Chapter 5

- Energy

Forms of Energy

- <u>Mechanical</u>
  - Focus for now
  - May be <u>kinetic</u> (associated with motion) or <u>potential</u> (associated with position)
- Chemical
- Electromagnetic
- Nuclear

Some Energy Considerations

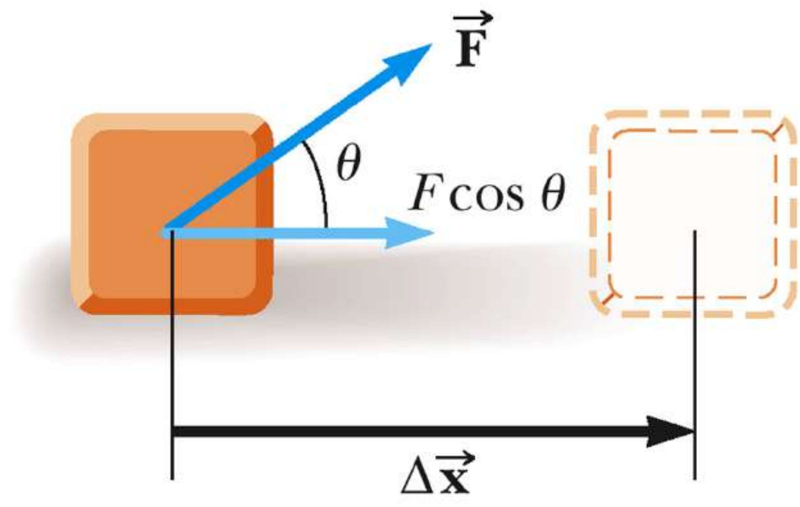
- Energy can be transformed from one form to another
  - Essential to the study of physics, chemistry, biology, geology, astronomy
- Can be used in place of Newton's laws to solve certain problems more simply

Work 5.1

- Provides a link between force and energy
- The work, *W*, done by a constant force on an object is defined as the product of the component of the force along the direction of displacement and the magnitude of the displacement

Work, cont.

- $W \equiv (F\cos\theta)\Delta x$
  - F is the magnitude of the force
  - Δ x is the magnitude of the object's displacement
  - θ is the angle between $\vec{\mathbf{F}}$ and $\Delta\vec{\mathbf{x}}$



<u>Only force parallel to movement does work!</u>

Work, cont.

- This gives no information about
  - the time it took for the displacement to occur
  - the velocity or acceleration of the object
- Work is a scalar quantity

Units of Work

- SI
  - <u>Newton • meter = Joule</u>
    - N • m = J
    - J = kg • m^2 / s^2
- US Customary
  - foot • pound
    - ft • lb
      - no special name

More About Work

- The work done by a force is zero when the force is perpendicular to the displacement
  - $\cos 90° = 0$
- If there are multiple forces acting on an object, the total work done is the algebraic sum of the amount of work done by each force

More About Work, cont.

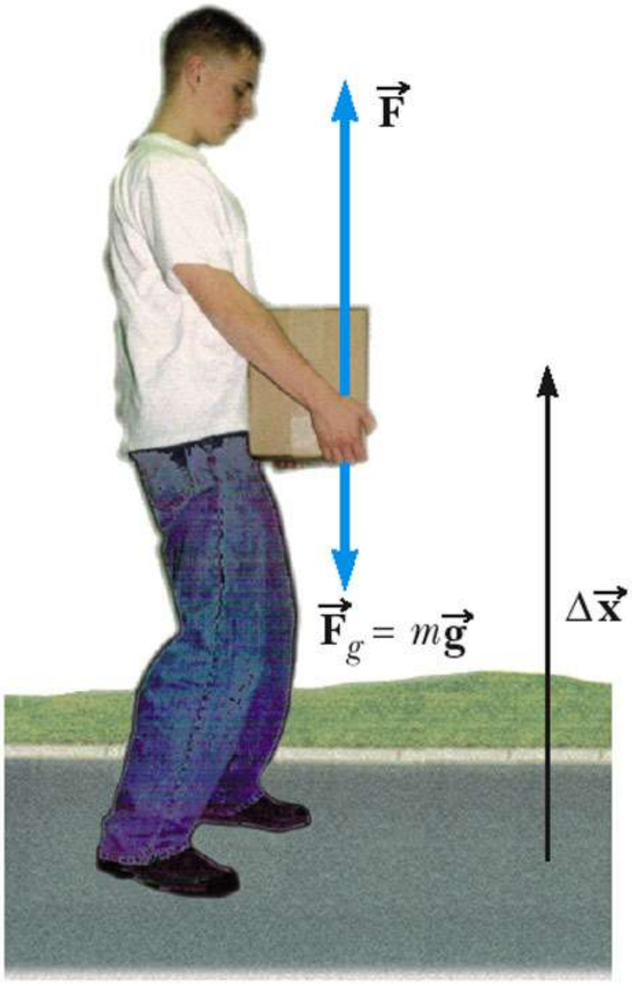
- Work can be positive or negative
  - Positive if the force and the displacement are in the same direction
  - Negative if the force and the displacement are in the opposite direction

When Work is Zero

- Displacement is horizontal
- Force is vertical
- $\cos 90° = 0$

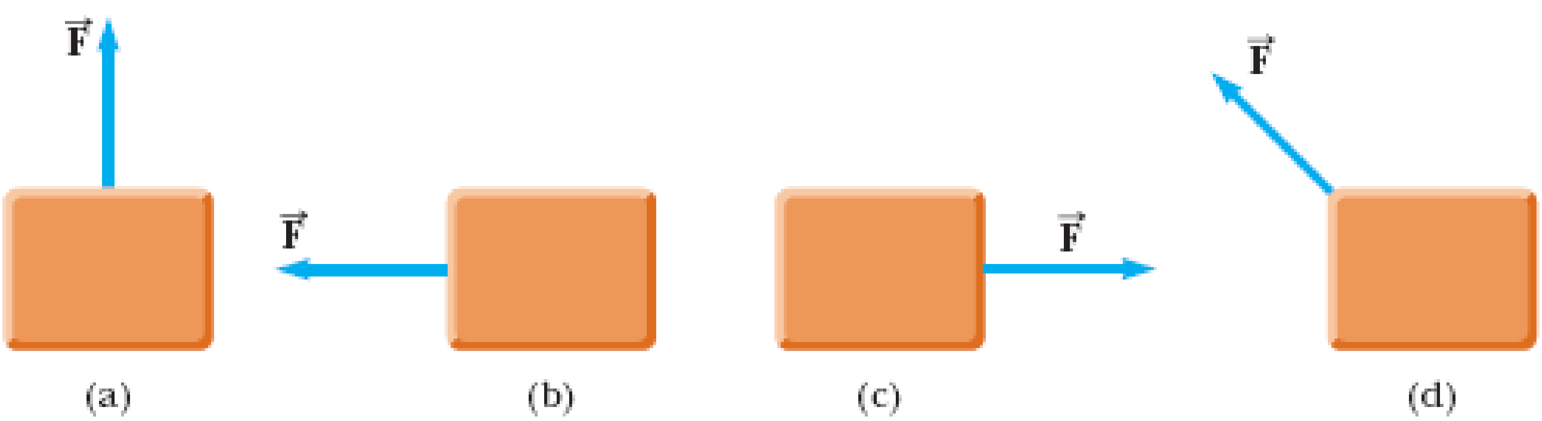
Work Can Be Positive or Negative

- Work is positive when lifting the box
- Work would be negative if lowering the box
  - The force would still be upward, but the displacement would be downward



QQ 5.1

In Active Figure 5.5 (a)–(d), a block moves to the right in the positive *x*-direction through the displacement Δx while under the influence of a force with the same magnitude *F*. Which of the following is the correct order of the amount of work done by the force *F*, from most positive to most negative? (A) d, c, a, b (B) c, a, b, d (C) c, a, d, b



ACTIVE FIGURE 5.5
(Quick Quiz 5.1) A force $\vec{F}$ is exerted on an object that undergoes a displacement to the right. Both the magnitude of the force and the displacement are the same in all four cases.

QQ 5.1 Answer

(c). The work done by the force is , where is the angle between the direction of the force and the direction of the displacement (positive *x*-direction). Thus, the work has its largest positive value in (c) where , the work done in (a) is zero since , the work done in (d) is negative since , and the work done is most negative in (b) where .

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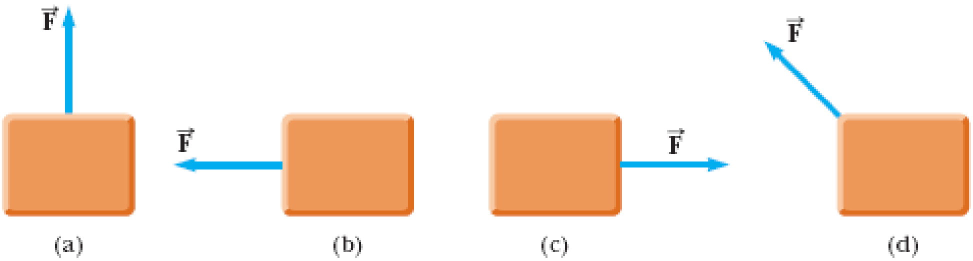

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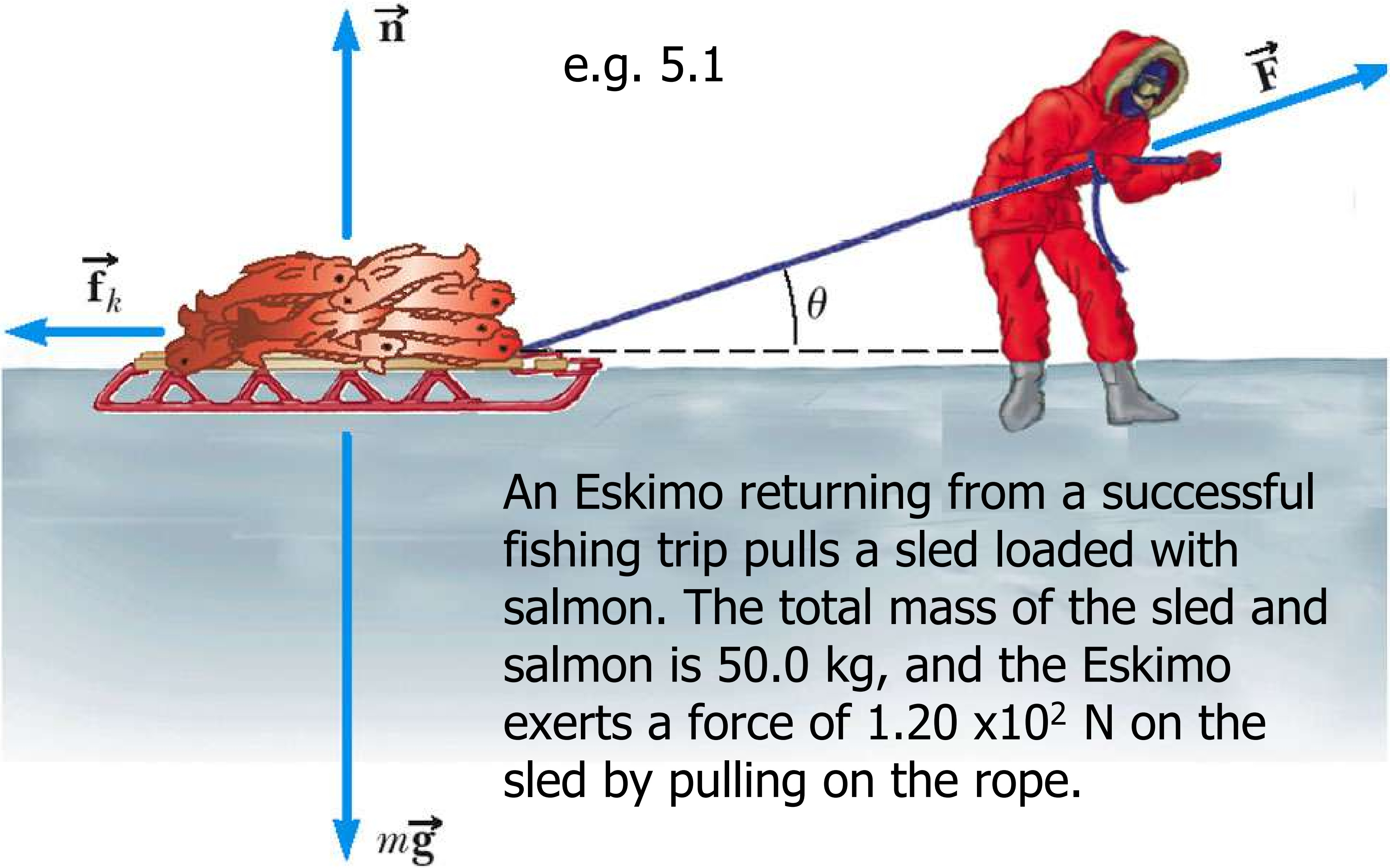
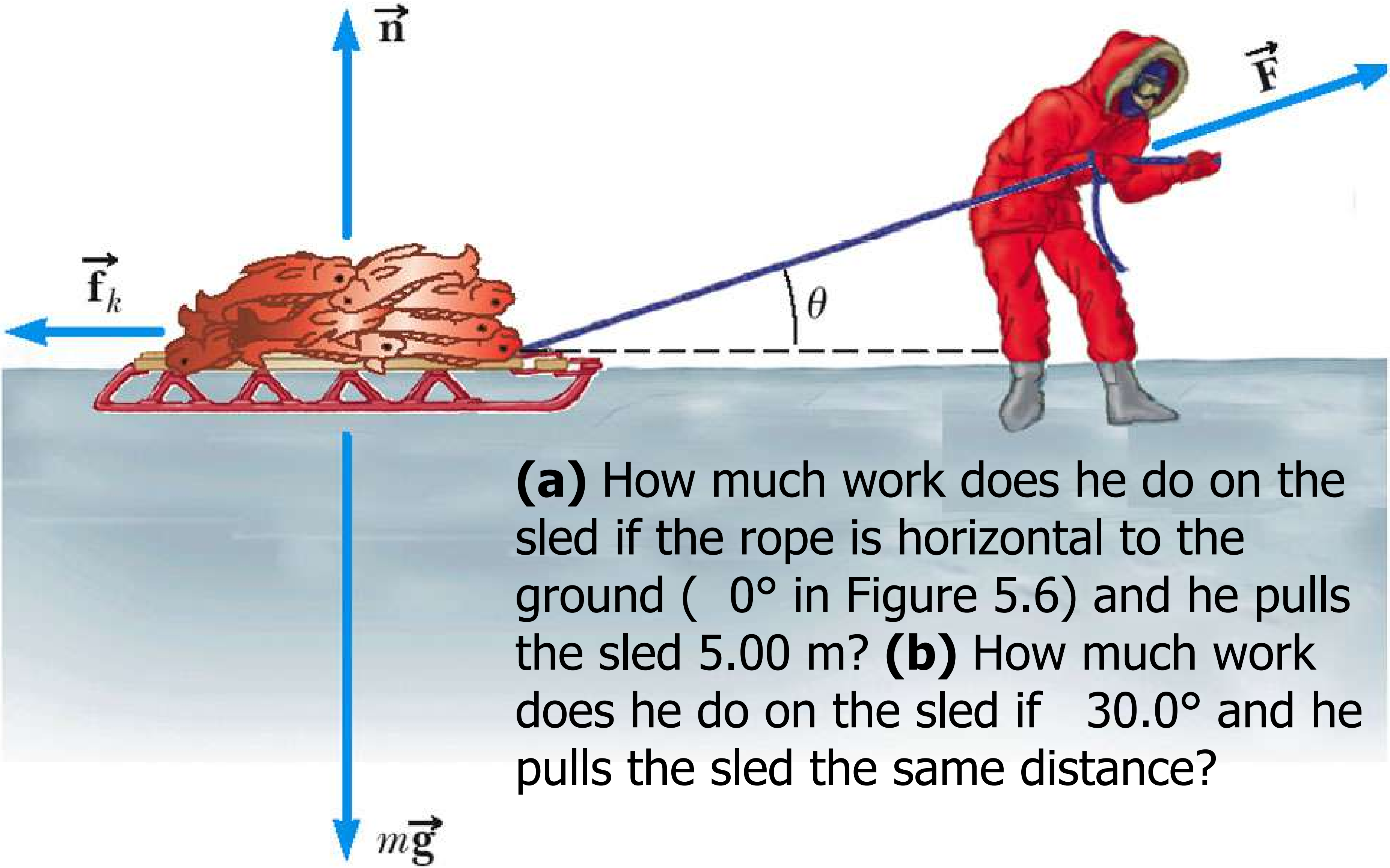
e.g. 5.1



An Eskimo returning from a successful fishing trip pulls a sled loaded with salmon. The total mass of the sled and salmon is 50.0 kg, and the Eskimo exerts a force of 1.20 x10^2 N on the sled by pulling on the rope.

Fig. 5-6, p.121



(a) How much work does he do on the sled if the rope is horizontal to the ground (0° in Figure 5.6) and he pulls the sled 5.00 m? **(b)** How much work does he do on the sled if 30.0° and he pulls the sled the same distance?

Fig. 5-6, p.121

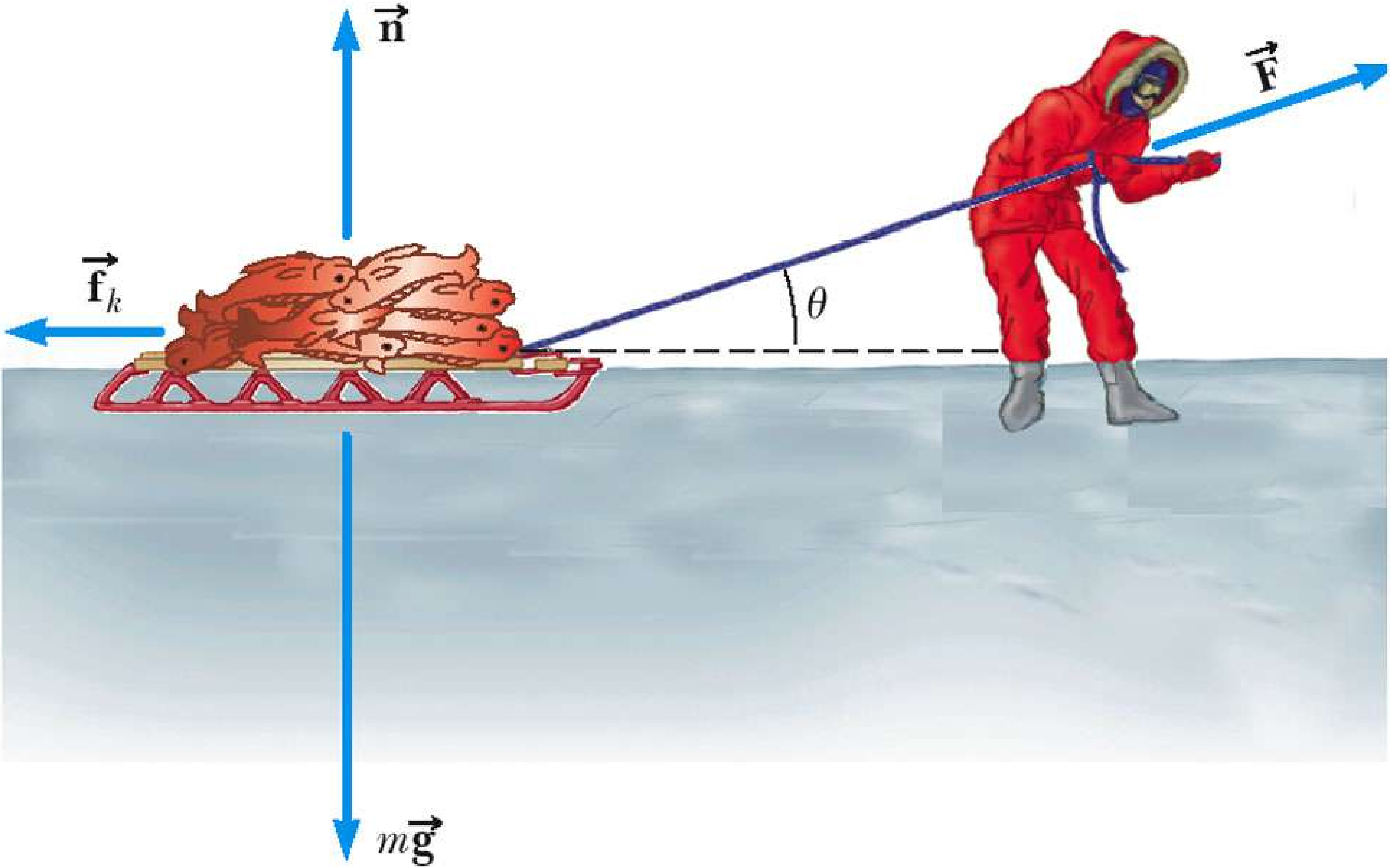
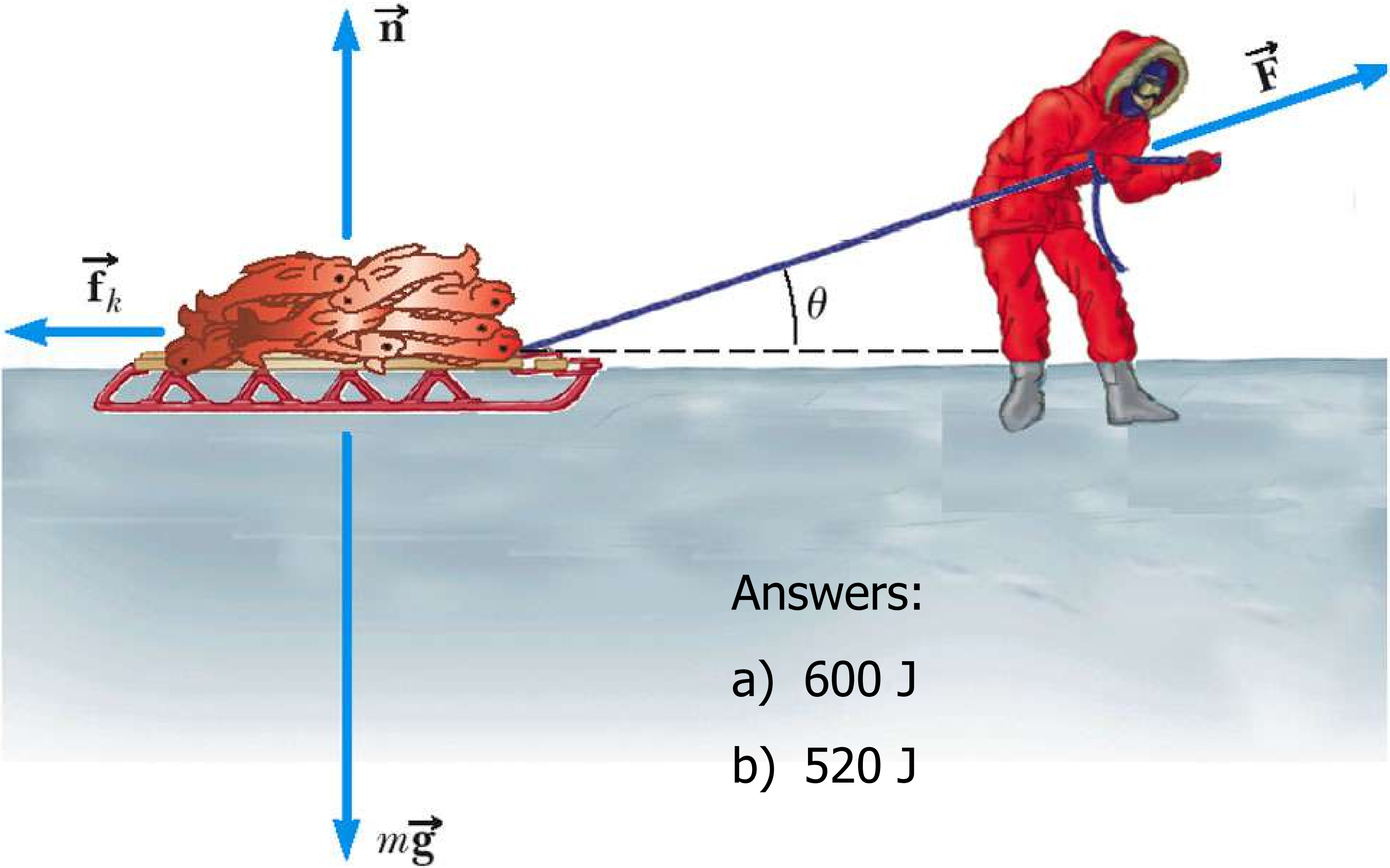


Fig. 5-6, p.121



Answers:

a) 600 J

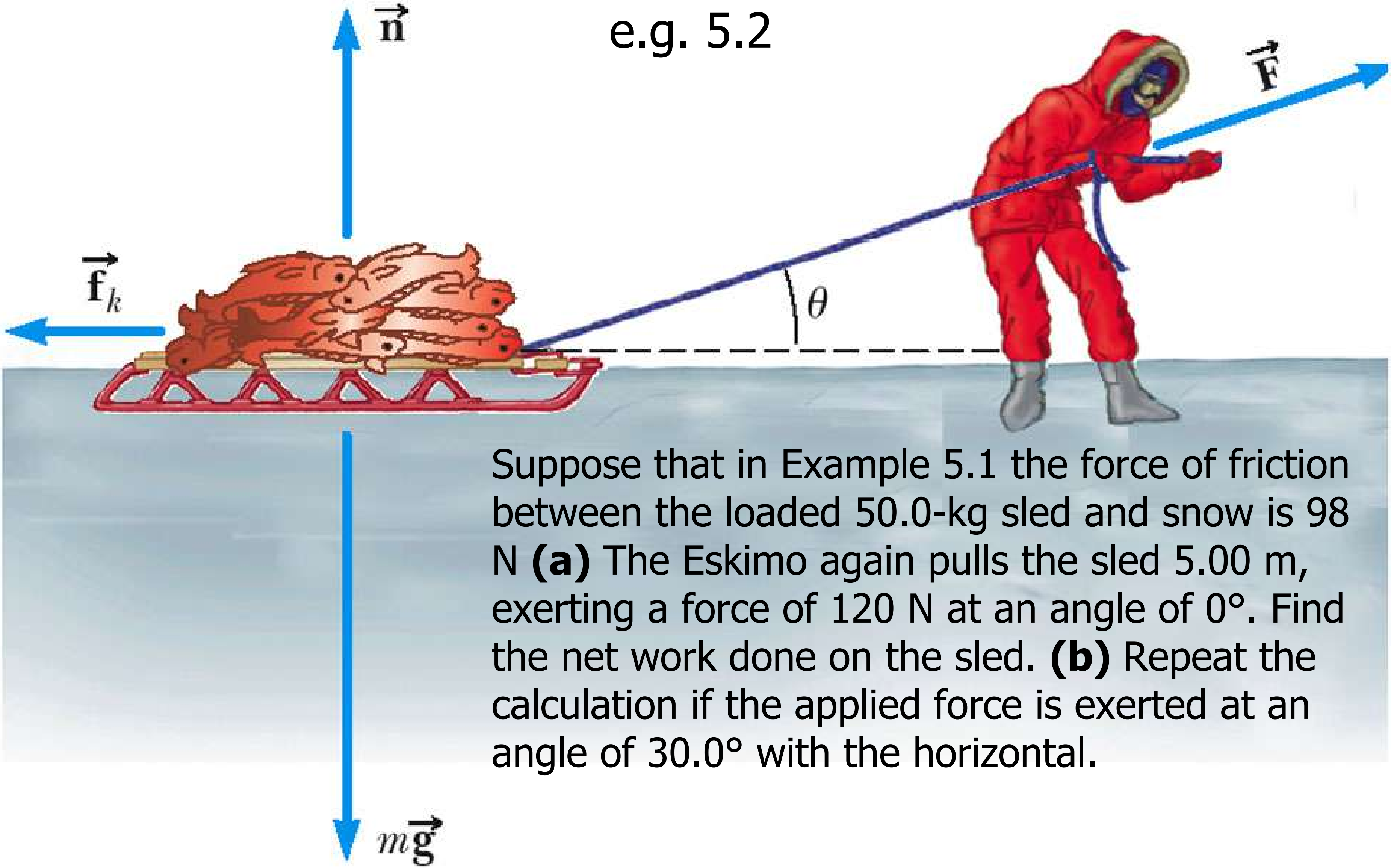
b) 520 J

Fig. 5-6, p.121

Work and Dissipative Forces

- Work can be done by friction
- The energy lost to friction by an object goes into heating both the object and its environment
  - Some energy may be converted into sound
- For now, the phrase "Work done by friction" will denote the effect of the friction processes on mechanical energy alone

e.g. 5.2



Suppose that in Example 5.1 the force of friction between the loaded 50.0-kg sled and snow is 98 N **(a)** The Eskimo again pulls the sled 5.00 m, exerting a force of 120 N at an angle of 0°. Find the net work done on the sled. **(b)** Repeat the calculation if the applied force is exerted at an angle of 30.0° with the horizontal.

Fig. 5-6, p.121

e.g. 5.2

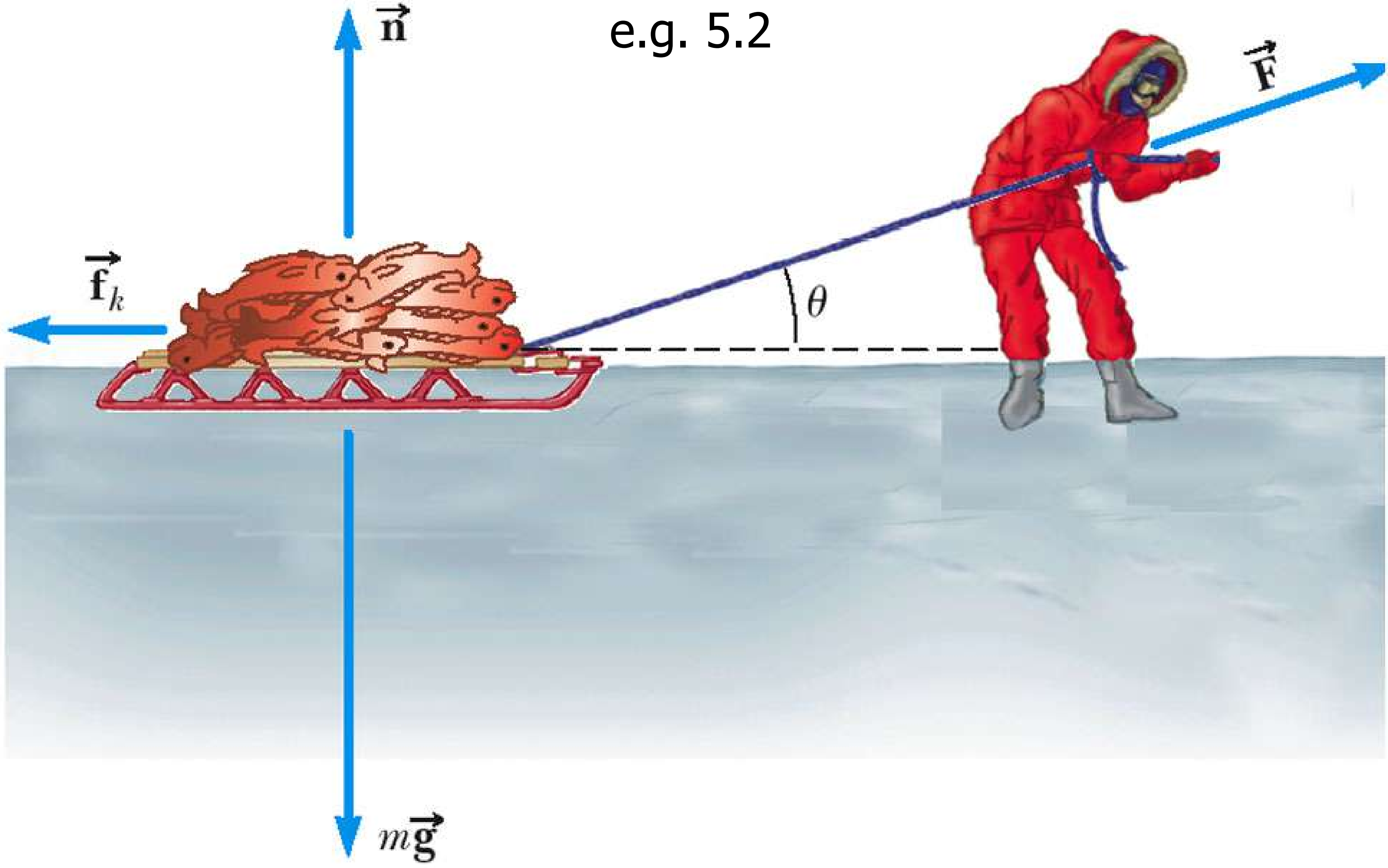
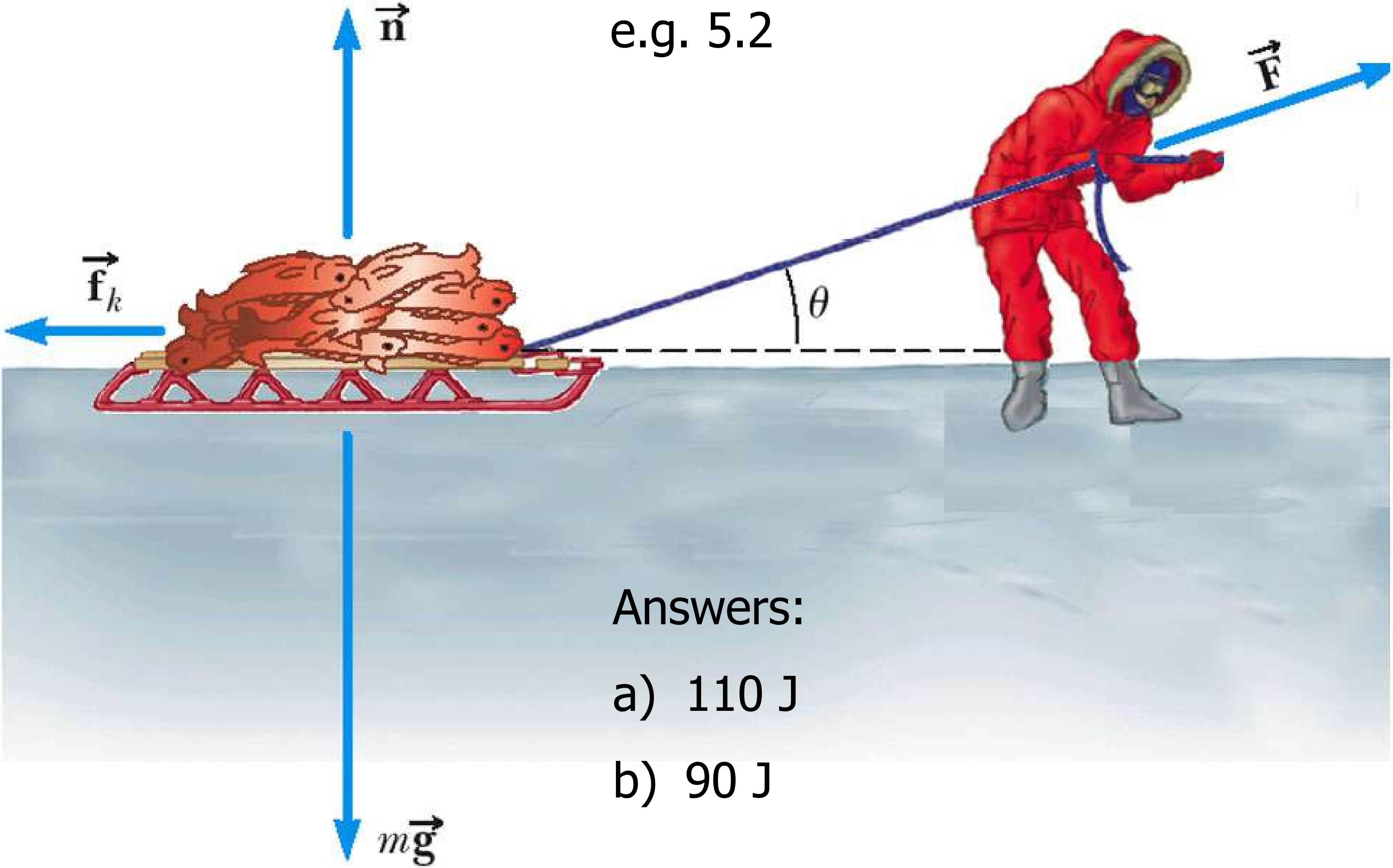


Fig. 5-6, p.121

e.g. 5.2



Answers:

a) 110 J

b) 90 J

Fig. 5-6, p.121

Kinetic Energy 5.2

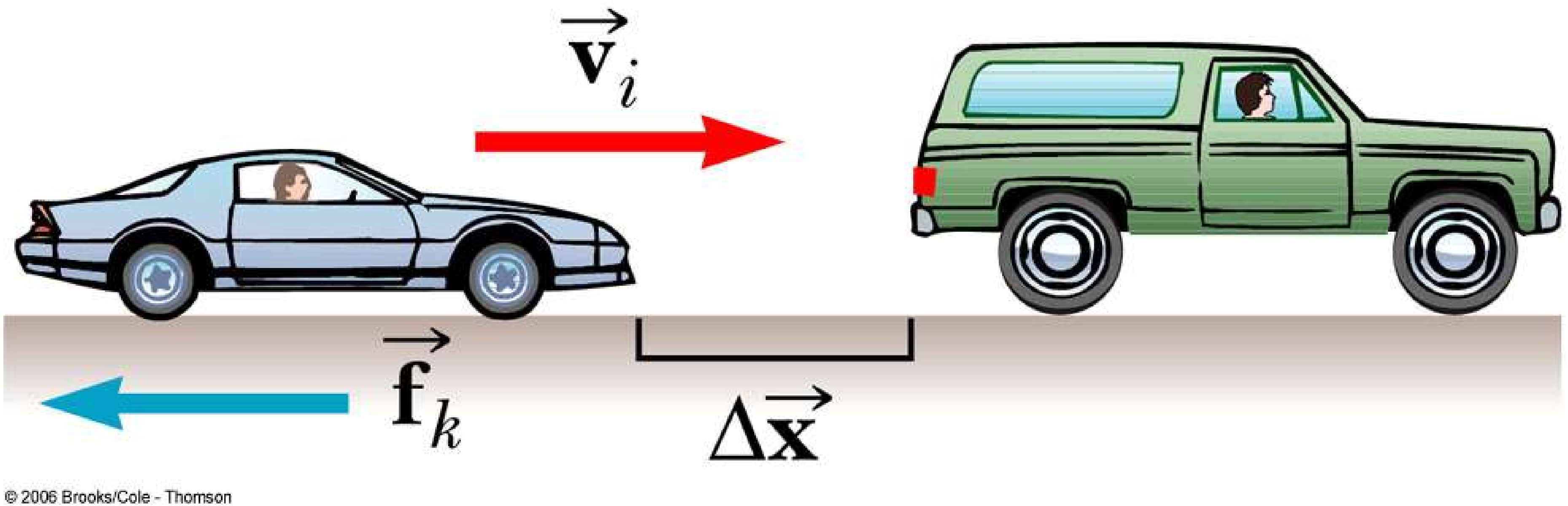
- Energy associated with the motion of an object
- $KE = \frac{1}{2}mv^2$
- Scalar quantity with the same units as work
- Work is related to kinetic energy

Work-Kinetic Energy Theorem

- When work is done by a net force on an object and the only change in the object is its speed, the work done is equal to the change in the object's kinetic energy
- $W_{net} = KE_f - KE_i = \Delta KE$
  - Speed will increase if work is positive
  - Speed will decrease if work is negative

Work and Kinetic Energy

- An object's kinetic energy can also be thought of as the amount of work the moving object could do in coming to rest
  - The moving hammer has kinetic energy and can do work on the nail



Work-energy Theorem allow for collision analysis. (see e.g. 5.3 on p. 124)

Fig. 5-9, p.124

Types of Forces (Read on own)

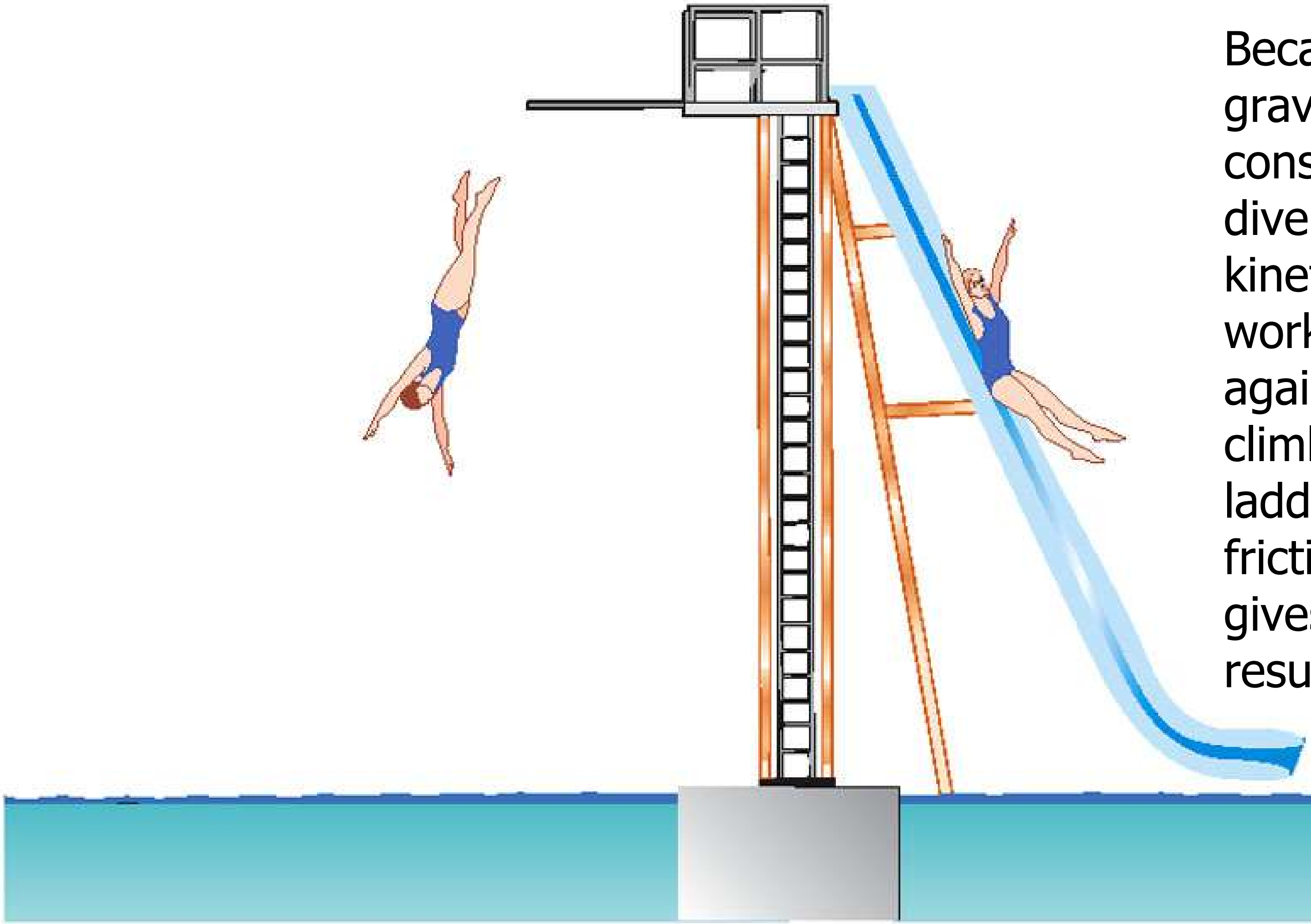
- There are two general kinds of forces
  - Conservative
    - Work and energy associated with the force can be recovered
  - Nonconservative
    - The forces are generally dissipative and work done against it cannot easily be recovered

Conservative Forces (Read on own)

- A force is conservative if the work it does on an object moving between two points is independent of the path the objects take between the points
  - The work depends only upon the initial and final positions of the object
  - Any conservative force can have a potential energy function associated with it

More About Conservative Forces (Read on own)

- Examples of conservative forces include:
  - Gravity
  - Spring force
  - Electromagnetic forces
- Potential energy is another way of looking at the work done by conservative forces



Because the gravity field is conservative, the diver regains as kinetic energy the work she did against gravity in climbing the ladder. Taking the frictionless slide gives the same result.

Fig. 5-10, p.125

Nonconservative Forces (Read on own)

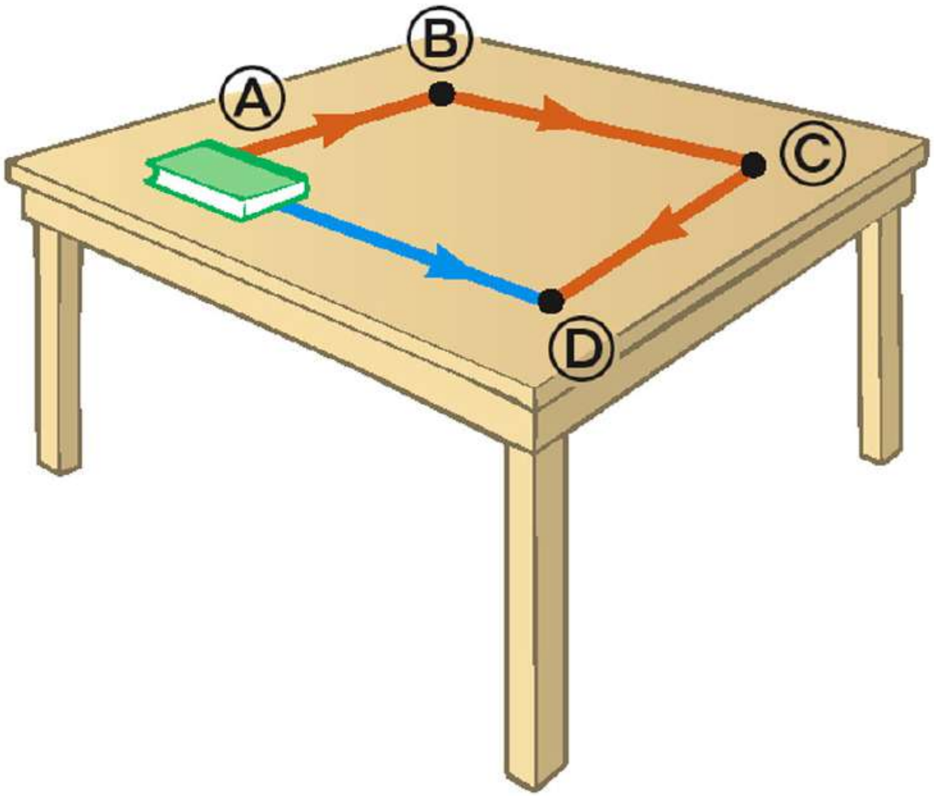
- A force is nonconservative if the work it does on an object depends on the path taken by the object between its final and starting points.
- Examples of nonconservative forces
  - kinetic friction, air drag, propulsive forces

Friction as a Nonconservative Force (Read on own)

- The friction force is transformed from the kinetic energy of the object into a type of energy associated with temperature
  - The objects are warmer than they were before the movement
  - *Internal Energy* is the term used for the energy associated with an object's temperature

Friction Depends on the Path (Read on own)

- The blue path is shorter than the red path
- The work required is less on the blue path than on the red path
- Friction depends on the path and so is a non-conservative force



Potential Energy 5.3

- Potential energy is associated with the position or elasticity of the object within some system
  - Potential energy is a property of the system, not the object
  - A system is a collection of objects interacting via forces or processes that are internal to the system

Work and Potential Energy

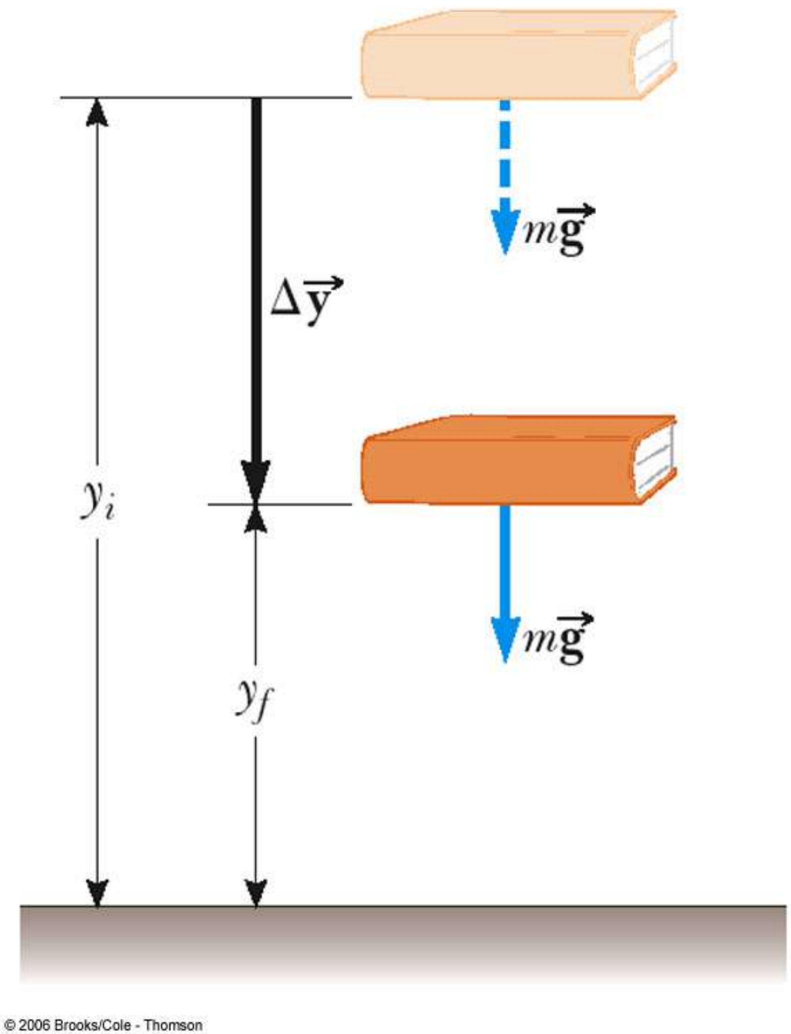
- For every conservative force a potential energy function can be found
- Evaluating the difference of the function at any two points in an object's path gives the negative of the work done by the force between those two points

Gravitational Potential Energy

- Gravitational Potential Energy is the energy associated with the relative position of an object in space near the Earth's surface
  - Objects interact with the earth through the gravitational force
  - Actually the potential energy is for the earth-object system

Work and Gravitational Potential Energy

- PE = mgy
- PE=mgh
- $W_{gravity} = PE_i - PE_f$
- Units of Potential Energy are the same as those of Work and Kinetic Energy (J)



Work-Energy Theorem, Extended

- The work-energy theorem can be extended to include potential energy:

$$W_{nc} = (KE_f - KE_i) + (PE_f - PE_i)$$

- If other conservative forces are present, potential energy functions can be developed for them and their change in that potential energy added to the right side of the equation

Reference Levels for Gravitational Potential Energy

- A location where the gravitational potential energy is zero must be chosen for each problem
  - The choice is arbitrary since the change in the potential energy is the important quantity
  - Choose a convenient location for the zero reference height
    - often the Earth's surface
    - may be some other point suggested by the problem
  - Once the position is chosen, it must remain fixed for the entire problem

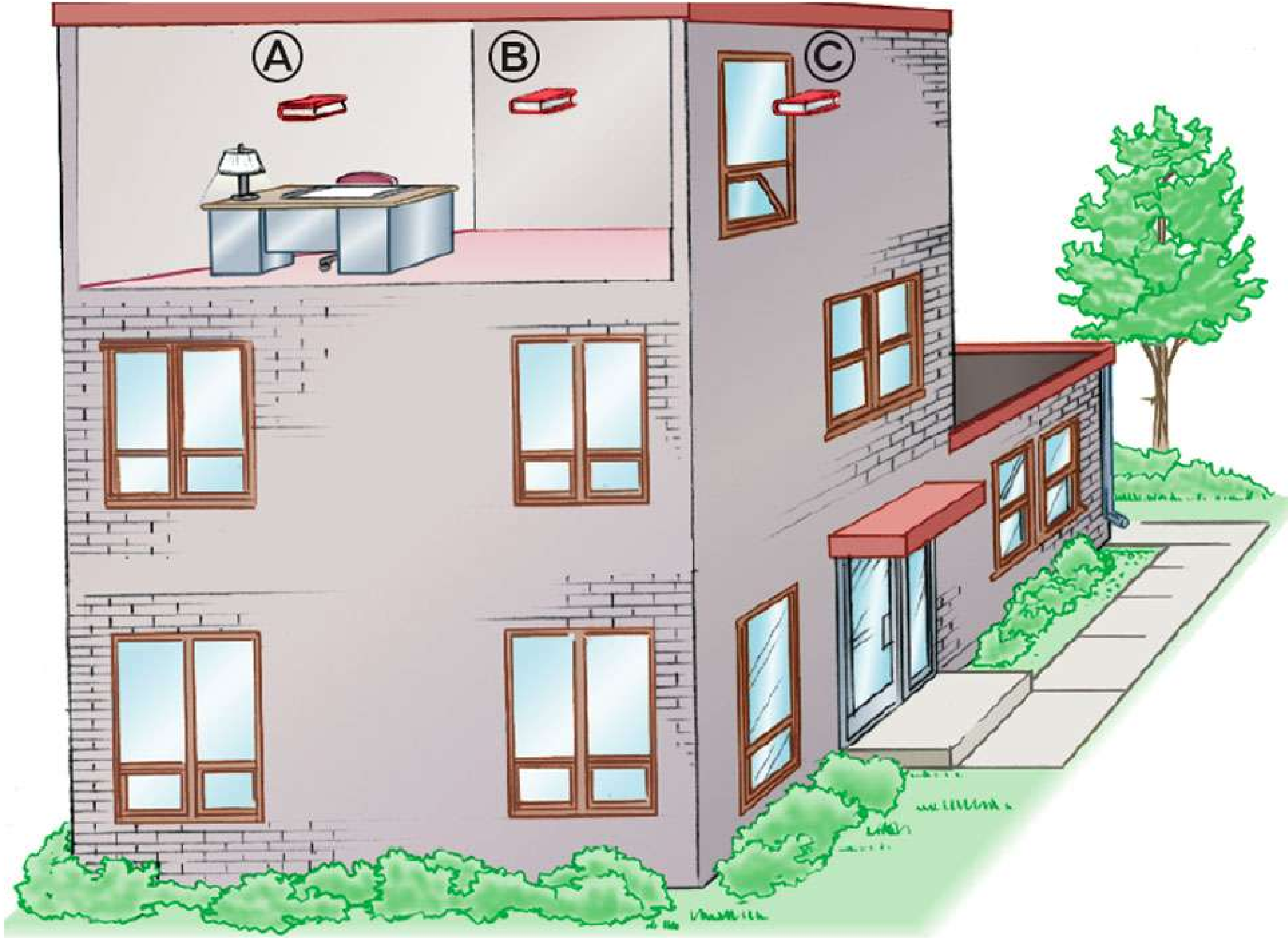


Fig. 5-13, p.128

e.g. 5.4

A 60.0-kg skier is at the top of a slope, as shown in Figure 5.14. At the initial point A, she is 10.0 m vertically above point B. Setting the zero level for gravitational potential energy at B, find the gravitational potential energy of this system when the skier is at A.

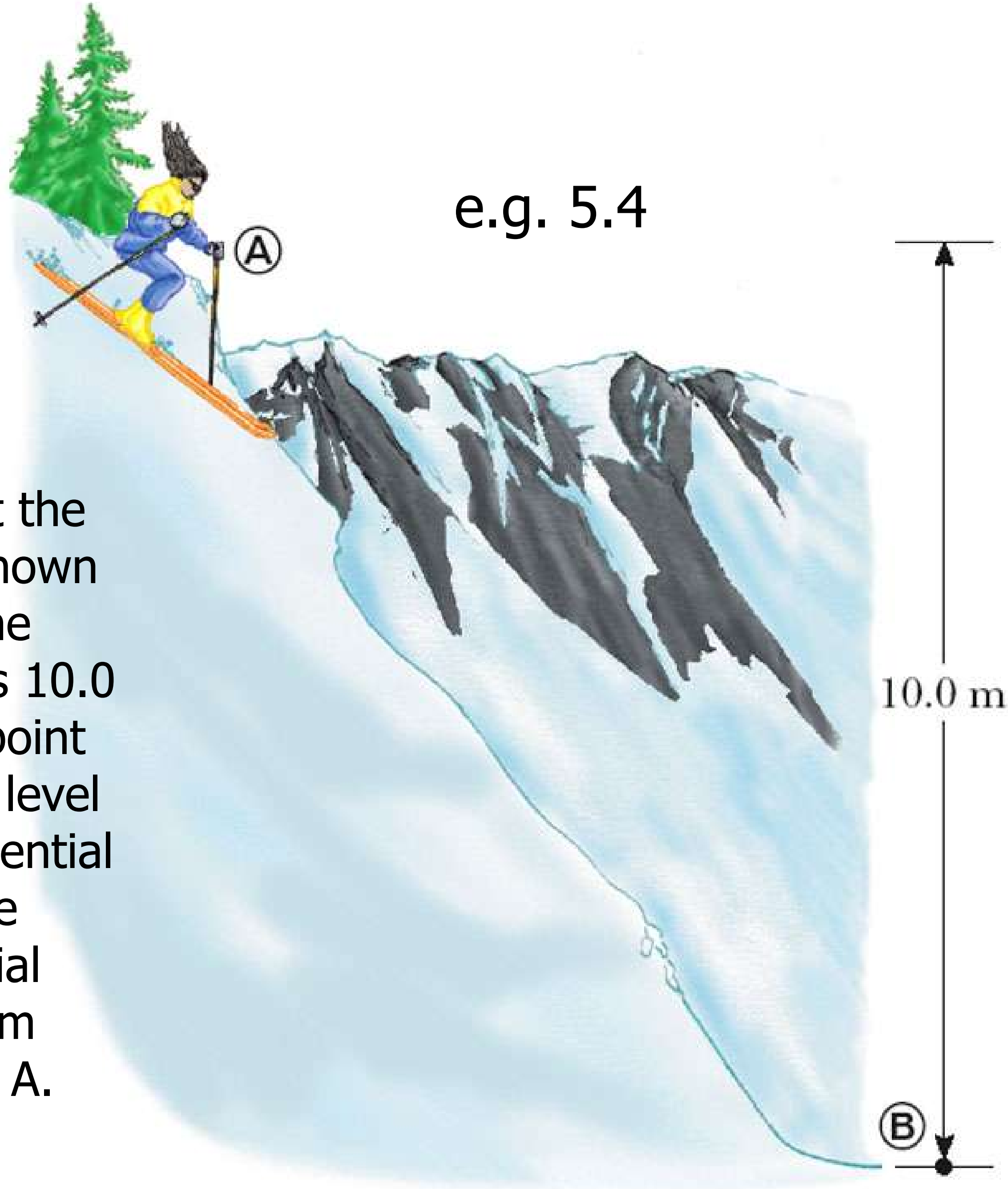


Fig. 5-14, p.128

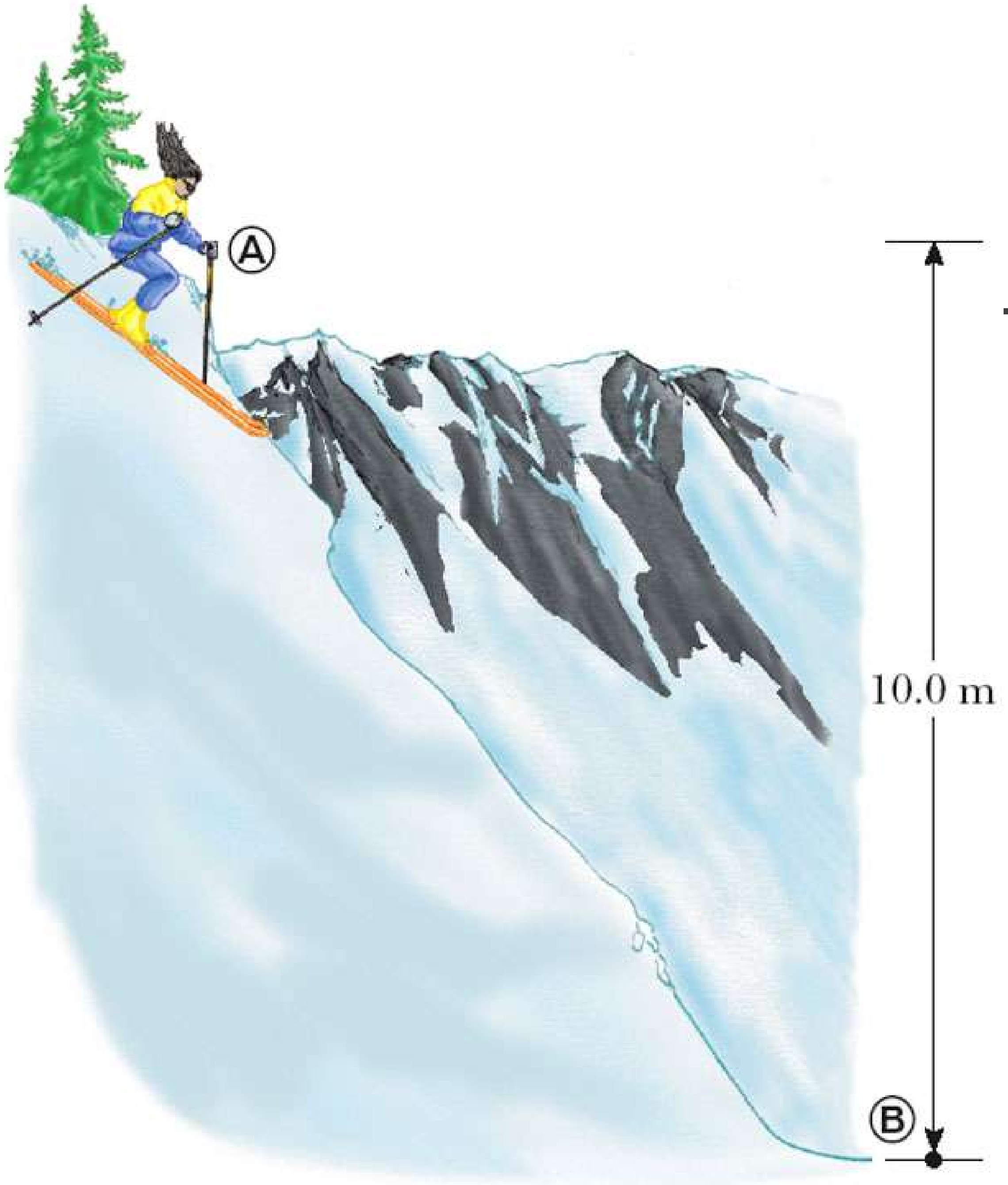
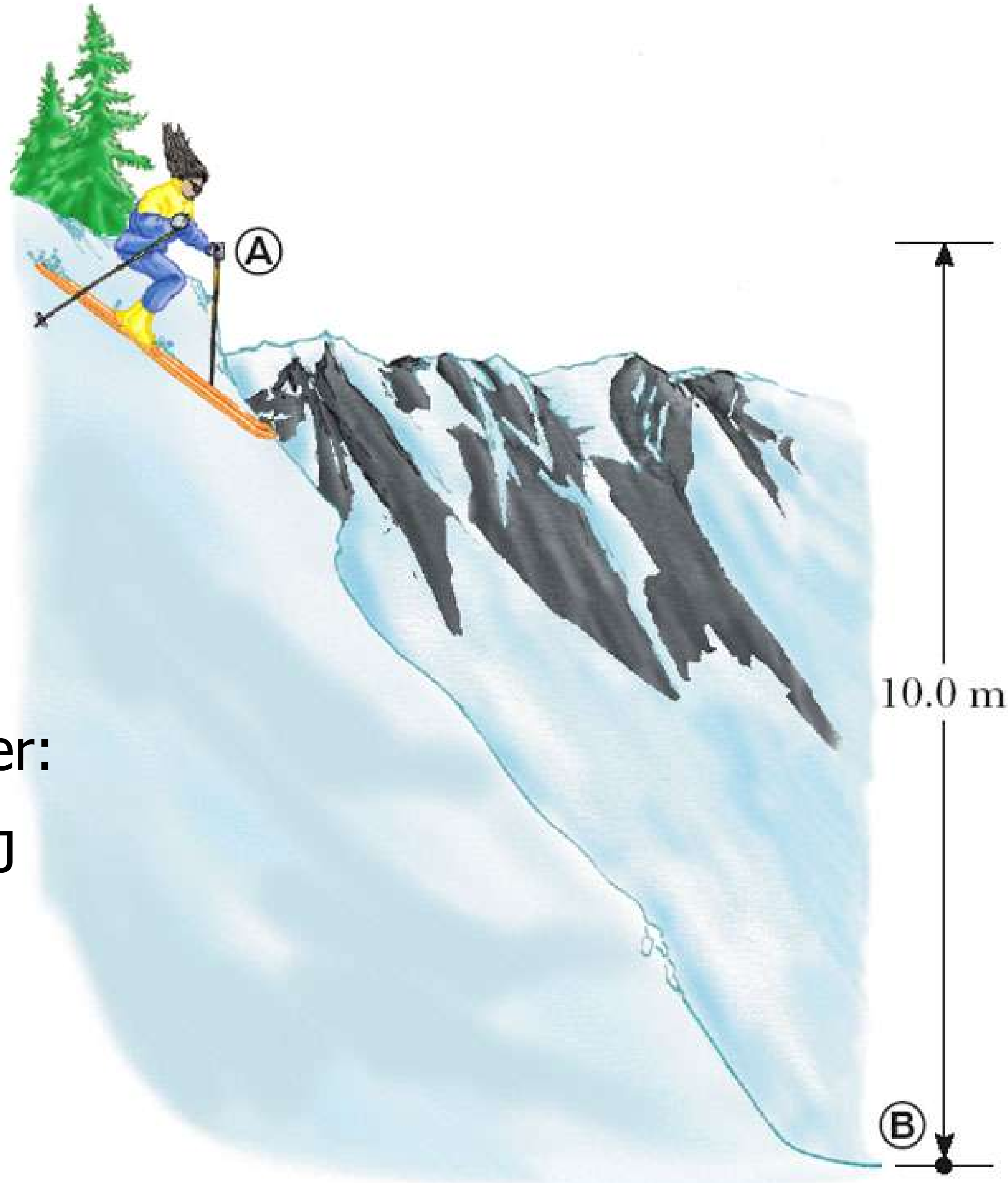


Fig. 5-14, p.128



Answer:

5880 J

Fig. 5-14, p.128

Conservation of Mechanical Energy

- Conservation in general
  - To say a physical quantity is *conserved* is to say that the numerical value of the quantity remains constant throughout any physical process
- In Conservation of Energy, the total mechanical energy remains constant
  - *In any isolated system of objects interacting only through conservative forces, the total mechanical energy of the system remains constant.*

Conservation of Energy, cont.

- Total mechanical energy is the sum of the kinetic and potential energies in the system

$$E_i = E_f$$

$$KE_i + PE_i = KE_f + PE_f$$

  - Other types of potential energy functions can be added to modify this equation

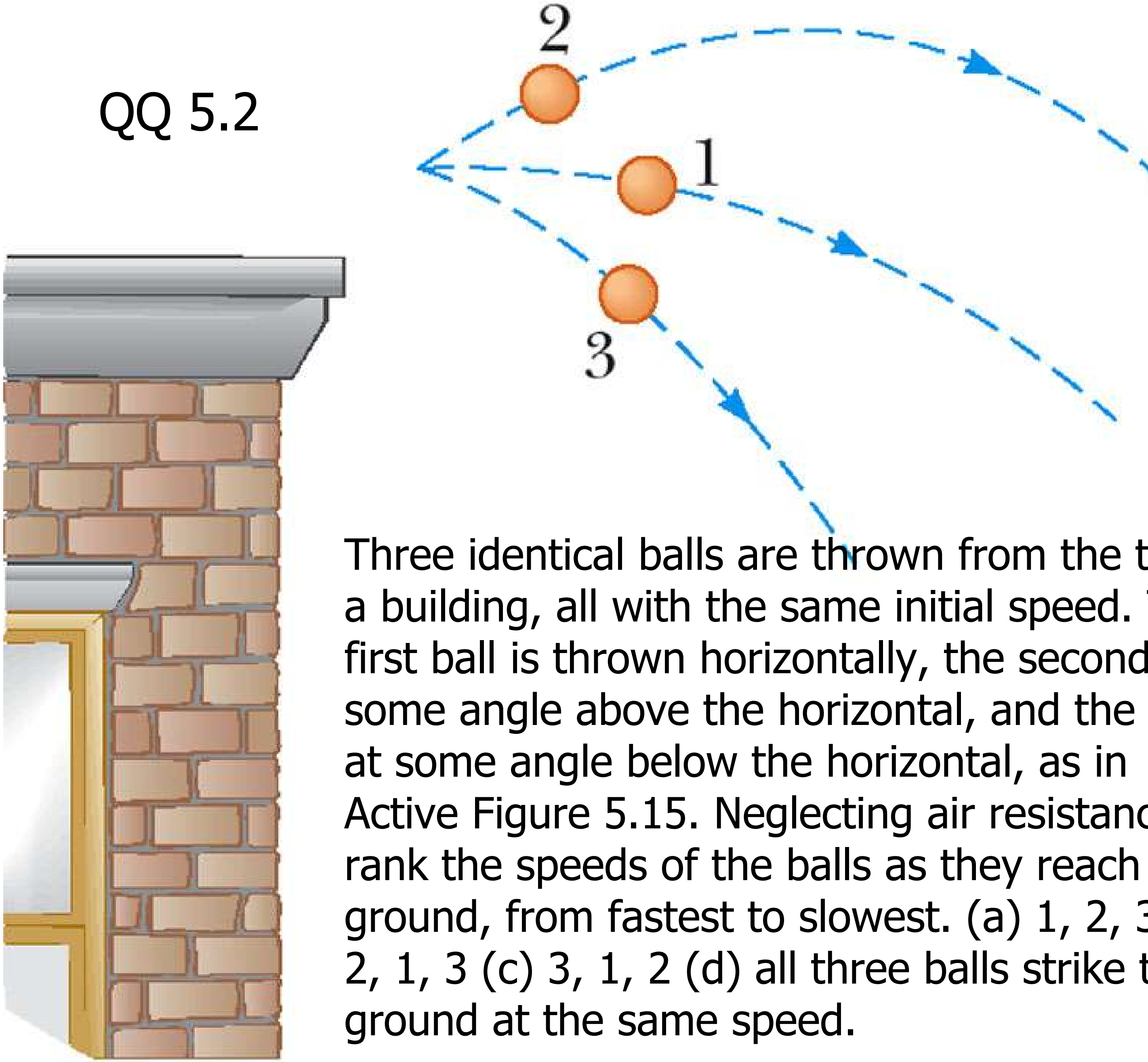
Problem Solving with Conservation of Energy

- Define the system
- Select the location of zero gravitational potential energy
  - Do *not* change this location while solving the problem
- Identify two points the object of interest moves between
  - One point should be where information is given
  - The other point should be where you want to find out something

Problem Solving, cont

- Verify that only conservative forces are present
- Apply the conservation of energy equation to the system
  - Immediately substitute zero values, then do the algebra before substituting the other values
- Solve for the unknown(s)

QQ 5.2



Three identical balls are thrown from the top of a building, all with the same initial speed. The first ball is thrown horizontally, the second at some angle above the horizontal, and the third at some angle below the horizontal, as in Active Figure 5.15. Neglecting air resistance, rank the speeds of the balls as they reach the ground, from fastest to slowest. (a) 1, 2, 3 (b) 2, 1, 3 (c) 3, 1, 2 (d) all three balls strike the ground at the same speed.

Fig. 5-15, p.130

QQ 5.2

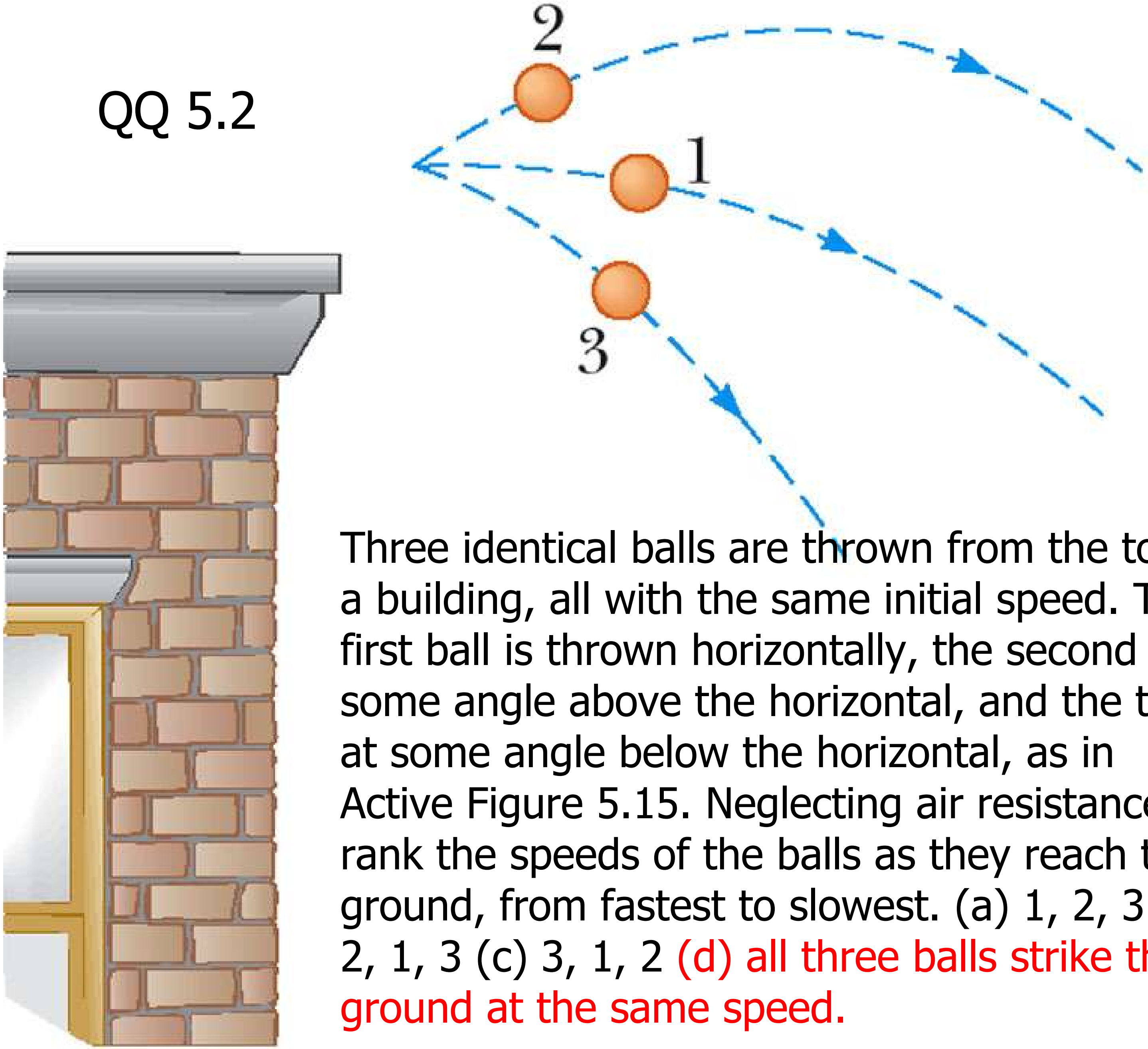


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Fig. 5-15, p.130

QQ 5.3

Bob, of mass *m*, drops from a tree limb at the same time that Esther, also of mass *m*, begins her descent down a frictionless slide. If they both start at the same height above the ground, which of the following is true about their kinetic energies as they reach the ground?

(a) Bob’s kinetic energy is greater than Esther’s.

(b) Esther’s kinetic energy is greater than Bob’s.

(c) They have the same kinetic energy.

(d) The answer depends on the shape of the slide.

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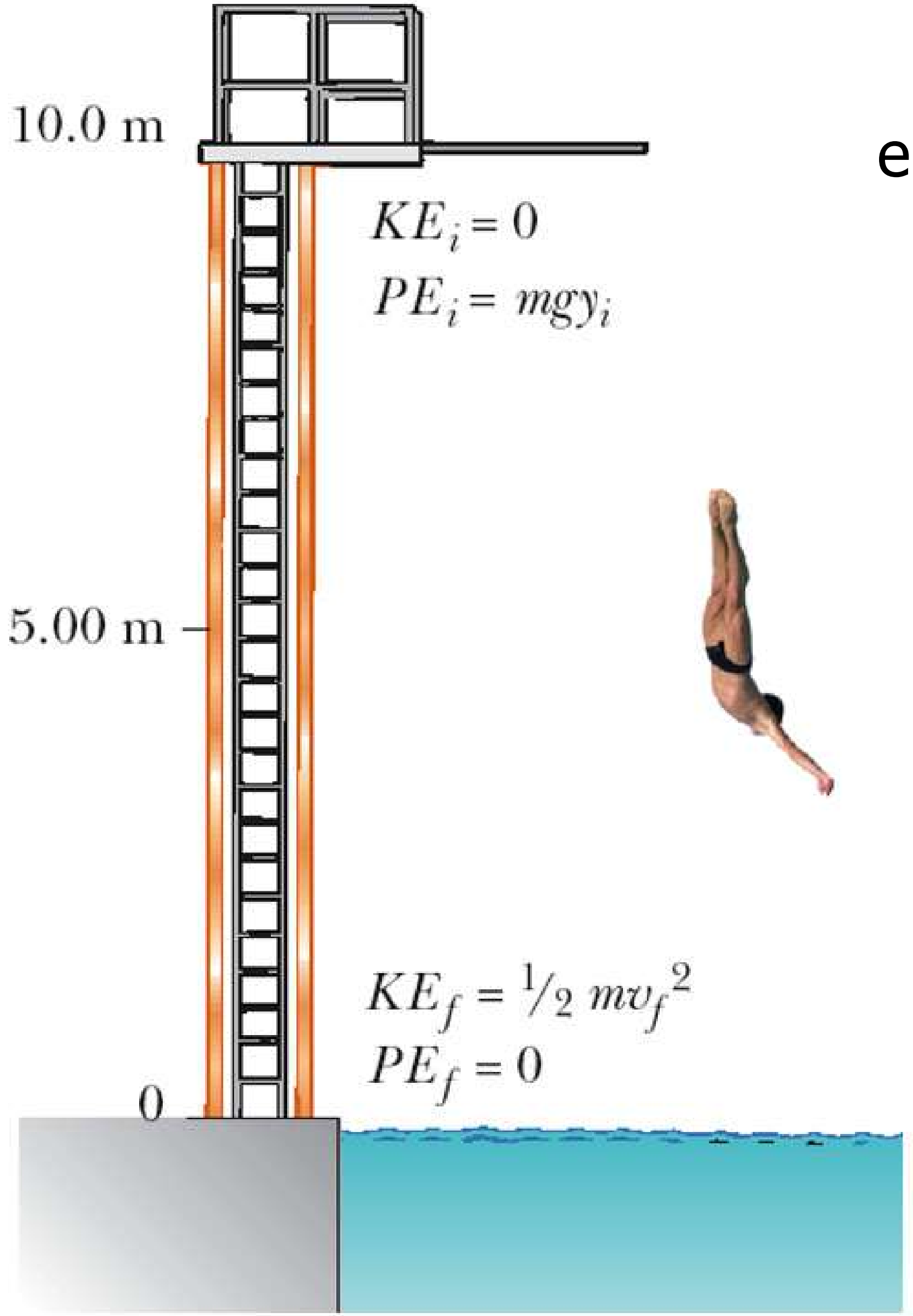


e.g. 5.5

A diver of mass *m* drops from a board 10.0 m above the water's surface, as in Figure 5.16. Neglect air resistance. **(a)** Use conservation of mechanical energy to find his speed 5.00 m above the water's surface. **(b)** Find his speed as he hits the water.

Fig. 5-16, p.131

e.g. 5.5

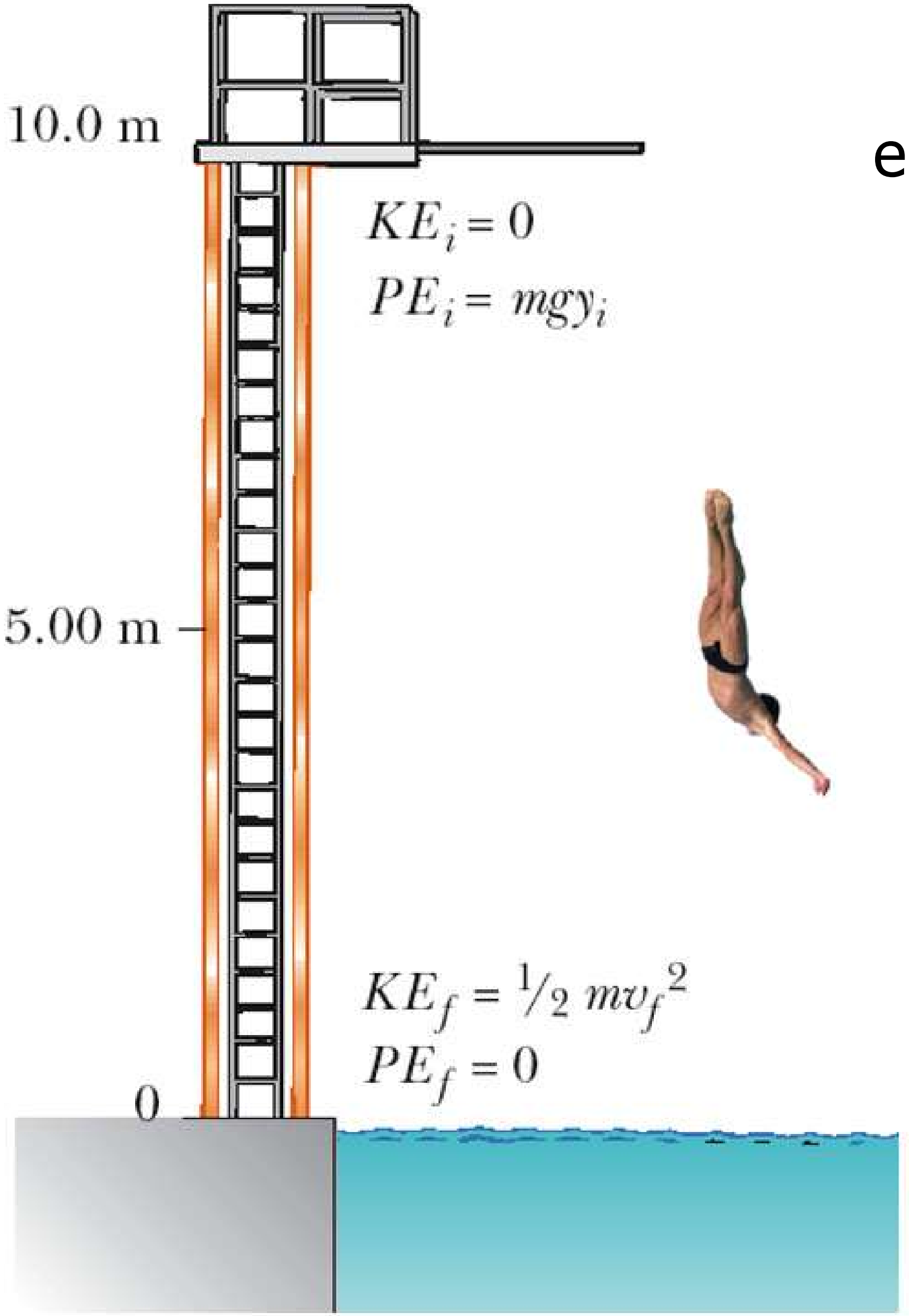
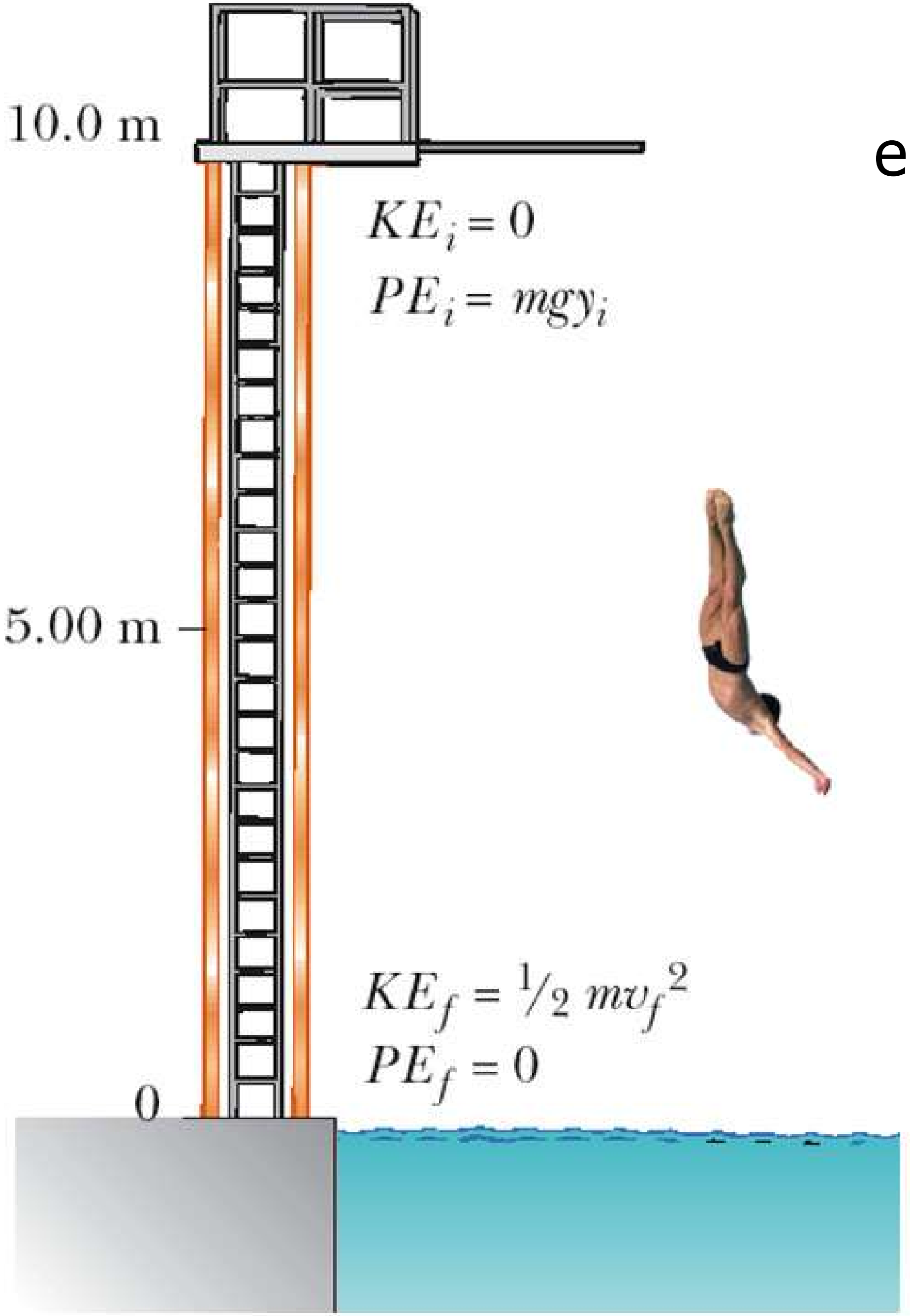


Fig. 5-16, p.131



e.g. 5.5

a) 9.90 m/s
b) 14.0 m/s

Fig. 5-16, p.131

Work-Energy With Nonconservative Forces

- If nonconservative forces are present, then the full Work-Energy Theorem must be used instead of the equation for Conservation of Energy
- Often techniques from previous chapters will need to be employed

e.g. 5.7

Waterslides are nearly frictionless, hence can provide bored students with high-speed thrills (Fig. 5.18). One such slide, Der Stuka, named for the terrifying German dive bombers of World War II, is 72.0 feet high (21.9 m), found at Six Flags in Dallas, Texas, and at Wet'n Wild in Orlando, Florida. **(a)** Determine the speed of a 60.0-kg woman at the bottom of such a slide, assuming no friction is present. **(b)** If the woman is clocked at 18.0 m/s at the bottom of the slide, how much mechanical energy was lost through friction?

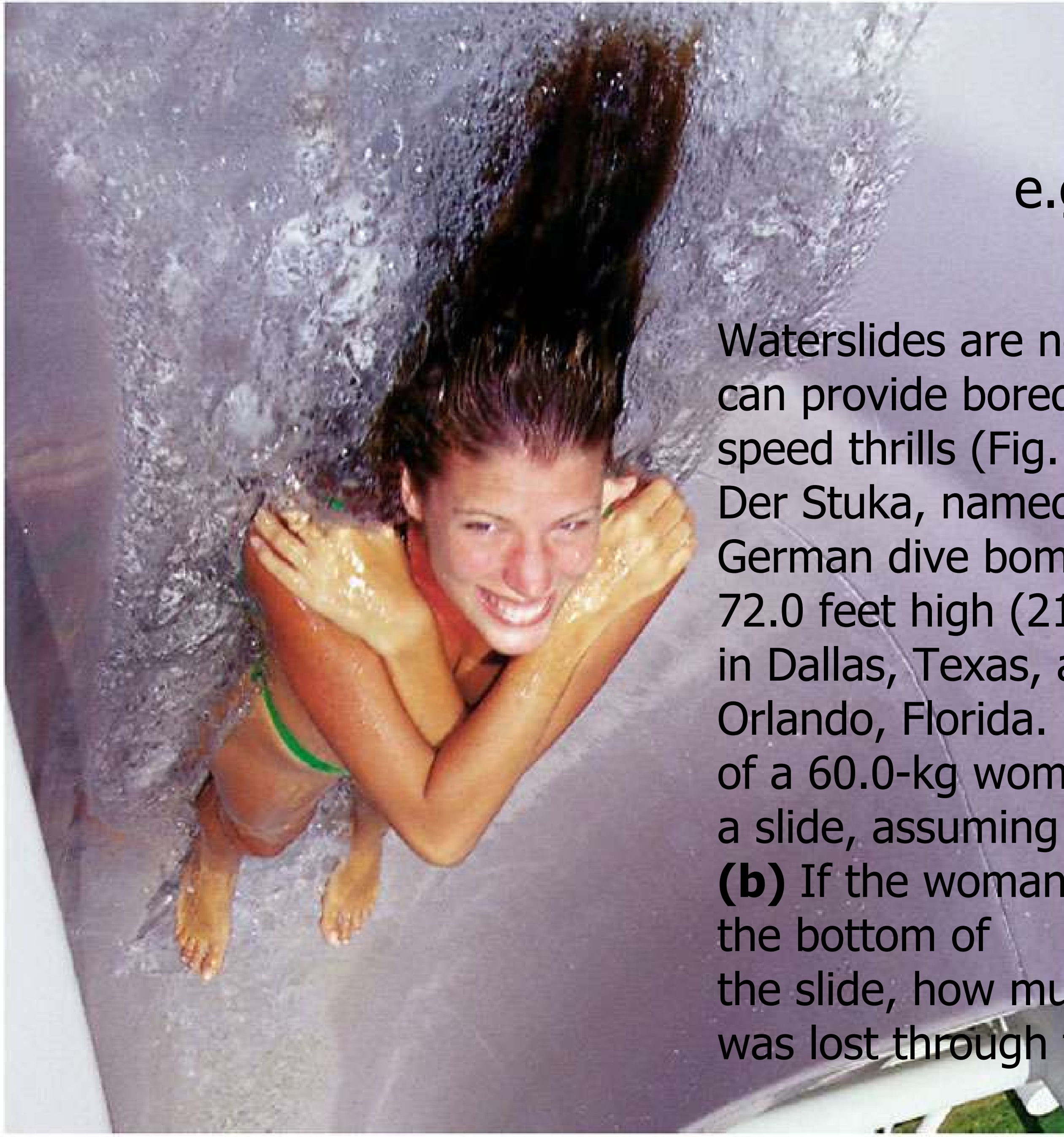


Fig. 5-18, p.132

e.g. 5.7

Fig. 5-18, p.132

e.g. 5.7

a) 20.7 m/s
b) -3160 J

Fig. 5-18, p.132

Potential Energy Stored in a Spring 5.4

- Involves the *spring constant*, k
- Hooke's Law gives the force
  - $F = - k x$
    - F is the restoring force
    - F is in the opposite direction of x
    - k depends on how the spring was formed, the material it is made from, thickness of the wire, etc.

Potential Energy in a Spring

- Elastic Potential Energy
  - related to the work required to compress (or stretch) a spring from its equilibrium position to some final, arbitrary, position x
  - $PE_s = \frac{1}{2}kx^2$

Work-Energy Theorem Including a Spring

- $W_{nc} = (KE_f - KE_i) + (PE_{gf} - PE_{gi}) + (PE_{sf} - PE_{si})$
  - PE_g is the gravitational potential energy
  - PE_s is the elastic potential energy associated with a spring
  - PE will now be used to denote the total potential energy of the system

Conservation of Energy Including a Spring 5.5

- The PE of the spring is added to both sides of the conservation of energy equation
- $$(KE + PE_g + PE_s)_i = (KE + PE_g + PE_s)_f$$
- The same problem-solving strategies apply

Nonconservative Forces with Energy Considerations

- When nonconservative forces are present, the total mechanical energy of the system is *not* constant
- The work done by all nonconservative forces acting on parts of a system equals the change in the mechanical energy of the system
  - $W_{nc} = \Delta Energy$

Nonconservative Forces and Energy

- In equation form:

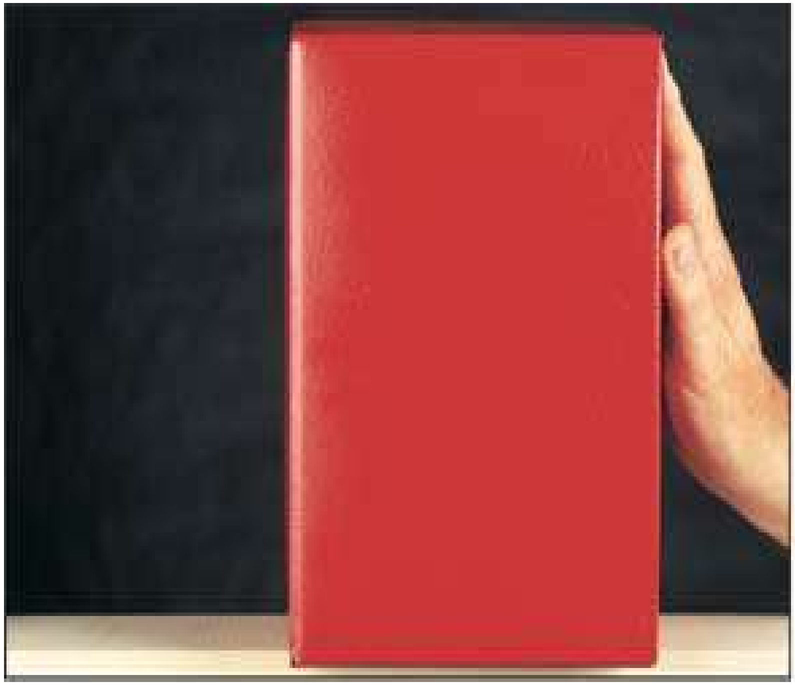
$$W_{nc} = \left(KE_f - KE_i\right) + \left(PE_i - PE_f\right) \text{ or}$$

$$W_{nc} = \left(KE_f + PE_f\right) - \left(KE_i + PE_i\right)$$

- The energy can either cross a boundary or the energy is transformed into a form of non-mechanical energy such as thermal energy

Transferring Energy

- By Work
  - By applying a force
  - Produces a displacement of the system



Transferring Energy

- Heat
  - The process of transferring heat by collisions between molecules
  - For example, the spoon becomes hot because some of the KE of the molecules in the coffee is transferred to the molecules of the spoon as internal energy

Transferring Energy

- Mechanical Waves
  - A disturbance propagates through a medium
  - Examples include sound, water, seismic

Transferring Energy

- Electrical transmission
  - Transfer by means of electrical current
  - This is how energy enters any electrical device

Transferring Energy

- Electromagnetic radiation
  - Any form of electromagnetic waves
    - Light, microwaves, radio waves

Notes About Conservation of Energy

- We can neither create nor destroy energy
  - Another way of saying energy is conserved
  - If the total energy of the system does not remain constant, the energy must have crossed the boundary by some mechanism
  - Applies to areas other than physics

Power 5.6

- Often also interested in the *rate* at which the energy transfer takes place
- *Power* is defined as this rate of energy transfer
  - $\overline{\wp} = \frac{W}{t} = F\overline{v}$
- SI units are Watts (W)
  - $W = \frac{J}{s} = \frac{kg\gamma m^2}{s^2}$

Power, cont.

- US Customary units are generally hp
  - Need a conversion factor

$$1\,\text{hp} = 550\,\frac{\text{ft lb}}{\text{s}} = 746\ \text{W}$$

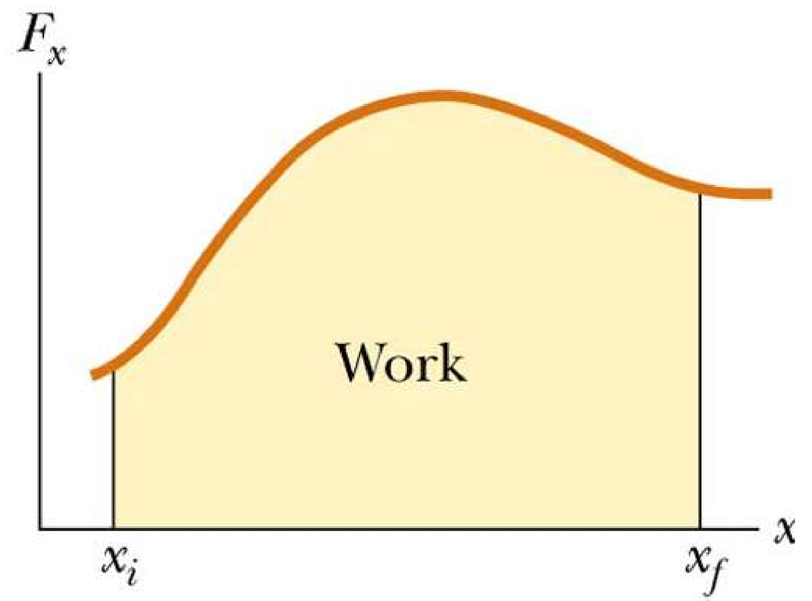
  - Can define units of work or energy in terms of units of power:
    - kilowatt hours (kWh) are often used in electric bills
    - This is a unit of energy, not power

Center of Mass

- The point in the body at which all the mass may be considered to be concentrated
  - When using mechanical energy, the change in potential energy is related to the change in height of the center of mass

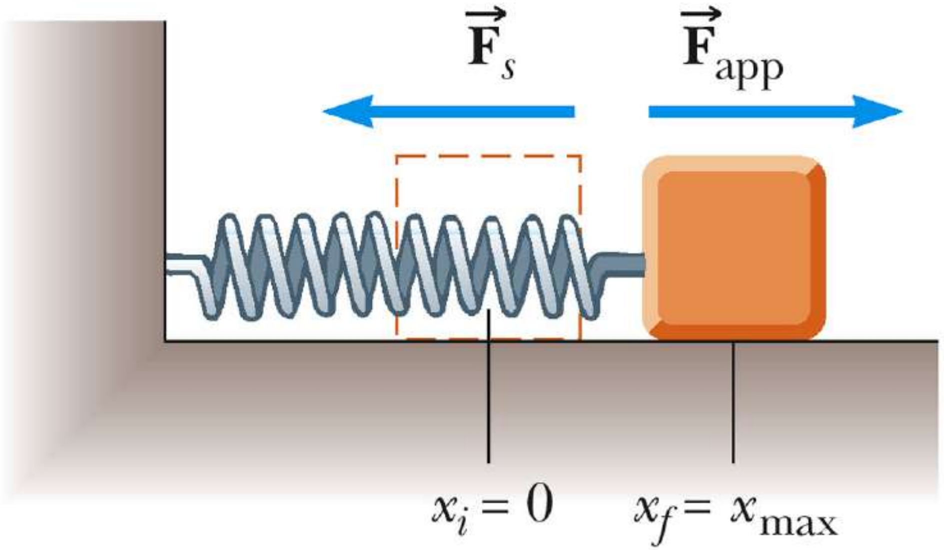
Work Done by Varying Forces 5.7 (Don’t do this section)

- The work done by a variable force acting on an object that undergoes a displacement is equal to the area under the graph of F versus x



Spring Example

- Spring is slowly stretched from 0 to xmax
- $\vec{F}_{applied} = -\vec{F}_{restoring} =$
- $W = \frac{1}{2}kx^2$



Spring Example, cont.

- The work is also equal to the area under the curve
- In this case, the "curve" is a triangle
- $A = ½ B h$ gives $W = ½ k x^2$