Hence the box does accelerate:

$$a_x = \frac{F_{Px} - F_{fr}}{m} = \frac{34.6\,\mathrm{N} - 23.4\,\mathrm{N}}{10.0\,\mathrm{kg}} = 1.1\,\mathrm{m/s^2}.$$

In the absence of friction, as we saw in Example 4–11, the acceleration would be much greater than this.

**NOTE** Our final answer has only two significant figures because our least significant input value $(\mu_k = 0.30)$ has two.

**EXERCISE B** If $\mu_k F_N$ were greater than $F_{Px}$, what would you conclude?

**EXAMPLE 4–20** **Two boxes and a pulley.** In Fig. 4–32a, two boxes are connected by a cord running over a pulley. The coefficient of kinetic friction between box A and the table is 0.20. We ignore the mass of the cord and pulley and any friction in the pulley, which means we can assume that a force applied to one end of the cord will have the same magnitude at the other end. We wish to find the acceleration, $a$, of the system, which will have the same magnitude for both boxes assuming the cord doesn't stretch. As box B moves down, box A moves to the right.

**APPROACH** We need a free-body diagram for each box, Figs. 4–32b and c, so we can apply Newton's second law to each. The forces on box A are the pulling force of the cord $F_T$, gravity $m_A g$, the normal force exerted by the table $F_N$, and a friction force exerted by the table $F_{fr}$; the forces on box B are gravity $m_B g$, and the cord pulling up, $F_T$.

**SOLUTION** Box A does not move vertically, so Newton's second law tells us the normal force just balances the weight,

$$F_N = m_A g = (5.0\,\mathrm{kg})(9.8\,\mathrm{m/s^2}) = 49\,\mathrm{N}.$$

In the horizontal direction, there are two forces on box A (Fig. 4–32b): $F_T$, the tension in the cord (whose value we don't know), and the force of friction

$$F_{fr} = \mu_k F_N = (0.20)(49\,\mathrm{N}) = 9.8\,\mathrm{N}.$$

The horizontal acceleration is what we wish to find; we use Newton's second law in the $x$ direction, $\Sigma F_{Ax} = m_A a_x$, which becomes (taking the positive direction to the right and setting $a_{Ax} = a$):

$$\Sigma F_{Ax} = F_T - F_{fr} = m_A a. \qquad \text{[box A]}$$

Next consider box B. The force of gravity $m_B g = (2.0\,\mathrm{kg})(9.8\,\mathrm{m/s^2}) = 19.6\,\mathrm{N}$ pulls downward; and the cord pulls upward with a force $F_T$. So we can write Newton's second law for box B (taking the downward direction as positive):

$$\Sigma F_{By} = m_B g - F_T = m_B a. \qquad \text{[box B]}$$

[Notice that if $a \neq 0$, then $F_T$ is not equal to $m_B g$.]

We have two unknowns, $a$ and $F_T$, and we also have two equations. We solve the box A equation for $F_T$:

$$F_T = F_{fr} + m_A a,$$

and substitute this into the box B equation:

$$m_B g - F_{fr} - m_A a = m_B a.$$

Now we solve for $a$ and put in numerical values:

$$a = \frac{m_B g - F_{fr}}{m_A + m_B} = \frac{19.6\,\mathrm{N} - 9.8\,\mathrm{N}}{5.0\,\mathrm{kg} + 2.0\,\mathrm{kg}} = 1.4\,\mathrm{m/s^2},$$

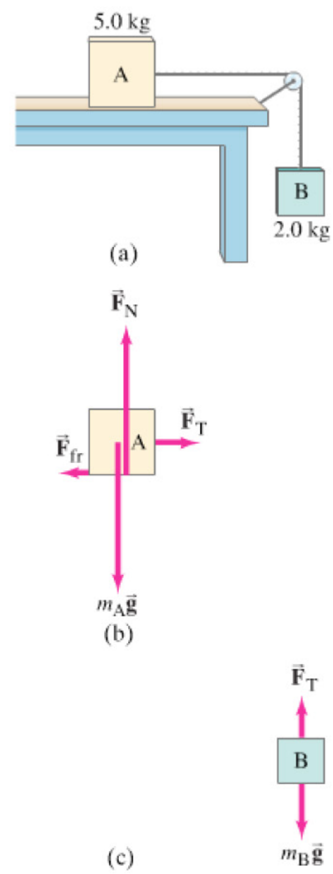
which is the acceleration of box A to the right, and of box B down.

If we wish, we can calculate $F_T$ using the first equation:

$$F_T = F_{fr} + m_A a = 9.8\,\mathrm{N} + (5.0\,\mathrm{kg})(1.4\,\mathrm{m/s^2}) = 17\,\mathrm{N}.$$

**NOTE** Box B is not in free fall. It does not fall at $a = g$ because an additional force, $F_T$, is acting upward on it.

**FIGURE 4–32** Example 4–20.




**CAUTION**

*Tension in a cord supporting a falling object may not equal object's weight*