EXAMPLE 7–1 ESTIMATE Force of a tennis serve. For a top player, a tennis ball may leave the racket on the serve with a speed of 55 m/s (about 120 mi/h), Fig. 7–1. If the ball has a mass of 0.060 kg and is in contact with the racket for about 4 ms $(4 \times 10^{-3}\,\mathrm{s})$, estimate the average force on the ball. Would this force be large enough to lift a 60-kg person?

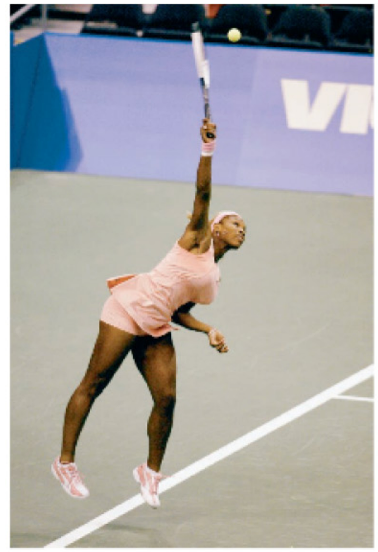

FIGURE 7–1 Example 7–1.

APPROACH The tennis ball is hit when its initial velocity is very nearly zero at the top of the throw, so we take $v_1 = 0$. We use Newton's second law, Eq. 7–2, to calculate the force, ignoring all other forces such as gravity in comparison to that exerted by the tennis racket.

SOLUTION The force exerted on the ball by the racket is

$$F = \frac{\Delta p}{\Delta t} = \frac{mv_2 - mv_1}{\Delta t}$$

where $v_2 = 55\,\mathrm{m/s}$, $v_1 = 0$, and $\Delta t = 0.004\,\mathrm{s}$. Thus

$$F = \frac{\Delta p}{\Delta t} = \frac{(0.060\,\mathrm{kg})(55\,\mathrm{m/s}) - 0}{0.004\,\mathrm{s}} \approx 800\,\mathrm{N}.$$

This is a large force, larger than the weight of a 60-kg person, which would require a force $mg = (60\,\mathrm{kg})(9.8\,\mathrm{m/s^2}) \approx 600\,\mathrm{N}$ to lift.

NOTE The force of gravity acting on the tennis ball is $mg = (0.060\,\mathrm{kg})(9.8\,\mathrm{m/s^2}) = 0.59\,\mathrm{N}$, which justifies our ignoring it compared to the enormous force the racket exerts.

Measuring force

NOTE High-speed photography and radar can give us an estimate of the contact time and the velocity of the ball leaving the racket. But a direct measurement of the force is not practical. Our calculation shows a handy technique for determining an unknown force in the real world.

EXAMPLE 7–2 Washing a car: momentum change and force. Water leaves a hose at a rate of 1.5 kg/s with a speed of 20 m/s and is aimed at the side of a car, which stops it, Fig. 7–2. (That is, we ignore any splashing back.) What is the force exerted by the water on the car?

FIGURE 7–2 Example 7–2.

APPROACH The water leaving the hose has mass and velocity, so it has a momentum p_{initial}. When the water hits the car, the water loses this momentum $(p_{\mathrm{final}} = 0)$. We use Newton's second law in the momentum form, Eq. 7–2, to find the force that the car exerts on the water to stop it. By Newton's third law, the force exerted by the water on the car is equal and opposite. We have a continuing process: 1.5 kg of water leaves the hose in each 1.0-s time interval. So let us choose $\Delta t = 1.0\,\mathrm{s}$, and $m = 1.5\,\mathrm{kg}$ in Eq. 7–2.

SOLUTION We take the x direction positive to the right. In each 1.0-s time interval, water with a momentum of $p_x = mv_x = (1.5\,\mathrm{kg})(20\,\mathrm{m/s}) = 30\,\mathrm{kg\cdot m/s}$ is brought to rest when it hits the car. The magnitude of the force (assumed constant) that the car must exert to change the momentum of the water by this amount is

$$F = \frac{\Delta p}{\Delta t} = \frac{p_{\mathrm{final}} - p_{\mathrm{initial}}}{\Delta t} = \frac{0 - 30\,\mathrm{kg\cdot m/s}}{1.0\,\mathrm{s}} = -30\,\mathrm{N}.$$

The minus sign indicates that the force on the water is opposite to the water's original velocity. The car exerts a force of 30 N to the left to stop the water, so by Newton's third law, the water exerts a force of 30 N to the right on the car.

NOTE Keep track of signs, although common sense helps too. The water is moving to the right, so common sense tells us the force on the car must be to the right.

EXERCISE B If the water splashes back from the car in Example 7–2, would the force on the car be larger or smaller?