ANNOUNCEMENTS

- Homework #6, due Wednesday, October 3

  Conceptual questions: Chapter 6, #4 and #12
  Problems: Chapter 6, #54, #80

- 5-minute quiz on Chapter 6: Friday, October 5

- Start reading Chapter 7!

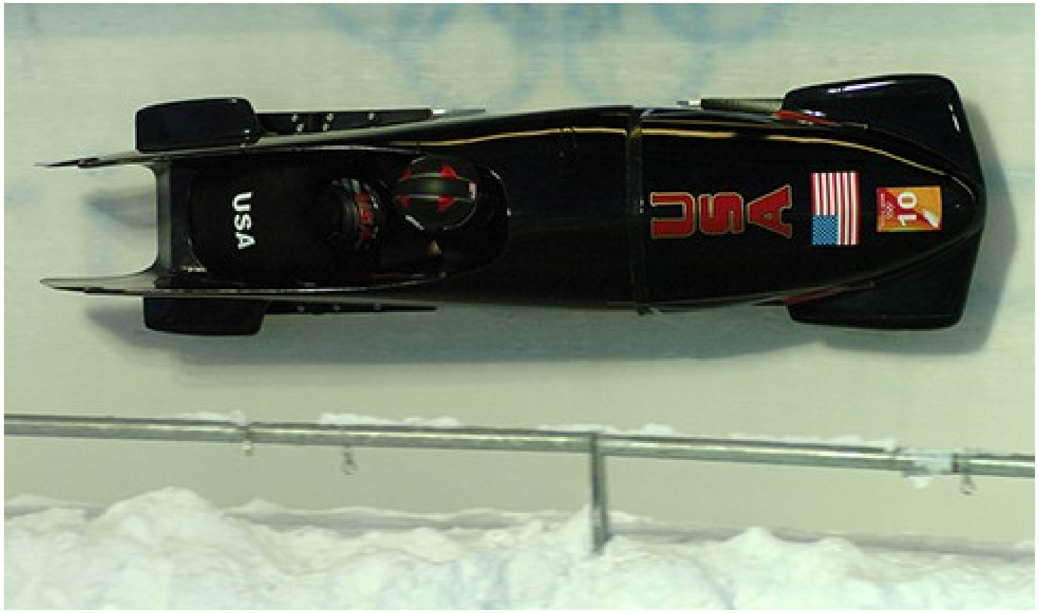
Drag Forces

Like friction, the **drag force** always opposes the motion of an object. Unlike simple friction, the drag force is proportional to some function of the velocity of the object in that fluid. This functionality is complicated and depends upon the shape of the object, its size, its velocity, and the fluid it is in. For most large objects such as cyclists, cars, and baseballs not moving too slowly, the magnitude of the drag force F_{D} is proportional to the square of the speed of the object. We can write this relationship mathematically as $F_{\mathrm{D}} \propto v^2$. When taking into account other factors, this relationship becomes

Drag force F_{D} is proportional to the square of the speed of the object. Mathematically,

$$F_{\mathrm{D}} = \frac{1}{2} C \rho A v^2,$$

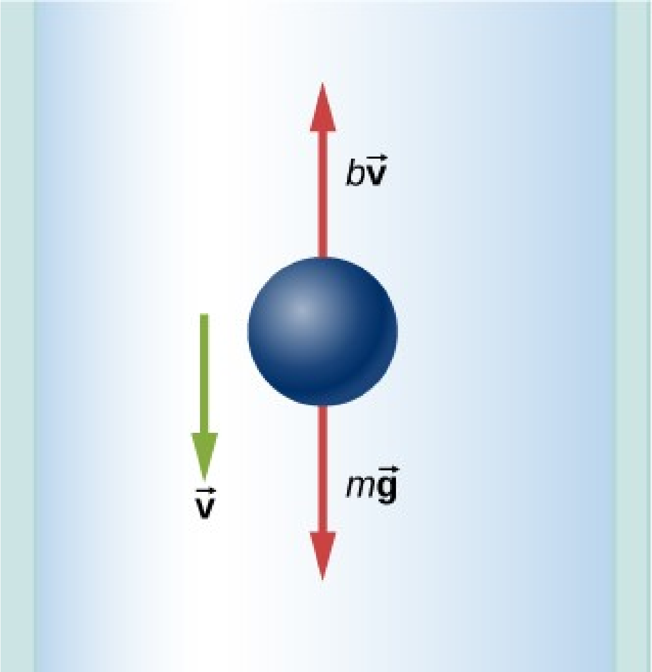
where *C* is the drag coefficient, *A* is the area of the object facing the fluid, and ρ is the density of the fluid.



From racing cars to bobsled racers, aerodynamic shaping is crucial to achieving top speeds. Bobsleds are designed for speed and are shaped like a bullet with tapered fins. (credit: “U.S. Army”/Wikimedia Commons)

FIGURE 6.30

FREE-BODY DIAGRAM AND TERMINAL VELOCITY



Free-body diagram of an object falling through a resistive medium.

At the terminal velocity,

$$F_{\text{net}} = mg - F_{\text{D}} = ma = 0.$$

Thus,

$$mg = F_{\text{D}}.$$

Using the equation for drag force, we have

$$mg = \frac{1}{2}C\rho A v_{\text{T}}^2.$$

Solving for the velocity, we obtain

$$v_{\text{T}} = \sqrt{\frac{2mg}{\rho CA}}.$$

STOKES' LAW

For a spherical object falling in a medium, the drag force is

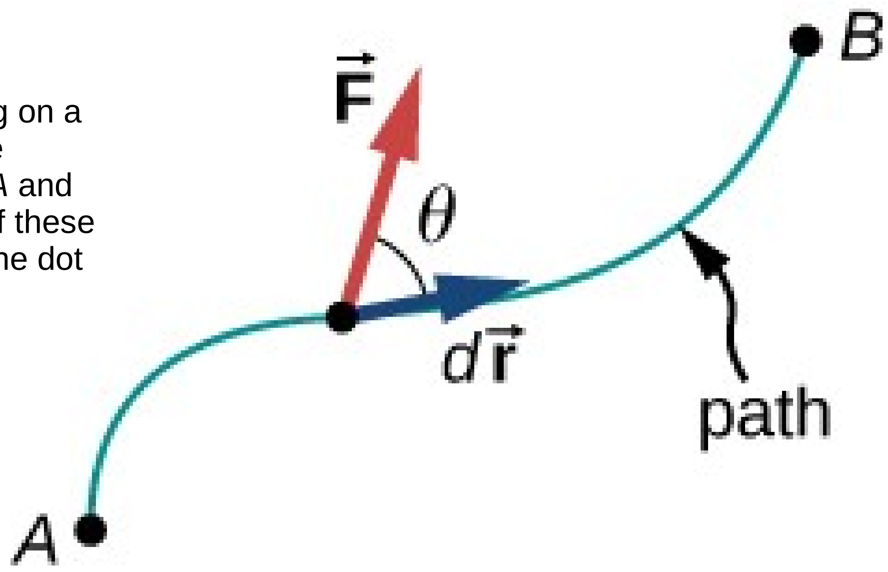
$$F_{\text{s}} = 6\pi r\eta v,$$

where r is the radius of the object, η is the viscosity of the fluid, and v is the object's velocity.

The Calculus of Velocity-Dependent Frictional Forces

WORK AND ENERGY

Vectors used to define work. The force acting on a particle and its infinitesimal displacement are shown at one point along the path between *A* and *B*. The infinitesimal work is the dot product of these two vectors; the total work is the integral of the dot product along the path.



$$dW = \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}} = \left|\vec{\mathbf{F}}\right| \left|d\vec{\mathbf{r}}\right| \cos\theta. \quad (7.1)$$

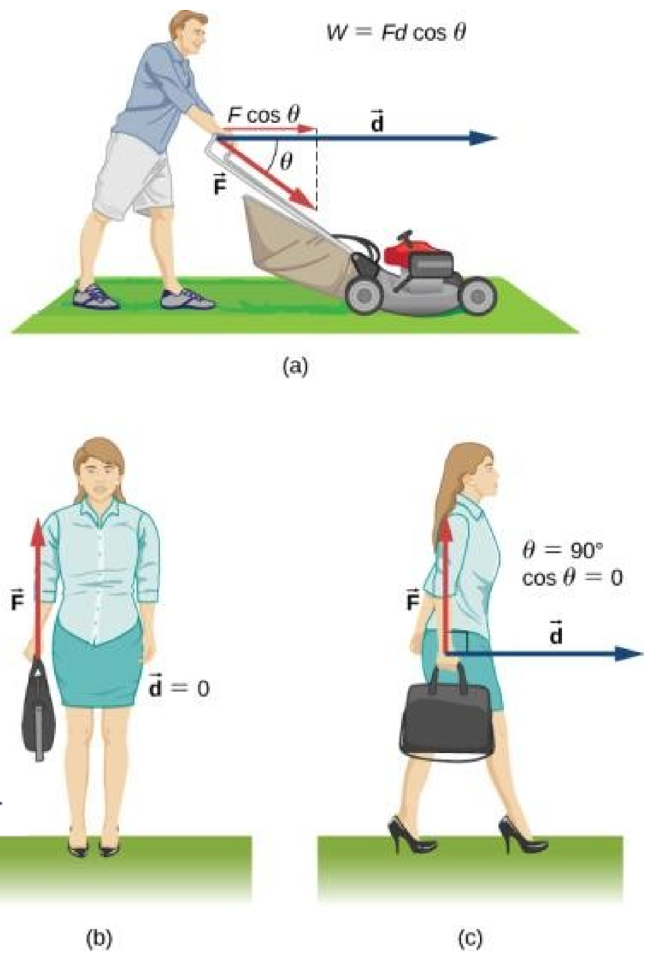
WORK DONE BY A FORCE

The work done by a force is the integral of the force with respect to displacement along the path of the displacement:

$$W_{AB} = \int_{\text{path } AB} \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}}. \quad (7.2)$$

WORK OF A CONSTANT FORCE

$$W_{AB} = \vec{\mathbf{F}} \cdot \int_A^B d\vec{\mathbf{r}} = \vec{\mathbf{F}} \cdot \left(\vec{\mathbf{r}}_B - \vec{\mathbf{r}}_A\right) = \left|\vec{\mathbf{F}}\right| \left|\vec{\mathbf{r}}_B - \vec{\mathbf{r}}_A\right| \cos\theta \quad \text{(constant force).}$$



$$dW_N = \vec{\mathbf{N}} \cdot d\vec{\mathbf{r}} = \vec{\mathbf{0}}.$$

Work done by a constant force.

(a) A person pushes a lawn mower with a constant force. The component of the force parallel to the displacement is the work done, as shown in the equation in the figure.

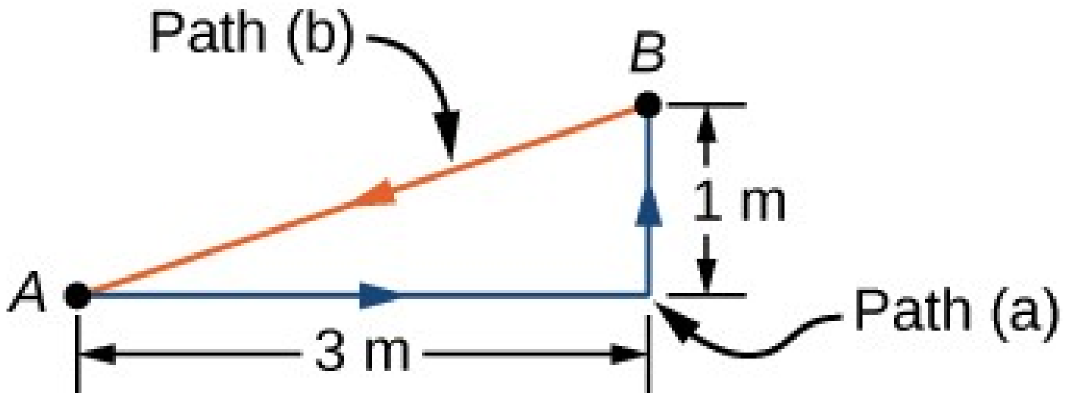
(b) A person holds a briefcase. No work is done because the displacement is zero.

(c) The person in (b) walks horizontally while holding the briefcase. No work is done because cos is zero.

WORK BY FRICTION

Moving a Couch

You decide to move your couch to a new position on your horizontal living room floor. The normal force on the couch is 1 kN and the coefficient of friction is 0.6. (a) You first push the couch 3 m parallel to a wall and then 1 m perpendicular to the wall (*A* to *B* in Figure 7.4). How much work is done by the frictional force? (b) You don't like the new position, so you move the couch straight back to its original position (*B* to *A* in Figure 7.4). What was the total work done against friction moving the couch away from its original position and back again?



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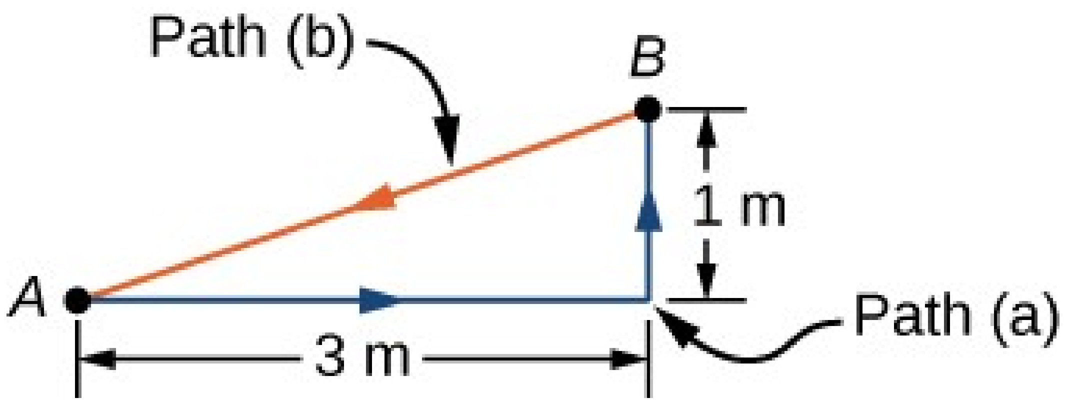


Solution

a. The work done by friction is

$$W = -(0.6)(1\ \text{kN})(3\ \text{m} + 1\ \text{m}) = -2.4\ \text{kJ}.$$

b. The length of the path along the hypotenuse is $\sqrt{10}\ \text{m}$, so the total work done against friction is

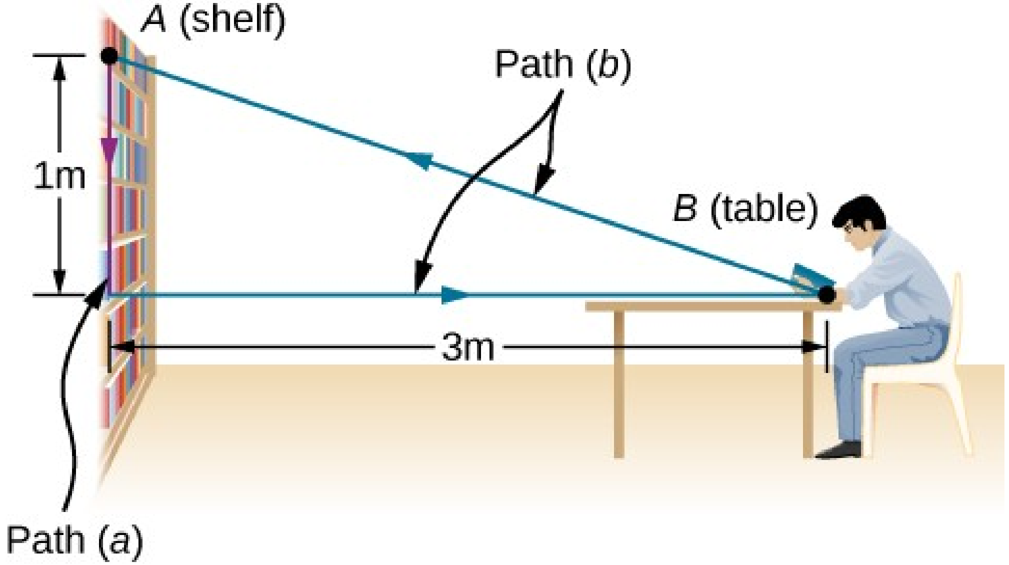
$$W = (0.6)(1\ \text{kN})(3\ \text{m} + 1\ \text{m} + \sqrt{10}\ \text{m}) = 4.3\ \text{kJ}.$$

WORK DONE BY GRAVITY

$$W_{\text{grav},AB} = -mg\hat{\mathbf{j}} \cdot (\vec{\mathbf{r}}_B - \vec{\mathbf{r}}_A) = -mg\,(y_B - y_A)\,.$$

Shelving a Book

You lift an oversized library book, weighing 20 N, 1 m vertically down from a shelf, and carry it 3 m horizontally to a table (Figure 7.5). How much work does gravity do on the book? (b) When you're finished, you move the book in a straight line back to its original place on the shelf. What was the total work done against gravity, moving the book away from its original position on the shelf and back again?



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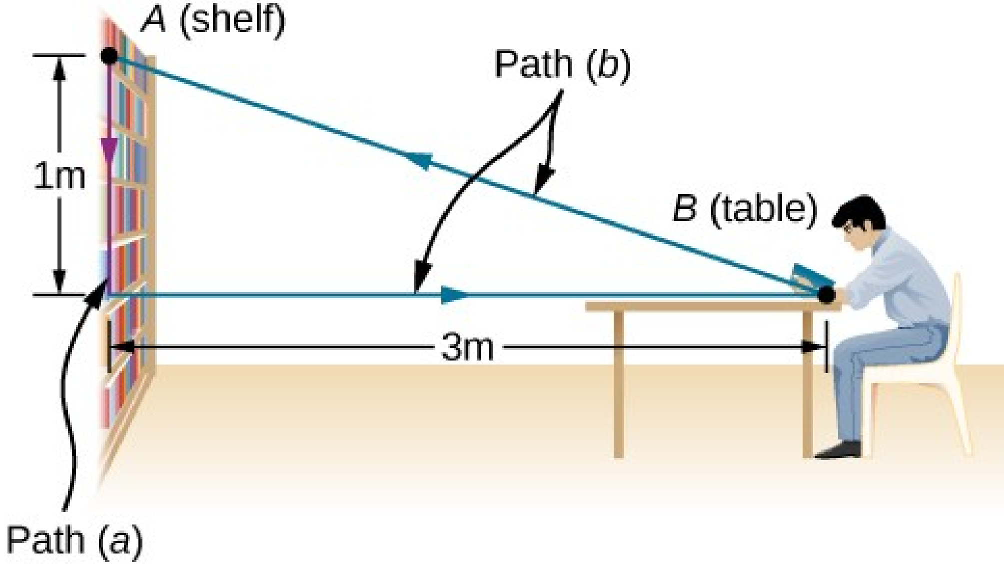

Solution

a. Since the book starts on the shelf and is lifted down $y_B - y_A = -1$ m, we have

$$W = -(20\text{ N})(-1\text{ m}) = 20\text{ J}.$$

b. There is zero difference in height for any path that begins and ends at the same place on the shelf, so $W = 0$.