of motion. For example, if a rectangular block of wood sliding across a horizontal surface has dimensions of 4.0 cm × 6.0 cm × 10. cm, the frictional force depends only on the weight of the block. It makes no difference which face of the block is in contact with the surface (24 cm^2, 40. cm^2, or 60. cm^2), since the normal force (the weight of the block) is the same in each case.

When a round object, such as a cylinder, rolls over a surface, the frictional force is usually much less than when the object slides across the surface. The friction of a rolling object is called **rolling friction.** Wheels and ball bearings reduce friction between moving objects in contact by replacing sliding friction with rolling friction.

The friction on an object moving through a fluid, such as water or air, is **fluid friction.** Unlike sliding friction, fluid friction varies with the speed of motion and with the shape and area of the surface in contact with the fluid. Airplanes are streamlined (given a special tapered shape) to reduce air friction, or "drag." Reducing fluid friction is also a consideration in the design of automobiles, boats, and other vehicles.

CAN YOU EXPLAIN THIS?

The sliding friction between two extremely smooth glass plates is very large.

Usually, sliding friction is increased by roughness of the surfaces in contact. If the surfaces are extremely smooth, however, friction is increased by the phenomenon of adhesion. The molecules on either side of the contact surface are so close together that they attract one another by the same kind of intermolecular forces that hold solids together. It is as though the two surfaces have been joined.

QUESTIONS

1. **If a cart is moving to the north at constant velocity, the force of kinetic friction on the cart is directed toward the (1) north (2) south (3) east (4) west**
2. **As an object initially at rest on a horizontal surface is set into motion, the force of friction between them (1) decreases (2) increases (3) remains the same**
3. **In a classroom, a steel ball and a sheet of paper are dropped to the floor from the same height at the same time. The ball hits the floor before the sheet of paper because of the effects of (1) static friction (2) kinetic friction (3) rolling friction (4) fluid friction**
4. **An *empty* wooden crate is slid across a warehouse floor. If the crate were *filled,* the *coefficient* of kinetic friction between the crate and the floor would (1) decrease (2) increase (3) remain the same**
5. **An *empty* wooden crate is slid across a warehouse floor. If the crate were *filled,* the *force* of kinetic friction between the crate and the floor would (1) decrease (2) increase (3) remain the same**

6. **A wooden block is at rest on a wooden inclined plane. As the angle the plane makes with the horizontal increases, the *coefficient* of static friction between the block and the plane (1) decreases (2) increases (3) remains the same**
7. **A wooden block is at rest on a wooden inclined plane. As the angle the plane makes with the horizontal increases, the *force* of static friction between the block and the plane (1) decreases (2) increases (3) remains the same**

Momentum

The product of the mass and the velocity of an object is a vector quantity called **momentum.** An object's momentum is in the same direction as its velocity and is given by the formula

$$p = mv \qquad \text{(Eq. 1-9)}$$

where m is mass in kilograms, v is velocity in meters per second, and p is momentum in kilogram · meters per second. The *SI* unit for momentum is the kilogram · meter per second, kg · m/s.

CAN YOU EXPLAIN THIS?

An automobile moving at 30 m/s has more momentum than a bullet moving at 500 m/s.

The magnitude of the momentum of an object is equal to the product of its mass and velocity. A car having a mass of 1,100 kg and traveling at 30. m/s has a momentum of 33,000 kg · m/s, whereas a 0.0050-kg bullet traveling at 500 m/s has a momentum of only 2.5 kg · m/s.

Impulse and Change in Momentum

If a force is applied to an object, the product of the force and the time during which the force is applied is called the **impulse.** Impulse, a vector quantity having the same direction as the force applied to the object, is given by the formula

$$J = F\Delta t \qquad \text{(Eq. 1-10)}$$

where F is the average force in newtons, Δt is the time during which the force acts, and J is the impulse in newton · seconds. The newton · second, N · s, is the *SI* unit for impulse. When an unbalanced force acts on a body, its velocity changes and therefore its momentum changes. The relationship between an impulse, $F\Delta t$, applied to a mass, m, and the resulting change in its momentum, $m\Delta v$, can be derived from Newton's second law of motion, $F = ma$ (Equation 1-6). Recall from Equation 1-2 that $a = \Delta v/\Delta t$. Therefore,

$$F = ma = \frac{m\Delta v}{\Delta t}, \quad \text{or}$$

$$F\Delta t = m\Delta v \qquad \text{(Eq. 1-11)}$$