(*c*) This is just like part (*b*), except $d = 0.50\text{ m}$, so

$$\Delta t = \frac{d}{\bar{v}} = \frac{0.50\text{ m}}{3.9\text{ m/s}} = 0.13\text{ s}$$

and

$$\bar{F} = \frac{540\text{ N}\cdot\text{s}}{0.13\text{ s}} = 4.2 \times 10^3\text{ N}.$$

The upward force exerted on the person's feet by the ground is, as in part (*b*):

$$F_{\text{grd}} = \bar{F} + mg = (4.2 \times 10^3\text{ N}) + (0.69 \times 10^3\text{ N}) = 4.9 \times 10^3\text{ N}.$$

Clearly, the force on the feet and legs is much less now with the knees bent, and the impulse occurs over a longer time interval. In fact, the ultimate strength of the leg bone (see Chapter 9, Table 9–2) is not great enough to support the force calculated in part (*b*), so the leg would likely break in such a stiff landing, whereas it probably wouldn't in part (*c*) with bent legs.

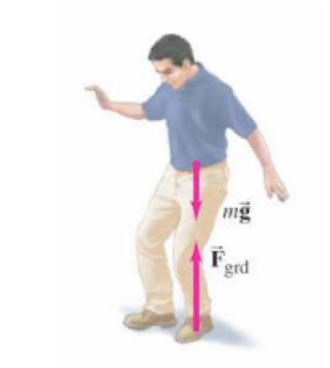

FIGURE 7–12 Example 7–6. When the person lands on the ground, the average net force during impact is $\bar{F} = F_{\text{grd}} - mg$, where F_{grd} is the force the ground exerts upward on the person.

EXERCISE E In part (*b*) of Example 7–6, we calculated the force exerted by the ground on the person during the collision, F_{grd}. Was F_{grd} much greater than the "external" force of gravity on the person? By what factor?

7–4 Conservation of Energy and Momentum in Collisions

During most collisions, we usually don't know how the collision force varies over time, and so analysis using Newton's second law becomes difficult or impossible. But by making use of the conservation laws for momentum and energy, we can still determine a lot about the motion after a collision, given the motion before the collision. We saw in Section 7–2 that in the collision of two objects such as billiard balls, the total momentum is conserved. If the two objects are very hard and no heat or other form of energy is produced in the collision, then kinetic energy is conserved as well. By this we mean that the sum of the kinetic energies of the two objects is the same after the collision as before. For the brief moment during which the two objects are in contact, some (or all) of the energy is stored momentarily in the form of elastic potential energy. But if we compare the total kinetic energy just before the collision with the total kinetic energy just after the collision, they are found to be the same. Such a collision, in which the total kinetic energy is conserved, is called an **elastic collision**. If we use the subscripts A and B to represent the two objects, we can write the equation for conservation of total kinetic energy as

$$\text{total KE before} = \text{total KE after}$$

$$\tfrac{1}{2}m_A v_A^2 + \tfrac{1}{2}m_B v_B^2 = \tfrac{1}{2}m_A v_A'^2 + \tfrac{1}{2}m_B v_B'^2. \quad \text{[elastic collision]} \quad \textbf{(7–6)}$$

Here, primed quantities (′) mean after the collision and unprimed mean before the collision, just as in Eq. 7–3 for conservation of momentum.

At the atomic level the collisions of atoms and molecules are often elastic. But in the "macroscopic" world of ordinary objects, an elastic collision is an ideal that is never quite reached, since at least a little thermal energy (and perhaps sound and other forms of energy) is always produced during a collision. The collision of two hard elastic balls, such as billiard balls, however, is very close to being perfectly elastic, and we often treat it as such.

We do need to remember that even when the kinetic energy is not conserved, the *total* energy is always conserved.

Collisions in which kinetic energy is not conserved are said to be **inelastic collisions**. The kinetic energy that is lost is changed into other forms of energy, often thermal energy, so that the total energy (as always) is conserved. In this case,

$$\text{KE}_A + \text{KE}_B = \text{KE}_A' + \text{KE}_B' + \text{thermal and other forms of energy.}$$

See Fig. 7–13, and the details in its caption.

FIGURE 7–13 Two equal-mass objects (a) approach each other with equal speeds, (b) collide, and then (c) bounce off with equal speeds in the opposite directions if the collision is elastic, or (d) bounce back much less or not at all if the collision is inelastic.