CONCEPTUAL EXAMPLE 7–5 **Falling on or off a sled.** (*a*) An empty sled is sliding on frictionless ice when Susan drops vertically from a tree above onto the sled. When she lands, does the sled speed up, slow down, or keep the same speed? (*b*) Later. Susan falls sideways off the sled. When she drops off, does the sled speed up, slow down, or keep the same speed?

RESPONSE (*a*) Because Susan falls vertically onto the sled, she has no initial horizontal momentum. Thus the total horizontal momentum afterward equals the momentum of the sled initially. Since the mass of the system (sled + person) has increased, the speed must decrease.
(*b*) At the instant Susan falls off, she is moving with the same horizontal speed as she was while on the sled. At the moment she leaves the sled, she has the same momentum she had an instant before. Because momentum is conserved, the sled keeps the same speed.

7–3 Collisions and Impulse

Collisions are a common occurrence in everyday life: a tennis racket or a baseball bat striking a ball, billiard balls colliding, a hammer hitting a nail. When a collision occurs, the interaction between the objects involved is usually far stronger than any interaction between our system of objects and their environment. We can then ignore the effects of any other forces during the brief time interval of the collision.

FIGURE 7–8 Tennis racket striking a ball. Both the ball and the racket strings are deformed due to the large force each exerts on the other.

During a collision of two ordinary objects, both objects are deformed, often considerably, because of the large forces involved (Fig. 7–8). When the collision occurs, the force usually jumps from zero at the moment of contact to a very large force within a very short time, and then rapidly returns to zero again. A graph of the magnitude of the force that one object exerts on the other during a collision, as a function of time, is something like the red curve in Fig. 7–9. The time interval Δt is usually very distinct and very small.

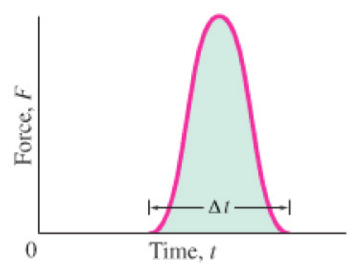
From Newton's second law, Eq. 7–2, the *net* force on one object is equal to the rate of change of its momentum:

$$\vec{\mathbf{F}} = \frac{\Delta \vec{\mathbf{p}}}{\Delta t}.$$

(We have written $\vec{\mathbf{F}}$ instead of $\Sigma\vec{\mathbf{F}}$ for the net force, which we assume is entirely due to the brief but large average force that acts during the collision.) This equation applies to *each* of the two objects in a collision. We multiply both sides of this equation by the time interval Δt, and obtain

$$\vec{\mathbf{F}}\,\Delta t = \Delta \vec{\mathbf{p}}. \quad \textbf{(7–5)}$$

FIGURE 7–9 Force as a function of time during a typical collision.

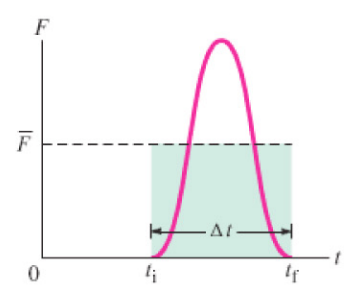


The quantity on the left, the product of the force $\vec{\mathbf{F}}$ times the time Δt over which the force acts, is called the **impulse**:

$$\text{Impulse} = \vec{\mathbf{F}}\,\Delta t.$$

We see that the total change in momentum is equal to the impulse. The concept of impulse is useful mainly when dealing with forces that act during a short time interval, as when a bat hits a baseball. The force is generally not constant, and often its variation in time is like that graphed in Figs. 7–9 and 7–10. We can often approximate such a varying force as an average force $\overline{F}$ acting during a time interval Δt, as indicated by the dashed line in Fig. 7–10. $\overline{F}$ is chosen so that the area shown shaded in Fig. 7–10 (equal to $\overline{F} \times \Delta t$) is equal to the area under the actual curve of F vs. t, Fig. 7–9 (which represents the actual impulse).

FIGURE 7–10 The average force $\overline{F}$ acting over an interval of time Δt gives the same impulse ($\overline{F}\,\Delta t$) as the actual force.



EXERCISE D Suppose Fig. 7–9 illustrates the force on a golf ball vs. the time when the ball hits a wall. How would the shape of this curve change if a softer rubber ball with the same mass and speed hit the same wall?