(a) 200 kg

(b)

FIGURE 9–4 Example 9–2.

EXAMPLE 9–2 **Chandelier cord tension.** Calculate the tensions $\vec{F}_A$ and $\vec{F}_B$ in the two cords that are connected to the vertical cord supporting the 200-kg chandelier in Fig. 9–4.

APPROACH We need a free-body diagram, but for which object? If we choose the chandelier, the cord supporting it must exert a force equal to the chandelier's weight $mg = (200 \text{ kg})(9.8 \text{ m/s}^2) = 1960 \text{ N}$. But the forces $\vec{F}_A$ and $\vec{F}_B$ don't get involved. Instead, let us choose as our object the point where the three cords join (it could be a knot). The free-body diagram is then as shown in Fig. 9–4a. The three forces—$\vec{F}_A$, $\vec{F}_B$, and the tension in the vertical cord equal to the weight of the 200-kg chandelier—act at this point where the three cords join. For this junction point we write $\Sigma F_x = 0$ and $\Sigma F_y = 0$, since the problem is laid out in two dimensions. The directions of $\vec{F}_A$ and $\vec{F}_B$ are known, since tension in a rope can only be along the rope—any other direction would cause the rope to bend, as already pointed out in Chapter 4. Thus, our unknowns are the magnitudes F_A and F_B.

SOLUTION We first resolve $\vec{F}_A$ into its horizontal (x) and vertical (y) components. Although we don't know the value of F_A, we can write (see Fig. 9–4b) $F_{Ax} = -F_A \cos 60°$ and $F_{Ay} = F_A \sin 60°$. $\vec{F}_B$ has only an x component. In the vertical direction, we have the downward force exerted by the vertical cord equal to the weight of the chandelier $= (200 \text{ kg})(g)$, and the vertical component of $\vec{F}_A$ upward. Since $\Sigma F_y = 0$, we have

$$\Sigma F_y = F_A \sin 60° - (200 \text{ kg})(g) = 0$$

so

$$F_A = \frac{(200 \text{ kg})g}{\sin 60°} = \frac{(200 \text{ kg})g}{0.866} = (231 \text{ kg})g = 2260 \text{ N}.$$

In the horizontal direction,

$$\Sigma F_x = F_B - F_A \cos 60° = 0.$$

Thus

$$F_B = F_A \cos 60° = (231 \text{ kg})(g)(0.500) = (115 \text{ kg})g = 1130 \text{ N}.$$

The magnitudes of $\vec{F}_A$ and $\vec{F}_B$ determine the strength of cord or wire that must be used. In this case, the wire must be able to hold more than 230 kg.

NOTE We didn't insert the value of g, the acceleration due to gravity, until the end. In this way we found the magnitude of the force in terms of g times the number of kilograms (which may be a more familiar quantity than newtons).

EXERCISE A In Example 9–2, F_A has to be greater than the chandelier's weight, mg. Why?

FIGURE 9–5 Although the net force on it is zero, the ruler will move (rotate). A pair of equal forces acting in opposite directions but at different points on an object (as shown here) is referred to as a *couple*.
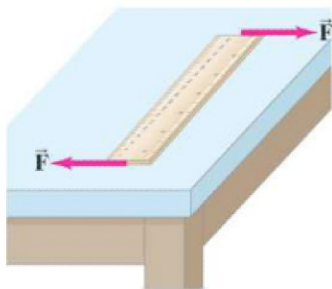
Second condition for equilibrium: the sum of all torques is zero

The Second Condition for Equilibrium

Although Eqs. 9–1 are a necessary condition for an object to be in equilibrium, they are not always a sufficient condition. Figure 9–5 shows an object on which the net force is zero. Although the two forces labeled $\vec{F}$ add up to give zero net force on the object, they do give rise to a net torque that will rotate the object. Referring to Eq. 8–14, $\Sigma \tau = I\alpha$, we see that if an object is to remain at rest, the net torque applied to it (calculated about *any* axis) must be zero. Thus we have the **second condition for equilibrium**: that the sum of the torques acting on an object, as calculated about any axis, must be zero:

$$\Sigma \tau = 0. \tag{9–2}$$

This condition will ensure that the angular acceleration, α, about any axis