Problems

4.1 The starting diameter of a shaft is 25.00 mm. This shaft is to be inserted into a hole in an expansion fit assembly operation. To be readily inserted, the shaft must be reduced in diameter by cooling. Determine the temperature to which the shaft must be reduced from room temperature (20°C) in order to reduce its diameter to 24.98 mm. Refer to Table 4.1.

Solution: For steel, $\alpha = 12(10^{-6})$ mm/mm/°C according to Table 4.1.
Revise Eq. (4.1) to $D_2 - D_1 = \alpha D_1 (T_2 - T_1)$.
$24.98 - 25.00 = 12(10^{-6})(25.00)(T_2 - 20)$
$-0.02 = 300(10^{-6})(T_2 - 20)$
$-0.02 = 0.0003(T_2 - 20) = 0.0003T_2 - 0.006$
$-.02 + 0.006 = 0.0003T_2$
$-0.014 = 0.0003T_2$ $\quad\quad T_2 = \mathbf{-46.67°C}$

4.2 A bridge built with steel girders is 500 m in length and 12 m in width. Expansion joints are provided to compensate for the change in length in the support girders as the temperature fluctuates. Each expansion joint can compensate for a maximum of 40 mm of change in length. From historical records it is estimated that the minimum and maximum temperatures in the region will be -35°C and 38°C, respectively. What is the minimum number of expansion joints required?

Solution: Assume L_1 =500 m at -35 C, α=12x10^{-6}/C
$L_2 - L_1 = \alpha L_1(T_2 - T_1)$
$L_2 - L_1 = 12\text{x}10^{-6}(500)(38 - (-35))$
$L_2 - L_1 = 0.42$ m
Each expansion joint will control 40 mm = 0.04 m of expansion.
10 joints will provide 0.40 m of expansion. 11 joints will provide 0.45 m of expansion. Therefore, a **minimum of 11 joints** are needed for coverage of the total length. Each bridge section will be 500/11 = 45.5 m long.

4.3 Aluminum has a density of 2.70 g/cm^3 at room temperature (20°C). Determine its density at 650°C, using data in Table 4.1 as a reference.

Solution: Assume a 1 cm^3 cube, 1 cm on each side.
From Table 4.1, $\alpha = 24(10^{-6})$ mm/mm/°C
$L_2 - L_1 = \alpha L_1 (T_2 - T_2)$.
$L_2 = 1.0 + 24(10^{-6})(1.0)(650 - 20) = 1.01512$ cm
$(L_2)^3 = (1.01512)^3 = 1.04605$ cm^3
Assume weight remains the same; thus ρ at 650°C = 2.70/1.04605 = **2.581 g/cm^3**

4.4 With reference to Table 4.1, determine the increase in length of a steel bar whose length = 10.0 in, if the bar is heated from room temperature of 70°F to 500°F.

Solution: Increase = (6.7 x 10^{-6} in/in/F)(10.0 in)(500°F - 70°F) = **0.0288 in**.

4.5 With reference to Table 4.2, determine the quantity of heat required to increase the temperature of an aluminum block that is 10 cm x 10 cm x 10 cm from room temperature (21°C) to 300°C.

Solution. Heat = (0.21 cal/g-°C)(10^3 cm^3)(2.70 g/cm^3)(300°C - 21°C) = **158,193 cal**.
Conversion: 1.0 cal = 4.184J, so heat = **662,196 J**.

4.6 What is the resistance R of a length of copper wire whose length = 10 m and whose diameter = 0.10 mm? Use Table 4.3 as a reference.

Solution: $R = rL/A$, $A = \pi(0.1)^2/4 = 0.007854$ mm^2 = $0.007854(10^{-6})$ m^2
From Table 4.3, $r = 1.7 \times 10^{-8}$ Ω-m^2/m

$R = (1.7 \times 10^{-8}\ \Omega\text{-m}^2/\text{m})(10\ \text{m})/(\ 0.007854(10^{-6})\ \text{m}^2) = 2164.5(10^{-2})\ \Omega = \mathbf{21.65\ \Omega}$

4.7 A 16 gage nickel wire (0.0508-in diameter) connects a solenoid to a control circuit that is 32.8 ft away. (a) What is the resistance of the wire? Use Table 4.3 as a reference. (b) If a current was passed through the wire, it would heat up. How does this affect the resistance?

Solution: (a) L = 32.8 ft = 393.6 in
Area $A = \pi(0.0508)^2/4 = 0.00203$ in^2
$R = r\ (L/A) = 6.8 \times 10^{-8}\ (39.4)(393.6/0.00203) =$ **0.520 ohm**

(b) If a current is passed through the wire causing the wire to heat up, the resistivity of the wire would change. Since nickel is a metal, the resistivity would increase, causing the resistance to increase. This, in turn, would cause slightly more heat to be generated.

4.8 Aluminum wiring was used in many homes in the 1960s due to the high cost of copper at the time. Aluminum wire that was 12 gauge (a measure of cross-sectional area) was rated at 15 A of current. If copper wire of the same gauge were used to replace the aluminum wire, what current should the wire be capable of carrying if all factors except resistivity are considered equal? Assume that the resistance of the wire is the primary factor that determines the current it can carry and the cross-sectional area and length are the same for the aluminum and copper wires.

Solution: The area and length are constant between the types of wires. The overall change in resistance is due to the change in resistivity of the materials. From Table 4.3:
For Aluminum $r = 2.8 \times 10^{-8}$
For Copper $r = 1.7 \times 10^{-8}$
The resistance will reduce by $1.7\text{x}10^{-8}/2.8\text{x}10^{-8} = 0.61$
Since $I = E/R$ and R_{cu}=0.61(R_{al}), then $I_{cu} = 1/0.61 * I_{al} = 15/0.61 =$ **25 A**
Note that the code value is actually 20 A due to several factors including heat dissipation and rounding down to the nearest 5 amp value.