1 Temperature and Thermal Expansion

$$\Delta L = \alpha L_0 \, \Delta T \qquad \Delta V = \beta V_0 \, \Delta T \qquad \beta \approx 3\alpha$$

$$\alpha_{steel} = 11 \times 10^{-6}/K \qquad \alpha_{brass} = 19 \times 10^{-6}/K \qquad \alpha_{alum.} = 23 \times 10^{-6}/K$$

1.a RHK Questions

21. What are the dimensions of α, the coefficient of linear expansion? Does the value of α depend on the unit of length used? When Fahrenheit degrees are used instead of Celsius degrees as the unit of temperature change, does the numerical value of α change? If so, how? If not, prove it.

22. A metal ball can pass through a metal ring. When the ball is heated, however, it gets stuck in the ring. What would happen if the ring, rather than the ball, were heated?

27. Water expands when it freezes. Can we define a coefficient of volume expansion for the freezing process?

29. Does the change in volume of an object when its temperature is raised depend on whether the object has cavities inside, other things being equal?

1.b RHK Exercises

15. Steel railroad tracks are laid when the temperature is -5.0 °C. A standard section of rail is then 12.0 m long. What gap should be left between rail sections so that there is no compression when the temperature gets as high as 42 °C?

20. Soon after the Earth formed, heat released by the decay of radioactive elements raised the average internal temperature from 300 to 3000 K, at about which value it remains today. Assuming an average coefficient of volume expansion of 3.2 $\times$ 10^{-5} K^{-1}, by how much has the radius of the Earth increased since its formation? *(The current radius of the earth is 6400 km)*

21. A rod is measured to be 20.05 cm long using a steel ruler at a room temperature of 20 °C. Both the rod and the ruler are placed in an oven at 270 °C, where the rod now measures 20.11 cm using the same rule. Calculate the coefficient of thermal expansion for the material of which the rod is made.

28. A composite bar of length $L = L_1 + L_2$ is made from a bar of material 1 and length L_1 attached to a bar of material 2 and length L_2 as shown in Fig. 21-15.

(a) Show that the effective coefficient of linear expansion α for this bar is given by $\alpha = (\alpha_1 L_1 + \alpha_2 L_2)/L$.

(b) Using steel and brass, design such a composite bar whose length is 52.4 cm and whose effective coefficient of linear expansion is 13 $\times$ 10^{-6}/°C.

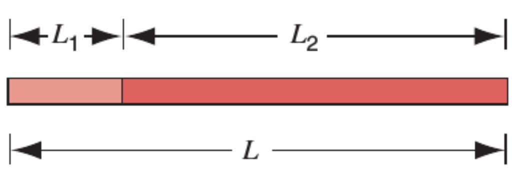

FIGURE 21-15. Exercise 28.

34. An aluminum cup of 110 cm^3 capacity is filled with glycerin at 22 °C. How much glycerin, if any, will spill out of the cup if the temperature of the cup and glycerin is raised to 28 °C? (The coefficient of volume expansion of glycerin is 5.1 $\times$ 10^{-4}/°C)

1.c RHK Problems

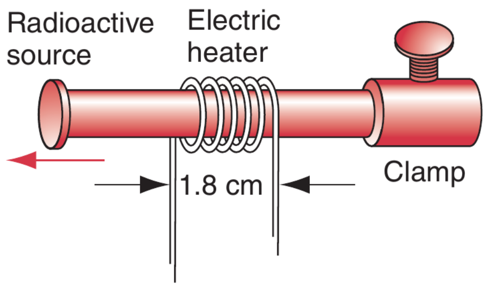

FIGURE 21-18. Problem 6.

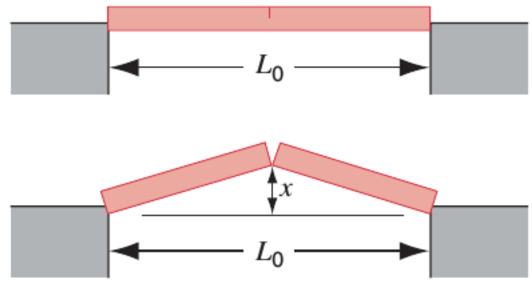

FIGURE 21-19. Problem 8.

6. In a certain experiment, it was necessary to be able to move a small radioactive source at selected, extremely slow speeds. This was accomplished by fastening the source to one end of an aluminum rod and heating the central section of the rod in a controlled way. If the effective heated section of the rod in Fig. 21-18 is 1.8 cm, at what constant rate must the temperature of the rod be made to change if the source is to move at a constant speed of 96 nm/s?

7. *(a)* Show that if the lengths of two rods of different solids are inversely proportional to their respective coefficients of linear expansion at the same initial temperature, the difference in length between them will be constant at all temperatures.

(b) What should be the lengths of a steel and a brass rod at 0 °C so that at all temperatures their difference in length is 0.30 m?

8. As a result of a temperature rise of 32 °C, a bar with a crack at its center buckles upward, as shown in Fig. 21-19. If the fixed distance $L_0 = 3.77$ m and the coefficient linear expansion is 25 $\times\ 10^{-6}$ °C, find x, the distance to which the center rises.

14. *(Modified)* Glass-to-metal seals are an important part of many electronic components, such as light bulbs. One way to make one is to thread metallic wire through molten glass, then let it cool down. For this problem, assume $\alpha_{glass} = 9 \times 10^{-6}$ / K at all temperatures, even when molten. Additionally, take $\alpha_{copper} = 17 \times 10^{-6}$ / K, and $\alpha_{Invar} = 0.7 \times 10^{-6}$ / K.

(a) A copper wire, initially 1.0 mm at 25 °C, is pushed through a layer of molten glass at 1400 °C, and comes to thermal equilibrium with it at that same temperature. What is its new diameter?

(b) When the wire and glass are cooled back down to 25 °C, what is the **area** of the hole in the glass? What is the cross-section area of the copper wire?

Dumet wire consists of a cylindrical core of Invar (nickel-steel alloy) surrounded by a cylindrical sheath of copper. The diameters of the core and of the sheath are chosen so that the wire duplicates the expansion characteristics of glass, allowing for an airtight seal.

(c) Show that the ratio of the Invar core radius to that of the copper sheath should be

$$\frac{r_{Invar}}{r_{copper}} = \sqrt{\frac{\alpha_{copper} - \alpha_{glass}}{\alpha_{copper} - \alpha_{Invar}}} \tag{1.1}$$

(d) What is a typical value for this ratio?