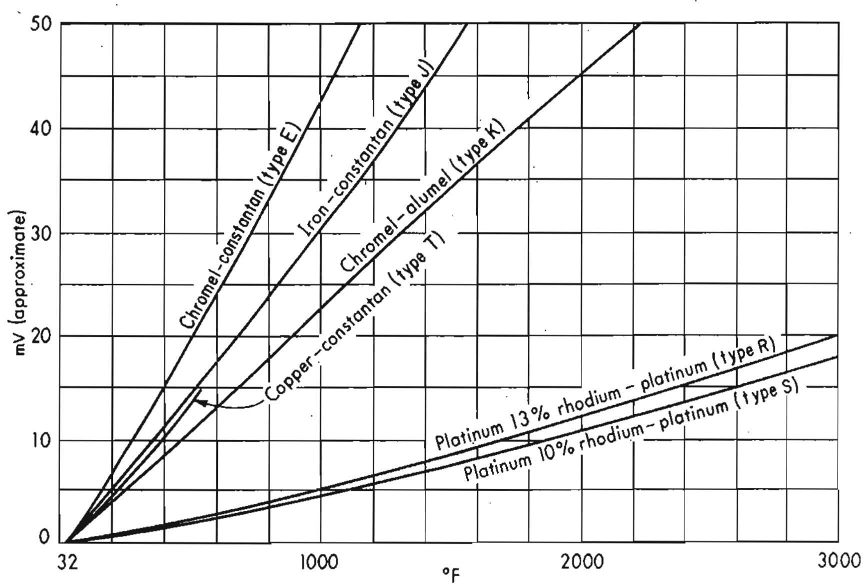
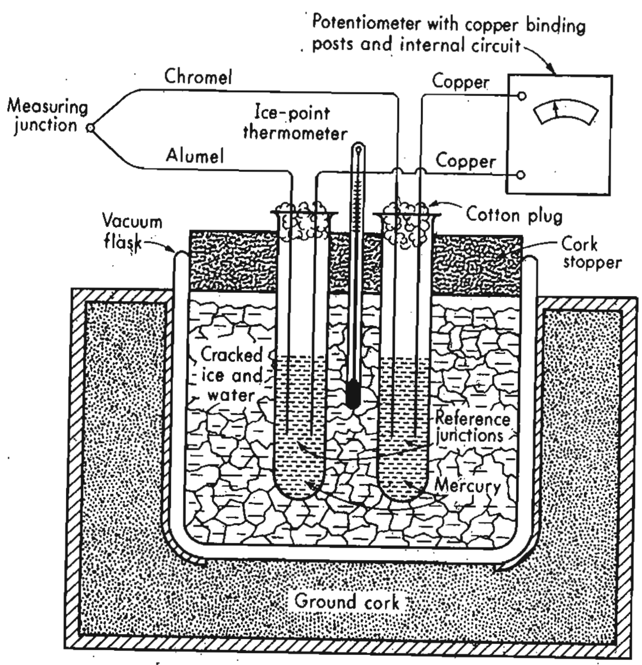


Figure 8.9 Thermocouple laws.

2. If a third homogeneous metal C is inserted into either A or B (see Fig. 8.9*b*), as long as the two new thermojunctions are at like temperatures, the net emf of the circuit is unchanged irrespective of the temperature of C away from the junctions.
3. If metal C is inserted between A and B at one of the junctions, the temperature of C at any point away from the AC and BC junctions is immaterial. As long as the junctions AC and BC are both at the temperature T_1, the net emf is the same as if C were not there (Fig. 8.9*c*).
4. If the thermal emf of metals A and C is E_{AC} and that of metals B and C is E_{CB}, then the thermal emf of metals A and B is $E_{AC} + E_{CB}$ (Fig. 8.9*d*).
5. If a thermocouple produces emf E_1 when its junctions are at T_1 and T_2, and E_2 when at T_2 and T_3, then it will produce $E_1 + E_2$ when the junctions are at T_1 and T_3 (Fig. 8.9*e*).



Thermocouple temperature/voltage curves.



Ice-bath reference junction.