Chapter 7

Energy

Energy Considerations

- Energy cannot be created, nor can it be destroyed, but it can change from one form into another.

  It is essential to the study of physics and then it is applied to chemistry, biology, geology, astronomy

- In some cases it is easier to solve problems with energy then Newton's laws

Forms of Energy

- Mechanical
  - focus for now
- chemical
- electromagnetic
- Nuclear
- Heat
- Sound

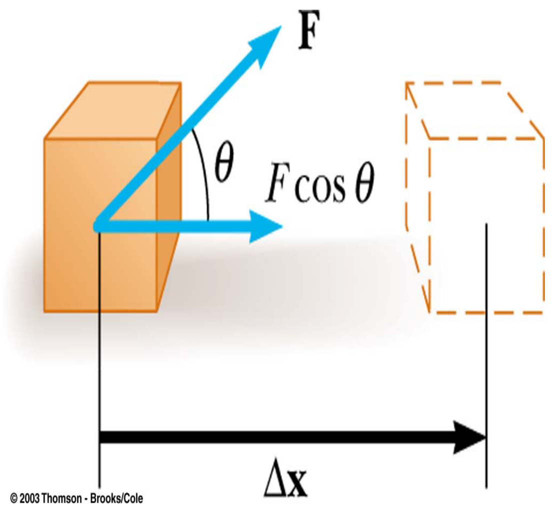
Work

- 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

$$W \equiv (F\cos\theta)\Delta x$$

Work, cont.

- $$W \equiv (F\cos\theta)\Delta x$$
  - F cos θ is the component of the force in the direction of the displacement
    - Process Called the Dot Product
  - Δ x is the displacement



Units of Work

- SI
  - Newton • meter = Joule
    - N • m = J

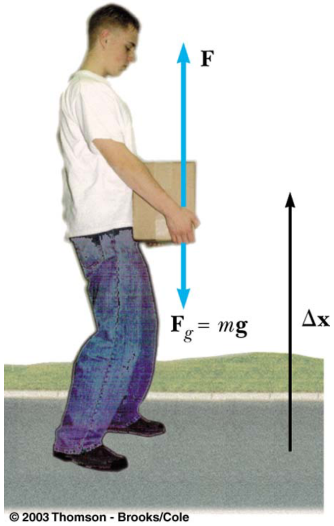
More About Work

- This gives no information about
  - the time it took for the displacement to occur
  - the velocity or acceleration of the object
- Scalar quantity
- The work done by a force is zero when the force is perpendicular to the displacement
  - $\cos 90^\circ = 0$
- 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

- Work is positive when lifting the box
- Work would be negative if lowering the box



When Work is Zero

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

Kinetic Energy

- Energy associated with the motion of an object
- $$W_{net} = F\Delta x = ma\Delta d$$
- Plug in:
- For $$v_f^2 = v_o^2 + 2ad$$

$$a\Delta d = \frac{v_f^2 - v_o^2}{2}$$

Kinetic Energy

- You get

$$Wnet = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_o^2$$

- The quantity $\frac{1}{2}mv^2$ we call kinetic energy

Kinetic Energy

- Once again Energy associated with the motion of an object
- The equation is:

$$E_k = \frac{1}{2}mv^2$$

- The units of energy are Joules!

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

Potential Energy

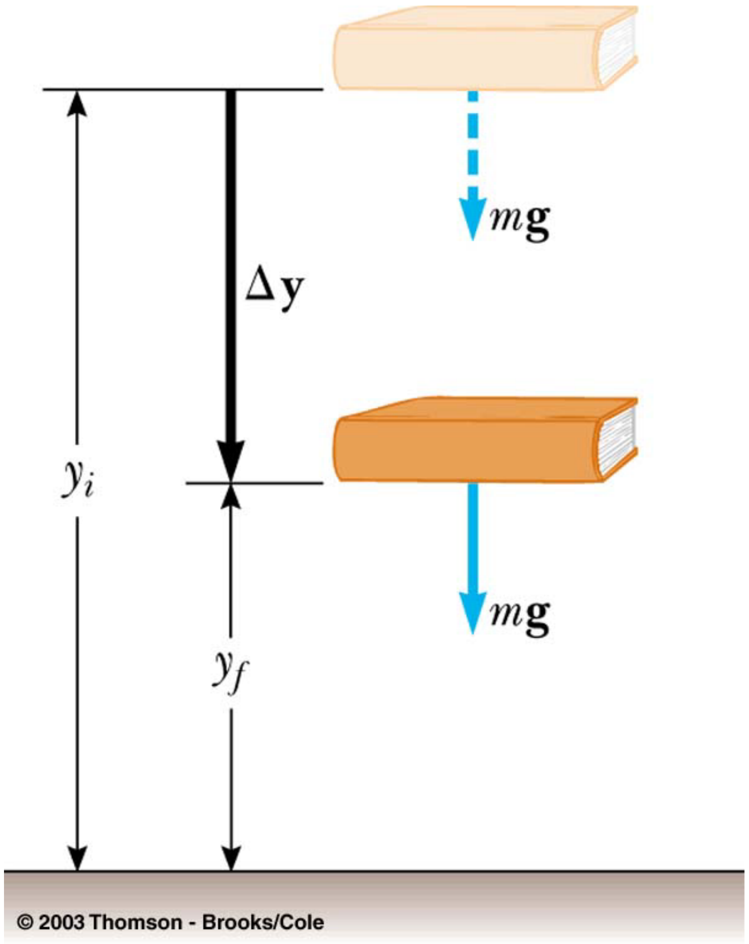
- Potential energy is associated with the position of the object within some system
  - Potential energy is a property of the system, not the object
  - A system is a collection of objects or particles interacting via forces or processes that are internal to the system

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 of the earth-object system

Work and Gravitational Potential Energy

- PE = mgy
- Units of Potential Energy are the same as those of Work and Kinetic Energy

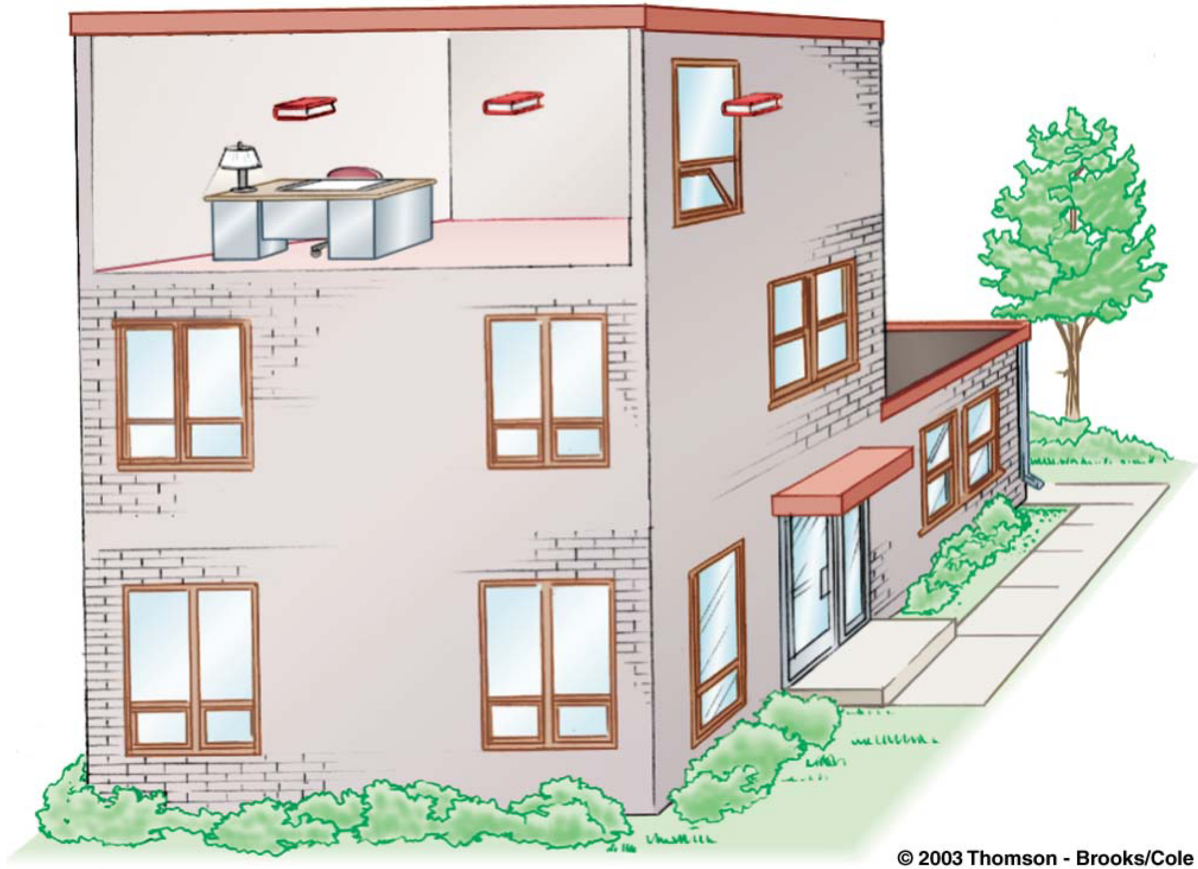


Reference Levels for Gravitational Potential Energy

- 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

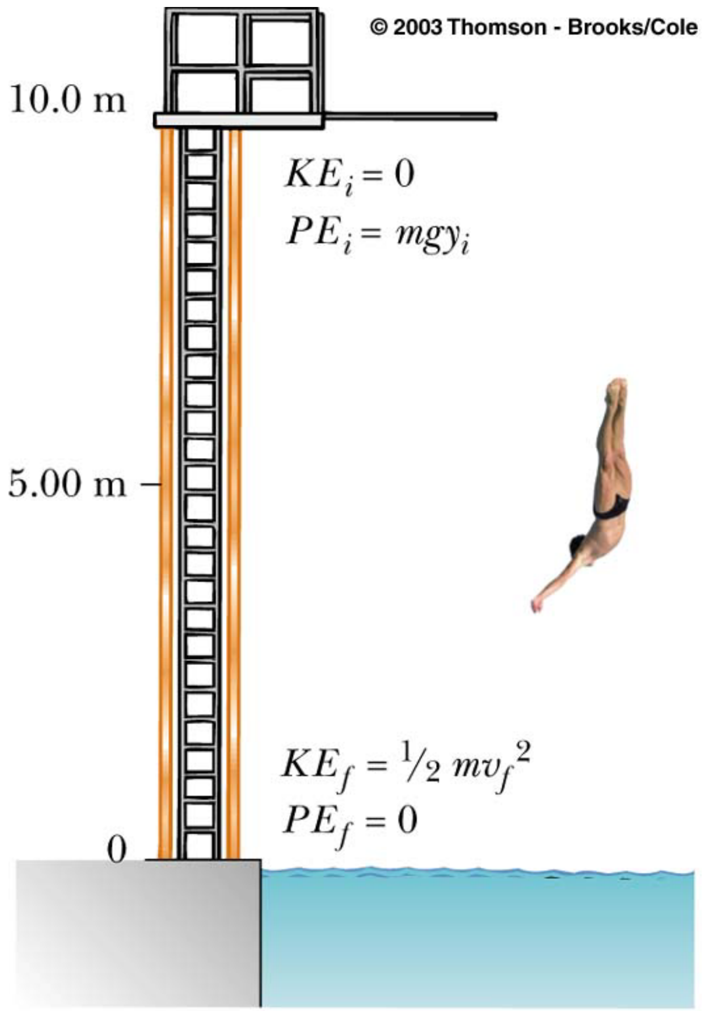
Potential Energy Example 1

- The 2kg book is .5m off the desk
- 1.25 meters above the floor
- 10 meters above the ground



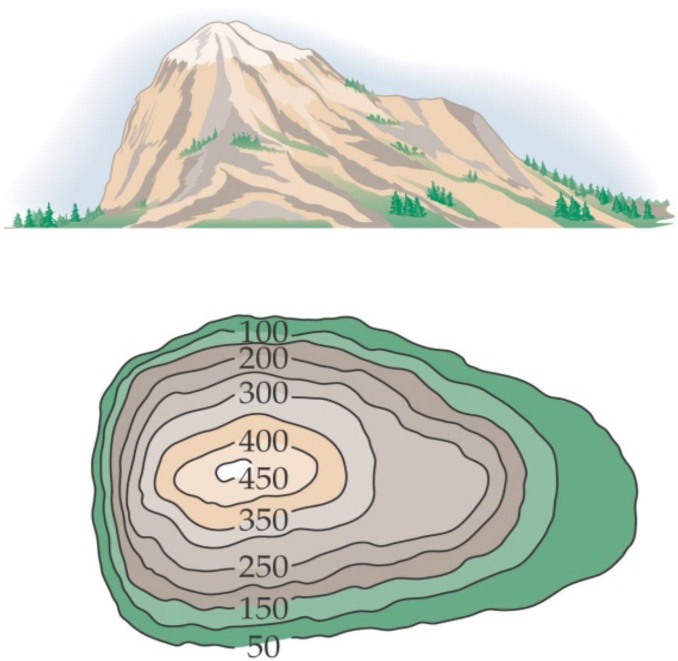
Potential Energy Example 2

- What is the Potential and Kinetic Energy of the 70kg diver at 10 m, 5m, and 0m?



Contour Lines

- A contour line is a line representing an imaginary line on the ground along which all points are at the same elevation. Therefore objects of the same mass have the same Potential energy at any point along this line.



- **Thinking of potential energy in the form of contour lines will be important when we talk about electrical potential energy.**

Power

- Is interested in the *rate* at which the energy transfer takes place
- *Power* is defined as this rate of energy transfer
  - $$\bar{P} = \frac{W}{t} = F\bar{v}$$
  - SI units are Watts (W)

- $$(W)att = \frac{J}{s} = \frac{\frac{kg \bullet m^2}{s^2}}{s} = \frac{kg \bullet m^2}{s^3}$$

Power, cont.

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

$$1\ hp = 746\ (W)$$

  - Can define units of work or energy in terms of units of power:
    - kilowatt hours (kWh) are often used in electric bills

TABLE 5.2 **Maximum Power Output from Humans for Various Time Periods**

Power	Time
2 hp or 1 500 W	6 s
1 hp or 750 W	60 s
0.35 hp or 260 W	35 min
0.2 hp or 150 W	5 h
0.1 hp or 75 W (Safe daily level)	8 h

Fig. T5.2, p. 142

Other Conversion Factors

- 4.18 Joule = 1 calorie
- 1 Calorie = 1000 calories

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
- The total mechanical energy of an isolated system is conserved

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

$$E_i = E_f$$

$$KE_i + PE_i = KE_f + PE_f$$

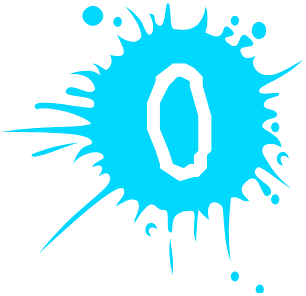
  - Other types of energy can be added to modify this equation

Problem Solving with Conservation of Energy

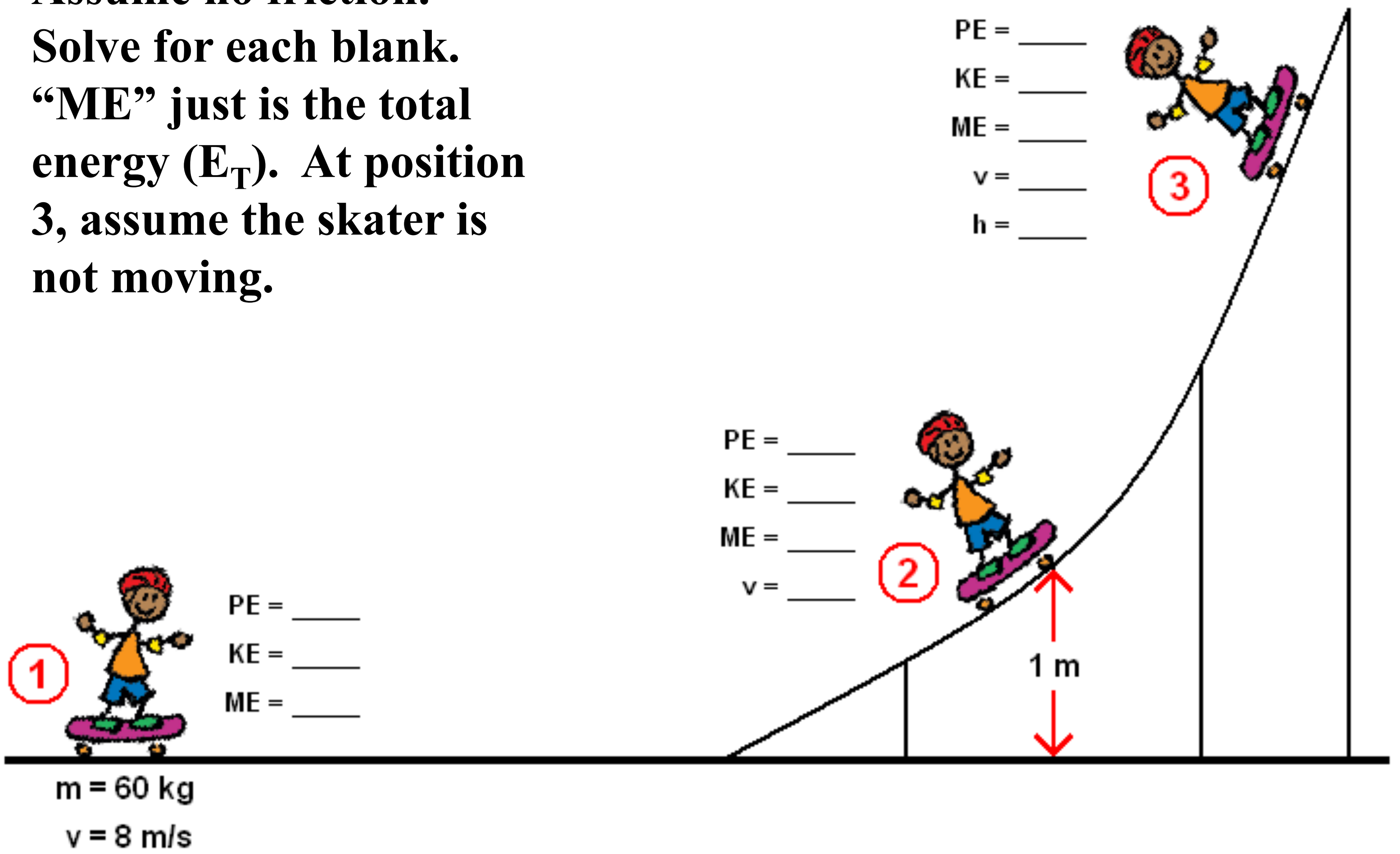
- Define the system
- Select the location of zero gravitational potential energy
  - Do *not* change this location while solving the problem
- Determine whether or not nonconservative forces are present
- If only conservative forces are present, apply conservation of energy and solve for the unknown

Energy Tables

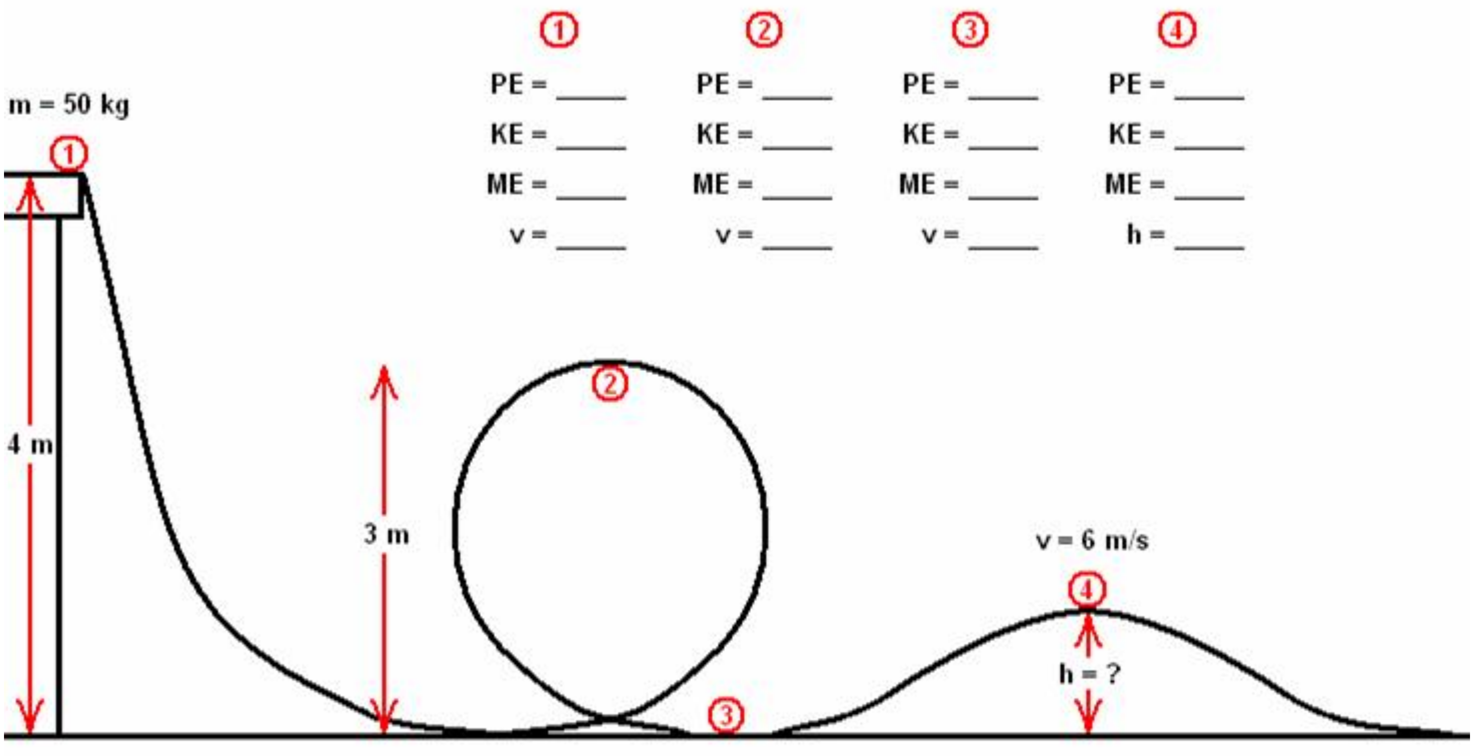
- To simplify our method of analyzing these situations, we will use an energy table. Each variable has to be found at each point.
- Remember:
  - v = 0 means **zero E_K**
  - h = 0 means **zero E_{PG}**
  - x = 0 (no spring!) means **zero E_{PE}**



Assume no friction. Solve for each blank. "ME" just is the total energy (E_T). At position 3, assume the skater is not moving.



Assume no friction. Solve for each blank. "ME" just is the total energy (E_T). Assume the car starts from rest.



- A 30kg child slides down a water slide. What is the Childs velocity when his elevation is 2m, 1m, and 0m above the water?

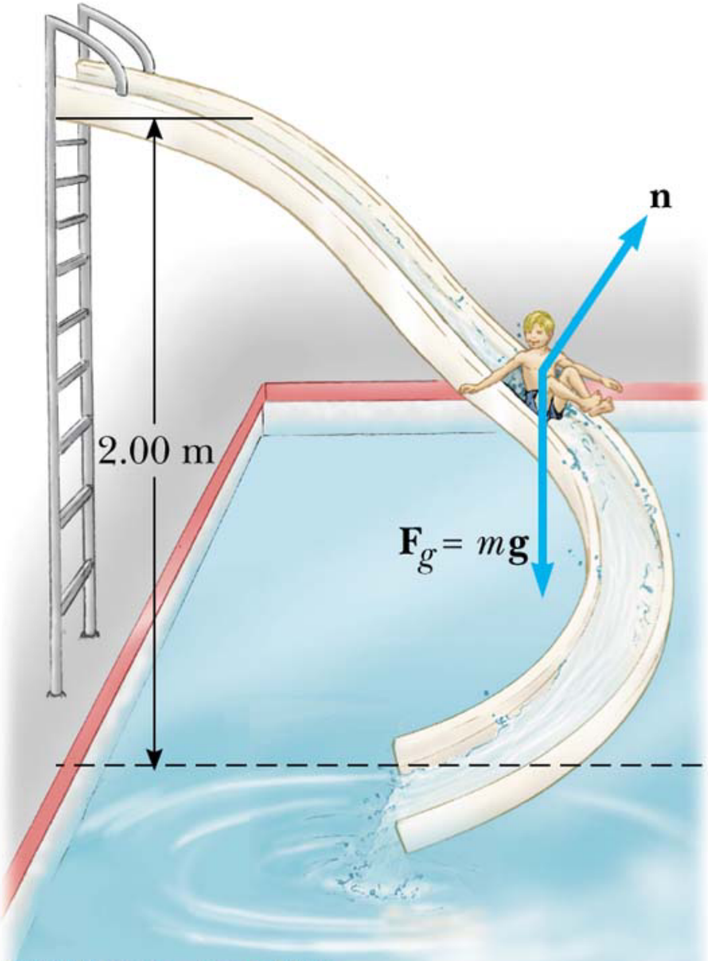
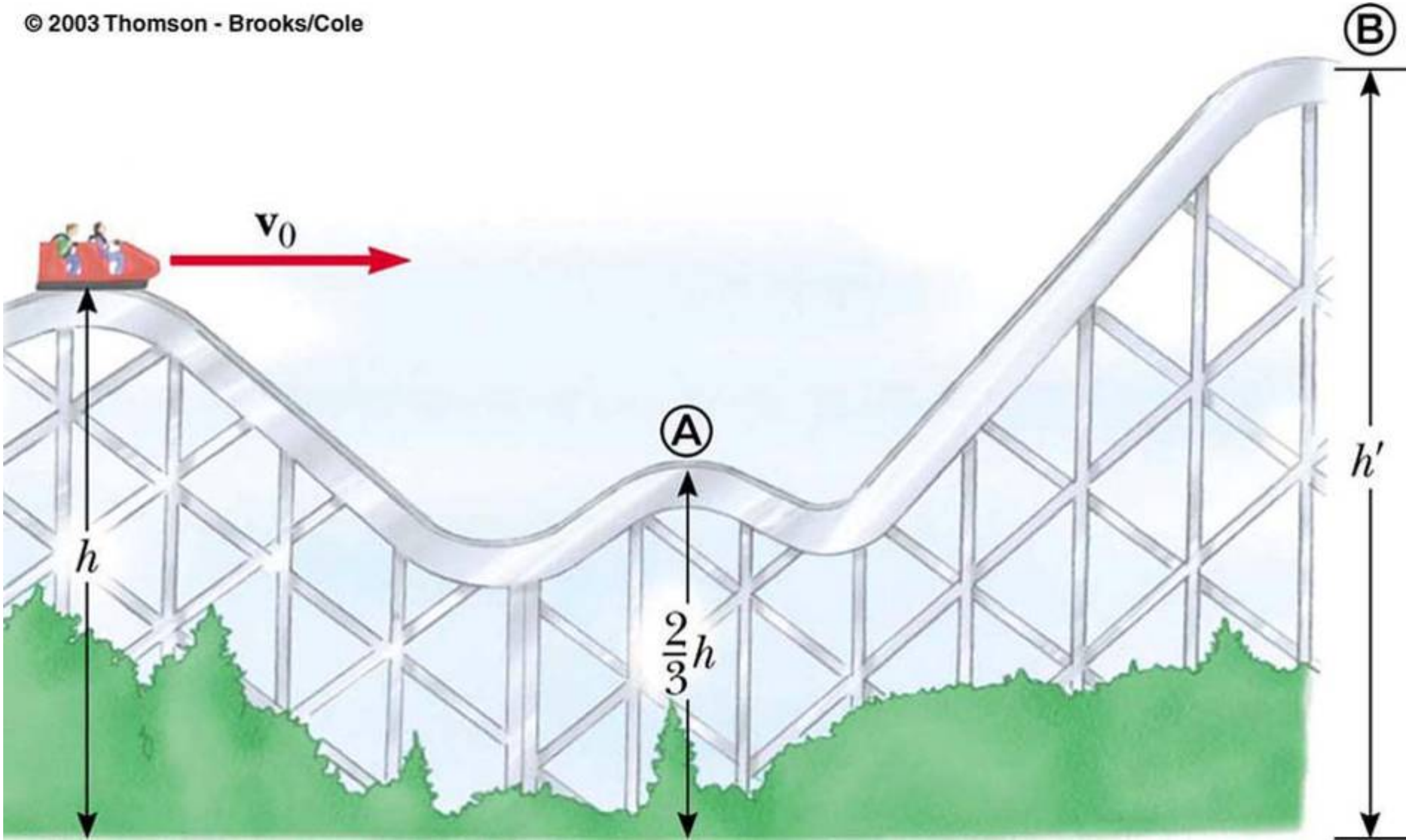


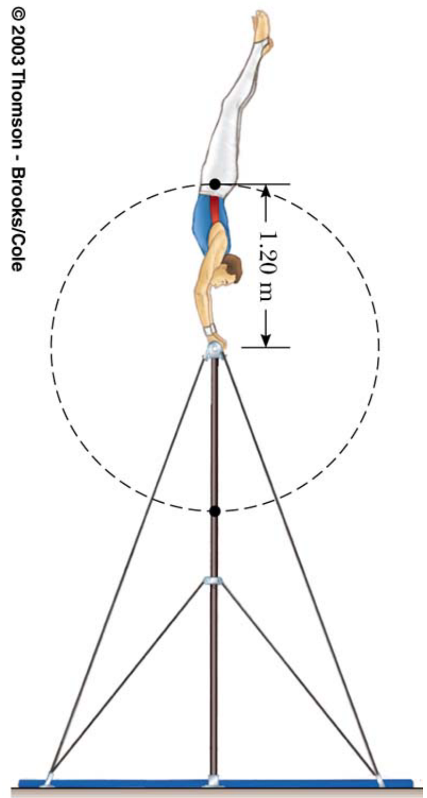
Fig. 5.24, p. 138

- **What velocity must the rollercoaster have to get from 12 meters above the ground to 18 meters above the ground?**



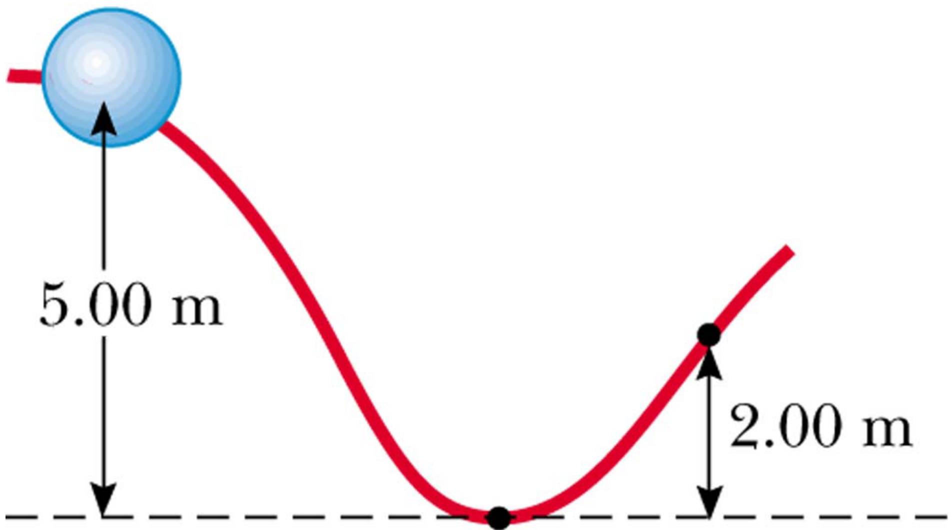
Conservation of Energy

A 65kg person's Kinetic Energy at the top is 0J. What is the persons Kinetic and Potential Energy at the bottom?



Conservation of Energy

A 7 kg ball is released from 5m. How much energy does it have at the bottom of its path? What about when it returns to 2m?



- A 65kg skier drops 10 meters. What is the skiers final velocity?

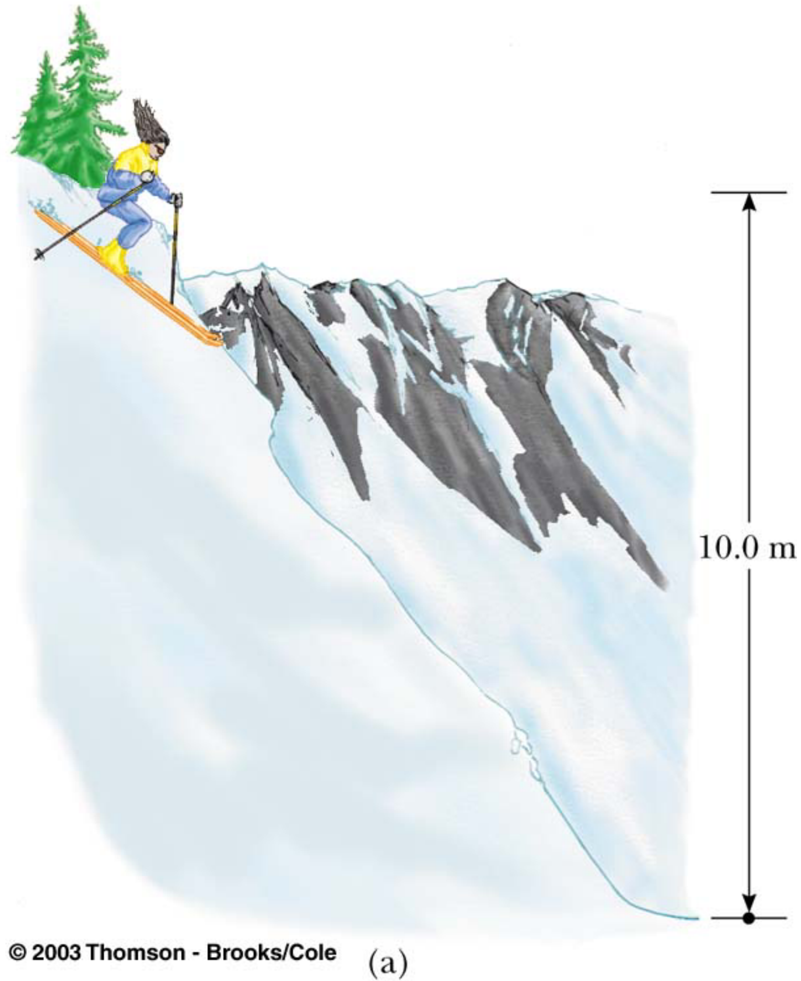
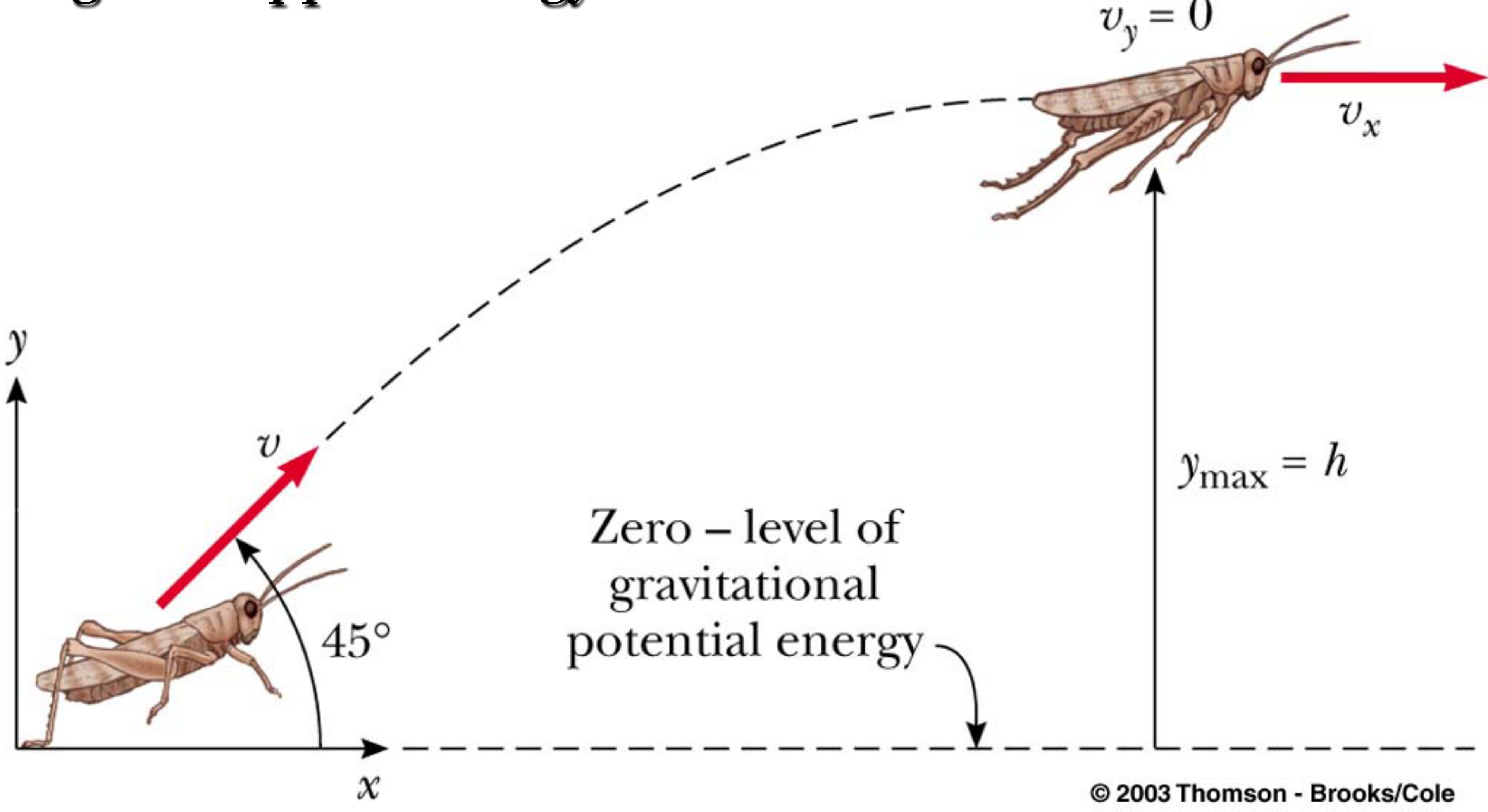


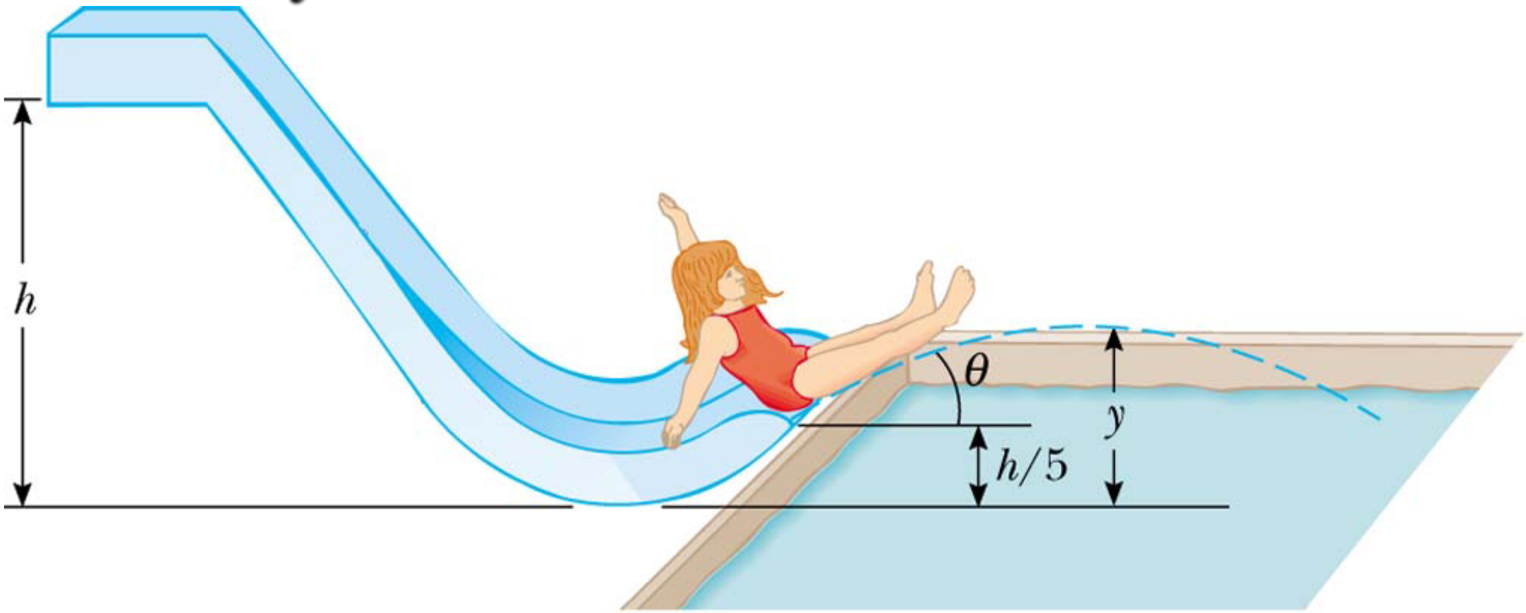
Fig. 5.13a, p. 124

- A 2g grasshopper jumps at 10m/s at 45 degrees. How far does it jump if the air resistance uses 10% of the grasshoppers energy.



Conservation of Energy

A 30 kg slides 2 meters down a slide. At the bottom of the slide it raises again 0.4 meters (0.6 meters above the water) vertically. If the angle the girl leaves the slide is 15 degrees. How high does she go, how far horizontally does she travel?



. P5.44, p. 149

Transferring Energy

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

- Heat
  - The process of transferring heat by collisions between molecules

Transferring Energy

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

- Electrical transmission
  - transfer by means of electrical current

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

Hooke's Law

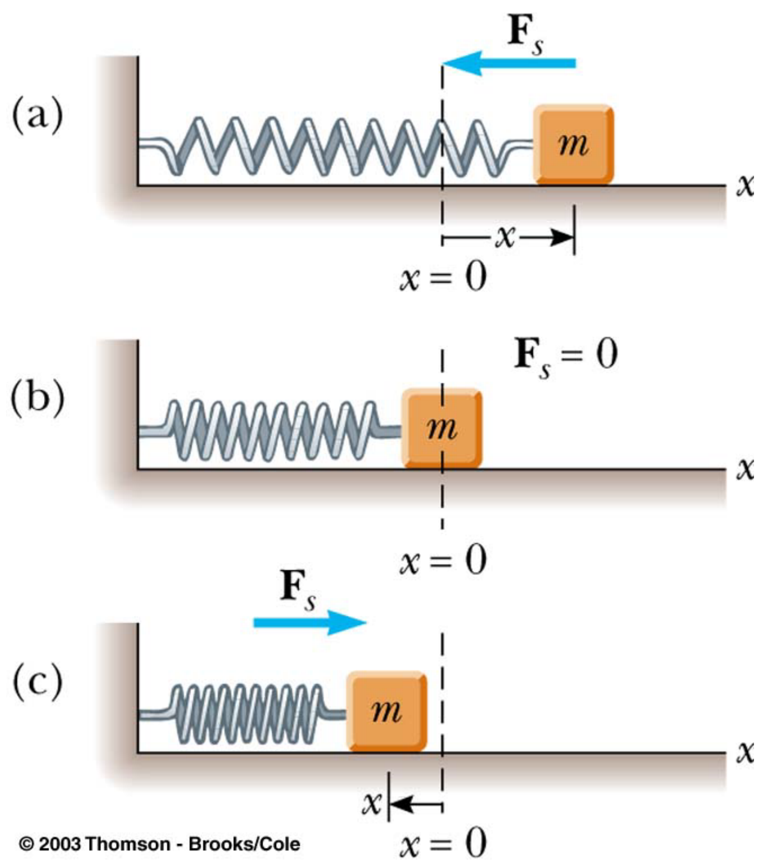
- $F_s = -k\,x$
  - F_s is the spring force
  - k is the spring constant
    - It is a measure of the stiffness of the spring
      - A large k indicates a stiff spring and a small k indicates a soft spring
  - x is the displacement of the object from its equilibrium position
  - The negative sign indicates that the force is always directed opposite to the displacement

Hooke's Law Force

- The force always acts toward the equilibrium position
  - It is called the *restoring force*
- The direction of the restoring force is such that the object is being either pushed or pulled toward the equilibrium position
- F is in the opposite direction of x

Hooke's Law Applied to a Spring – Mass System

- When x is positive (to the right), F is negative (to the left)
- When x = 0 (at equilibrium), F is 0
- When x is negative (to the left), F is positive (to the right)



Motion of the Spring-Mass System

- Assume the object is initially pulled to x = A and released from rest
- As the object moves toward the equilibrium position, F and a decrease, but v increases
- At x = 0, F and a are zero, but v is a maximum
- The object's momentum causes it to overshoot the equilibrium position
- The force and acceleration start to increase in the opposite direction and velocity decreases
- The motion continues indefinitely

Simple Harmonic Motion

- Motion that occurs when the net force along the direction of motion is a Hooke's Law type of force
  - The force is proportional to the displacement and in the opposite direction
- The motion of a spring mass system is an example of Simple Harmonic Motion
- Not all periodic motion over the same path can be considered Simple Harmonic motion
- To be Simple Harmonic motion, the force needs to obey Hooke's Law

Amplitude

- Amplitude, A
  - The amplitude is the maximum position of the object relative to the equilibrium position
  - In the absence of friction, an object in simple harmonic motion will oscillate between $\pm A$ on each side of the equilibrium position

Period and Frequency

- The period, T, is the time that it takes for the object to complete one complete cycle of motion
  - From x = A to x = - A and back to x = A
- The frequency, *f*, is the number of complete cycles or vibrations per unit time

$$T = \frac{1}{f}$$

Simple Harmonic Motion of a Spring System

- Period $T = 2\pi\sqrt{\frac{m}{k}}$
  - This gives the time required for an object of mass m attached to a spring of constant k to complete one cycle of its motion
- Frequency $f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
  - Units are cycles/second or Hertz, Hz

Acceleration of an Object in Simple Harmonic Motion

- Newton's second law will relate force and acceleration
- The force is given by Hooke's Law
- $F = - k x = m a$
  - $a = -kx / m$
- The acceleration is a function of position
  - Acceleration is *not* constant and therefore the uniformly accelerated motion equation cannot be applied

Velocity as a Function of Position

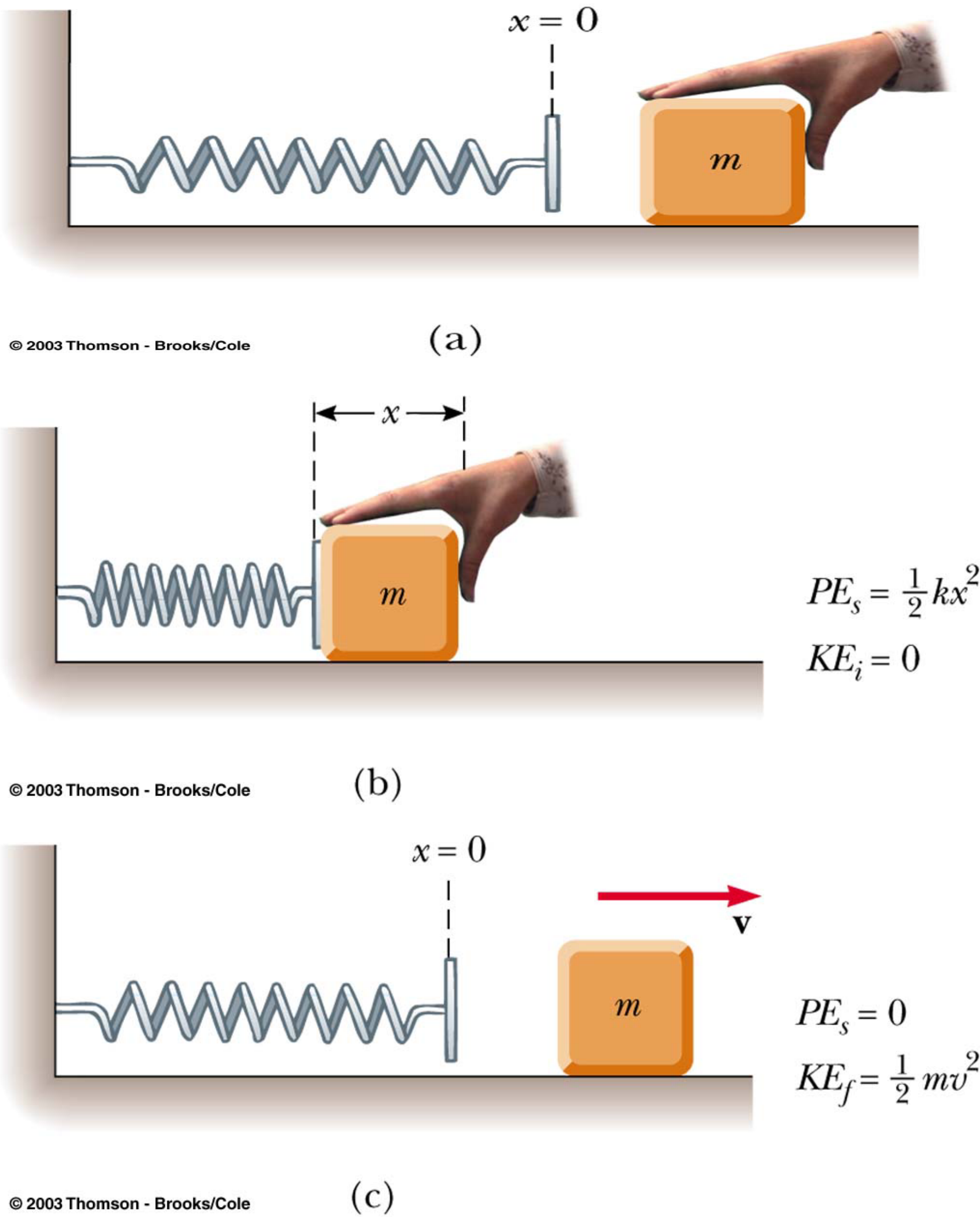
- Conservation of Energy allows a calculation of the velocity of the object at any position in its motion

$$v = \pm\sqrt{\frac{k}{m}\left(A^2 - x^2\right)}$$

  - Speed is a maximum at x = 0
  - Speed is zero at x = ±A
  - The ± indicates the object can be traveling in either direction

Work of Spring

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

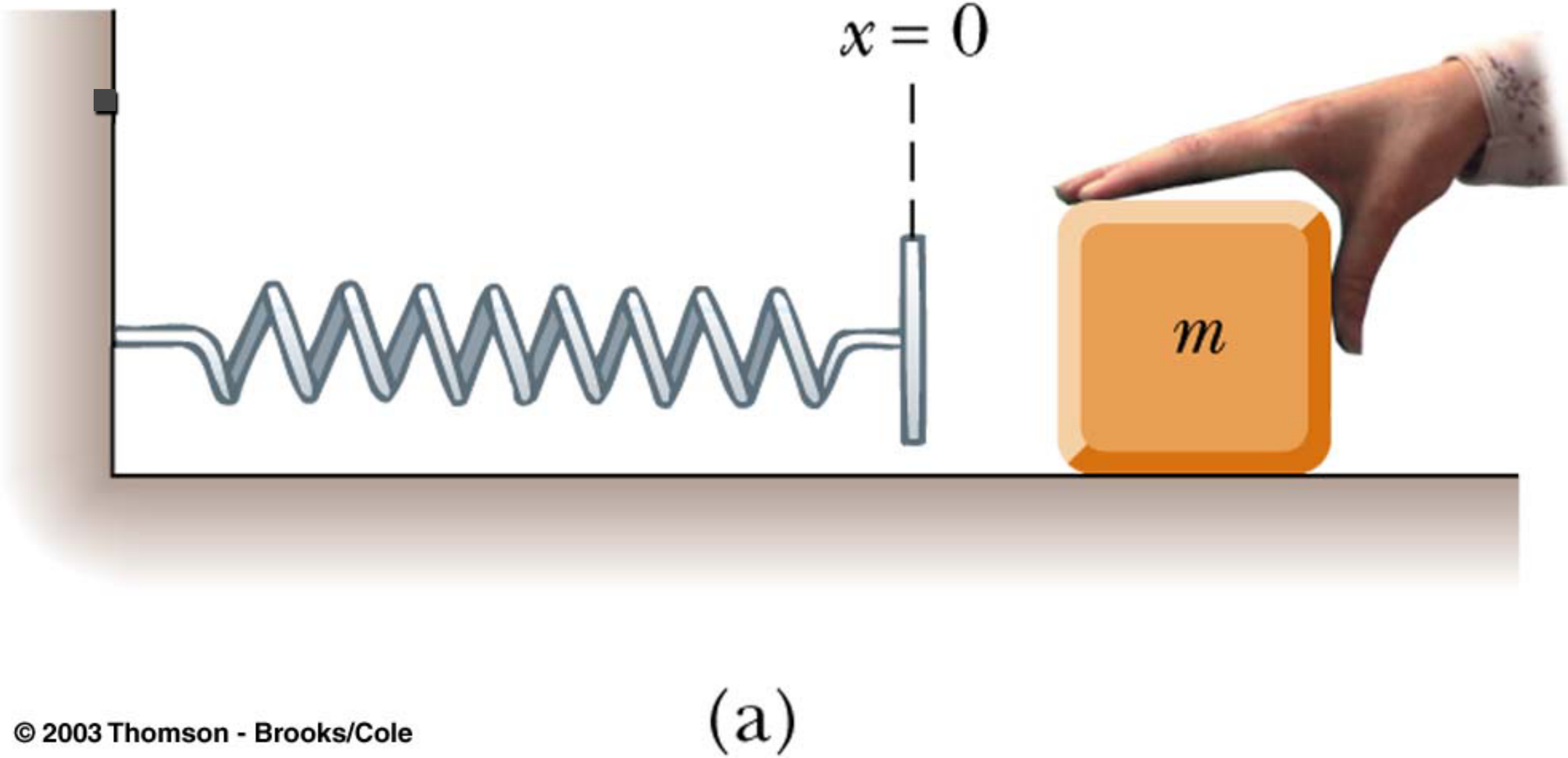


Elastic Potential Energy

- A compressed spring has potential energy
  - The compressed spring, when allowed to expand, can apply a force to an object
  - The potential energy of the spring can be transformed into kinetic energy of the object
- The energy stored in a stretched or compressed spring or other elastic material is called *elastic potential energy*
  - $Pe_s = ½kx^2$
- The energy is stored only when the spring is stretched or compressed
- Elastic potential energy is added to the statements of Conservation of Energy

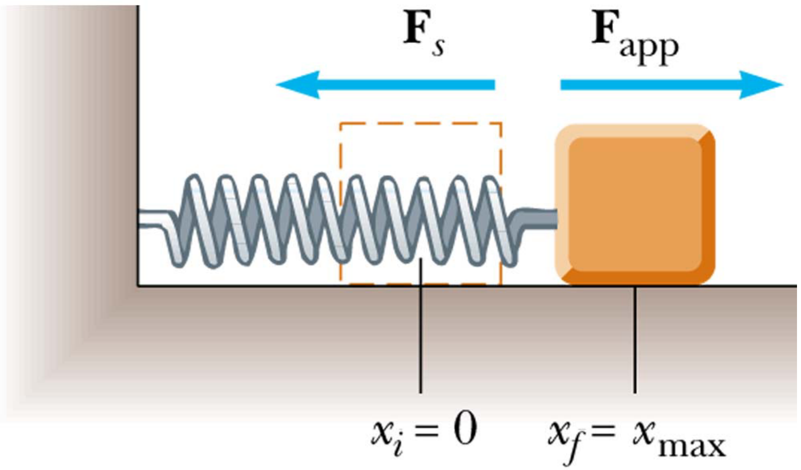
Potential Spring Energy Example 1

- Elastic Potential Energy
  - If you compress as spring with spring constant 4 N/M, 50 cm how much energy is stored?



Potential Spring Energy Example 2

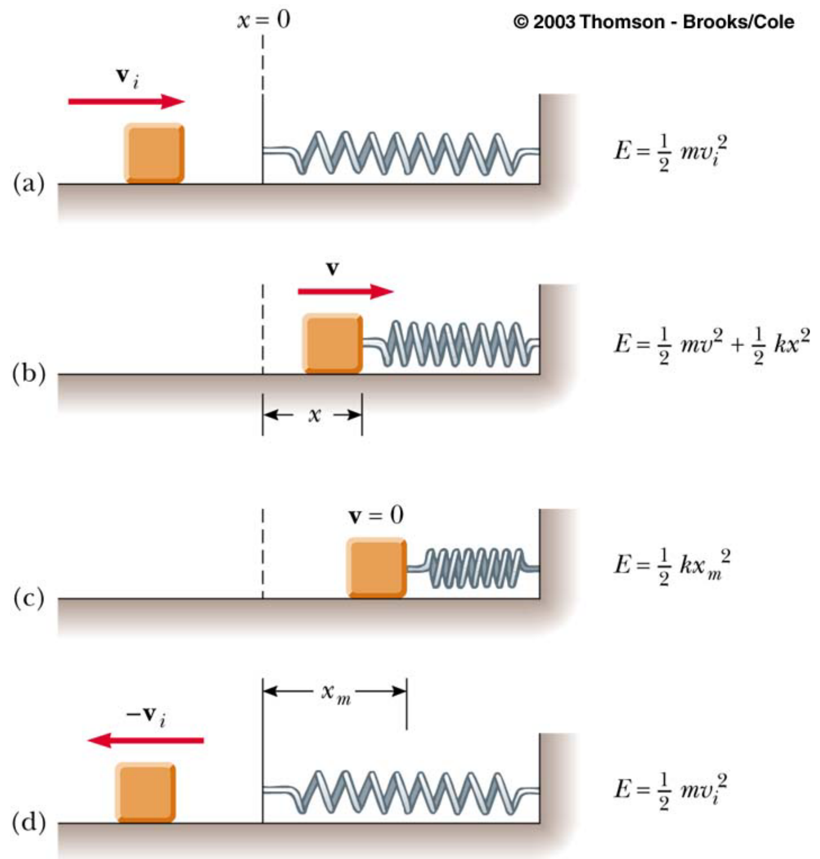
- Spring is slowly stretched from 0 to x_{max}
- $F_{applied} = -F_{restoring} = kx$
- $w = \frac{1}{2}kx^2$



- **If 500 J of work is done on a 40 N/m spring what force needed to be applied?**

Energy Transformation in a Spring Mass System

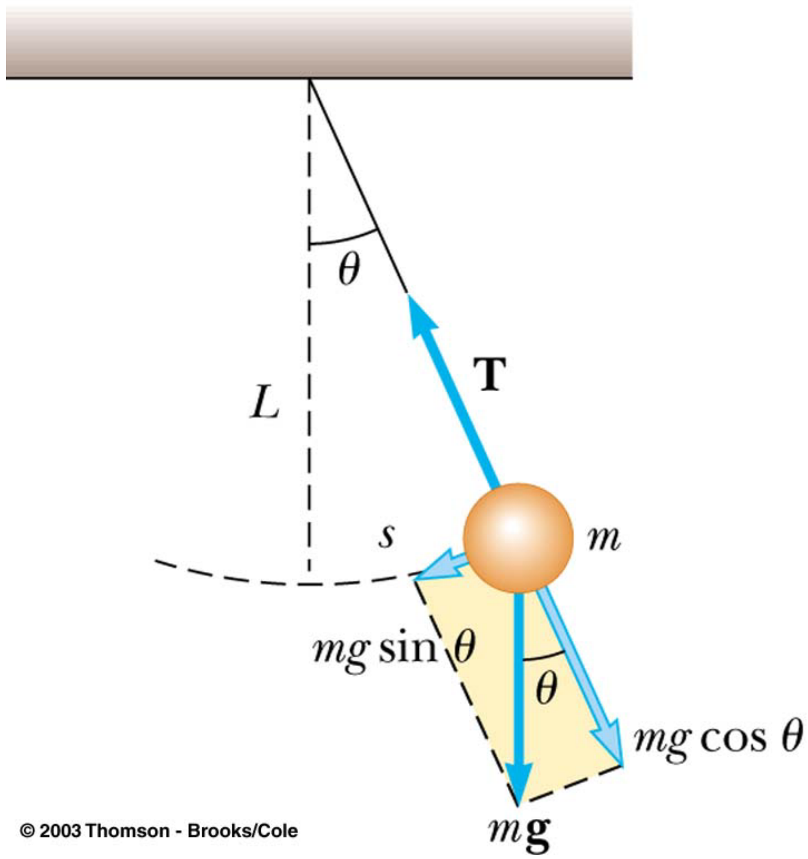
- A block sliding on a frictionless system collides with a light spring Energy is transferred.



$$(KE + PE_g + PE_s)_i = (KE + PE_g + PE_s)_f$$

Simple Pendulum (Less than 15 degrees)

- The simple pendulum is another example of simple harmonic motion
- The force is the component of the weight tangent to the path of motion
  - $F = - m\, g \sin \theta$



Simple Pendulum, cont

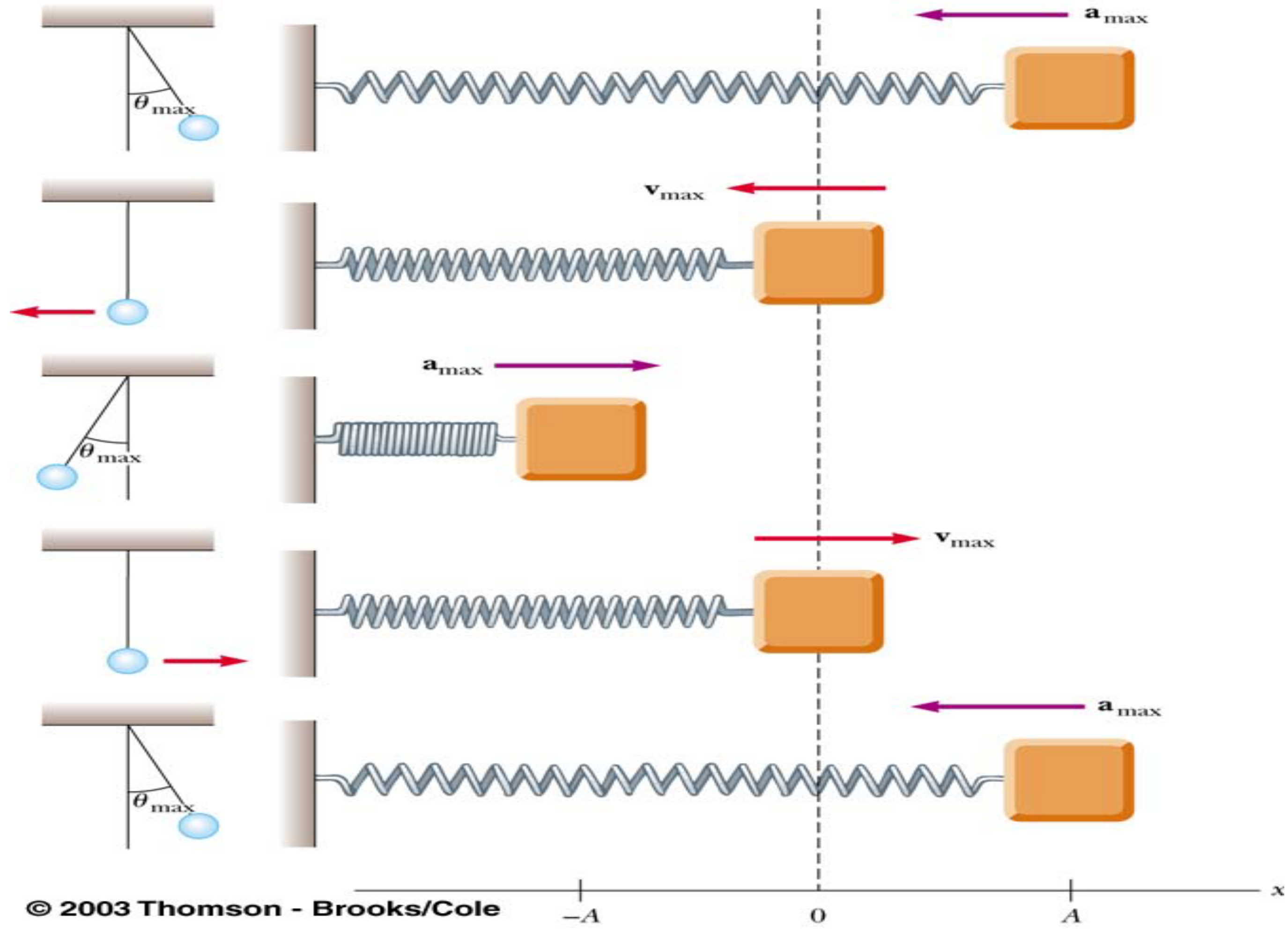
- In general, the motion of a pendulum is not simple harmonic
- However, for **small angles**, it becomes simple harmonic
  - In general, angles < 15° are small enough
  - $\sin \theta = \theta$
  - $F = - m g \theta$
    - This force obeys Hooke's Law

Period of Simple Pendulum

$$T = 2\pi\sqrt{\frac{L}{g}}$$

- This shows that the period is independent of of the amplitude
- The period depends on the length of the pendulum and the acceleration of gravity at the location of the pendulum
- Examples of Largers angles can be seen at
  - http://en.wikipedia.org/wiki/Pendulum_(mathematics)
  - http://en.wikipedia.org/wiki/Pendulum

Simple Pendulum Compared to a Spring-Mass System

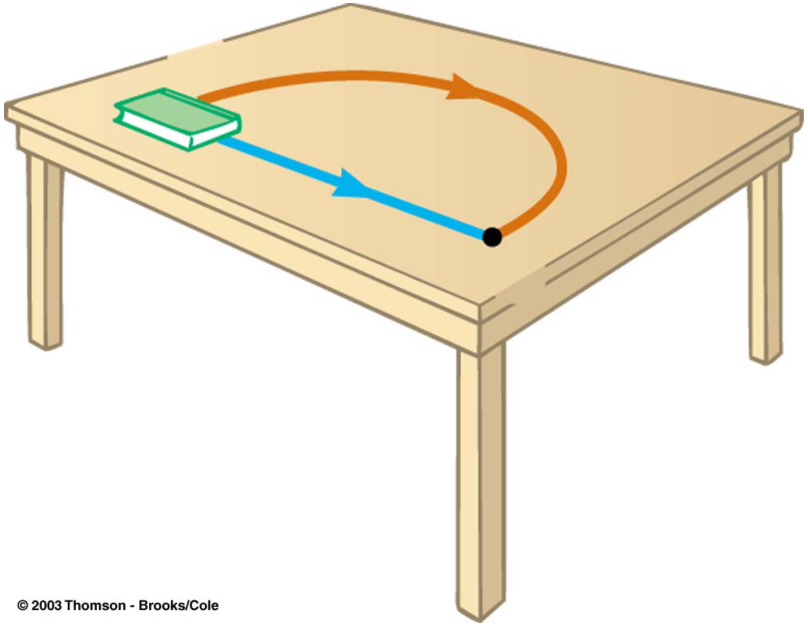


Nonconservative Forces

- 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
- 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

- 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 nonconservative force



Conservative Forces

- 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

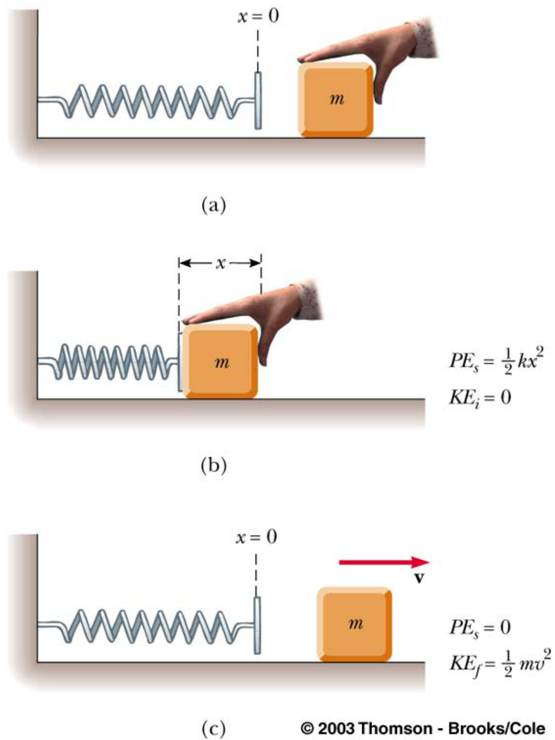
- Examples of conservative forces include:
  - Gravity
  - Spring force
  - Electromagnetic forces

Nonconservative Forces with Energy Considerations

- When nonconservative forces are present, the total mechanical energy of the system is *not* constant
  - That is energy is lost from the system to the environment.

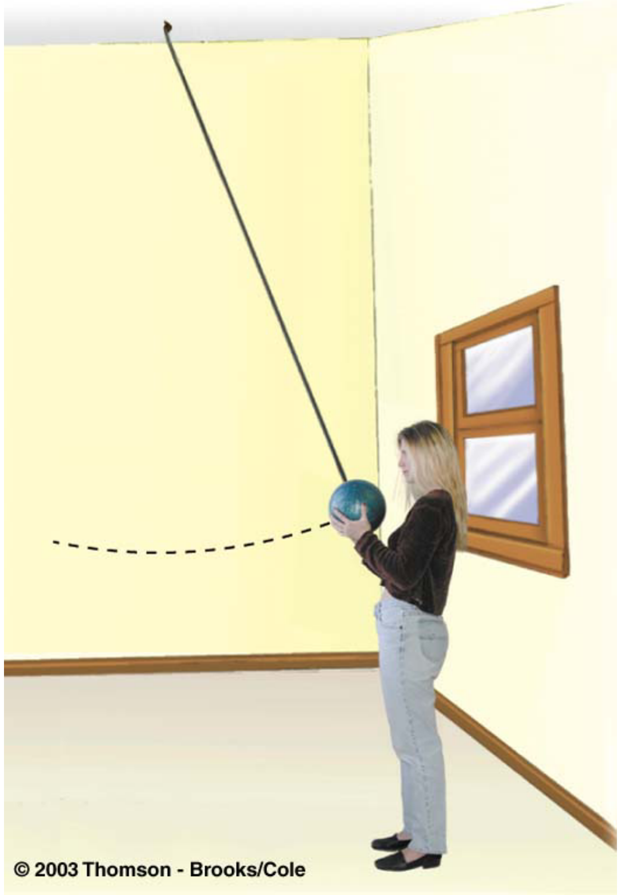
Nonconservation of Energy Example 1

A 4kg block is compressed 0.25 meters on a spring that has a spring constant of 60 N/m. The coefficient of friction is 0.15. How much energy does the system have by the time it is elongated 0.05 meters. Will it reach an elongation of 0.25?



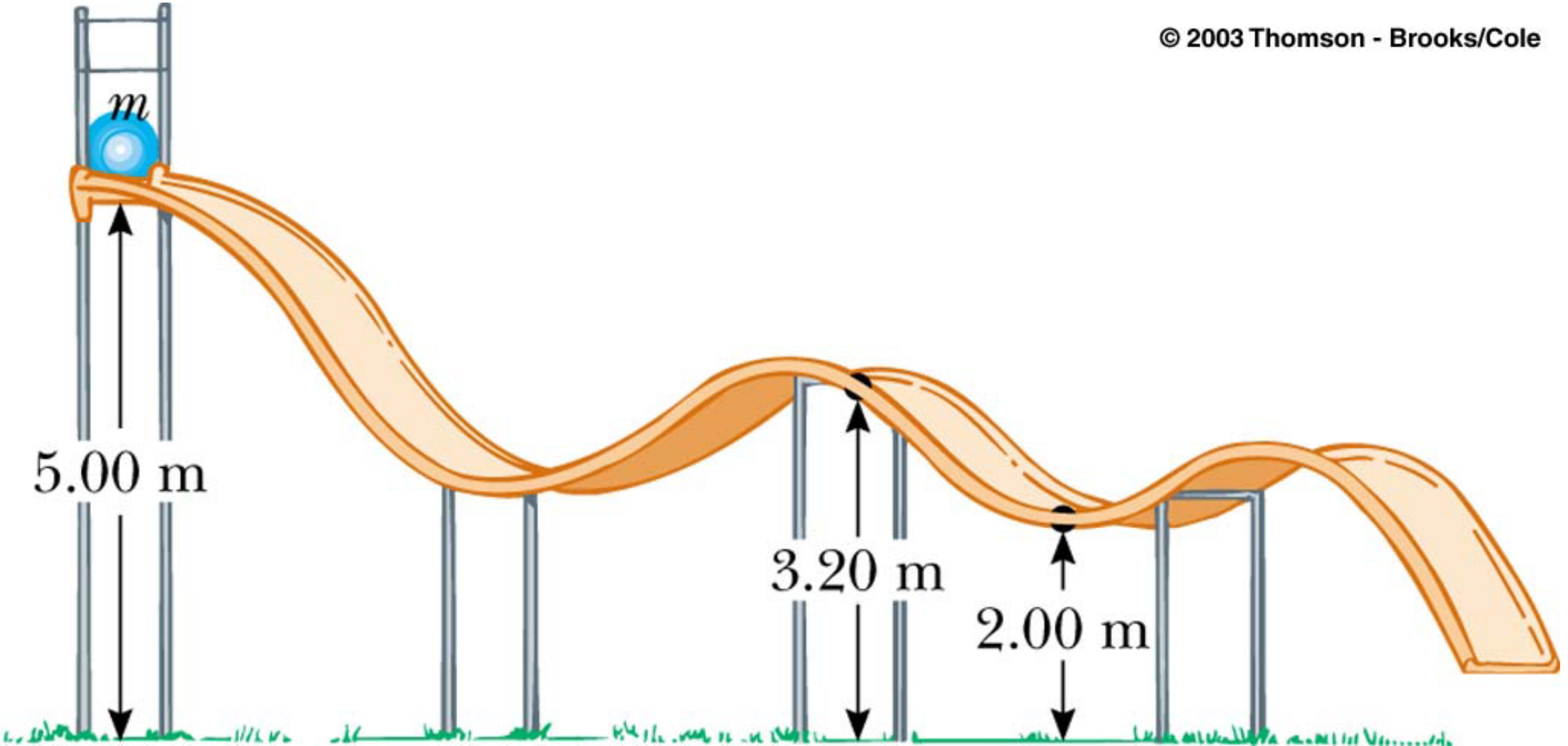
Nonconservation of Energy Example 2

A 5kg bowling ball is release from 1.5 meters above the ground while touching the ladies chin. If she doesn't move, will it come back and hit her?



Nonconservation of Energy Example 3

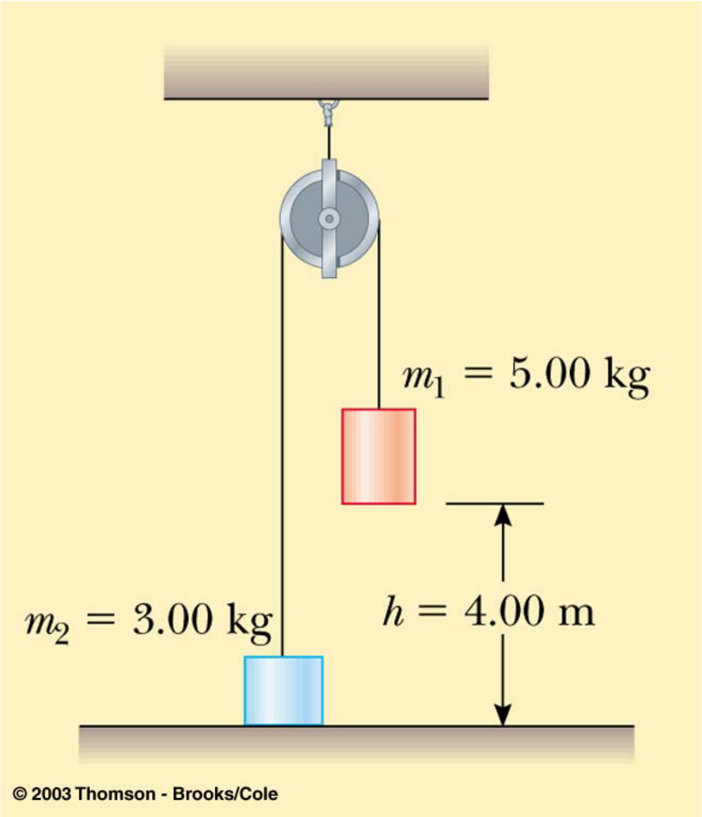
A ball of mass 3.25kg is released from the top of a 5m high ramp. If the track the ball rolls on is 4 meters and the coefficient of friction is .18, what is the velocity of the ball as it hits the ground?



Nonconservation of Energy Example 4

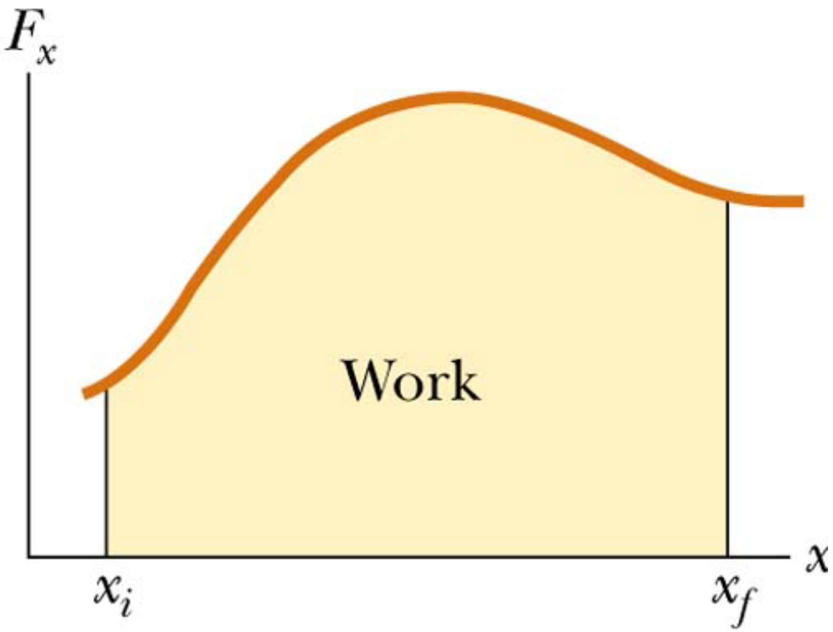
The air resistance provided a force of 10N.

What is the kinetic energy gained by the red block? What is the potential energy gained by the blue block?

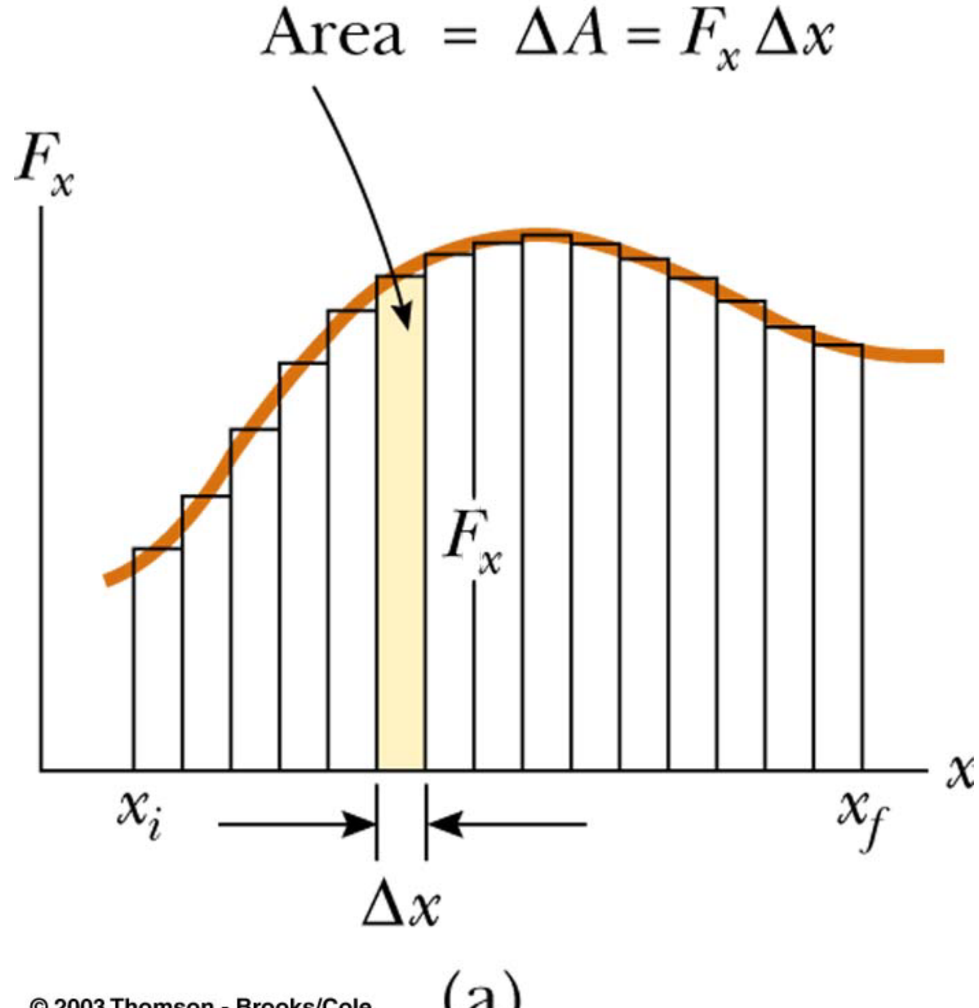


Work Done by Varying Forces

- 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

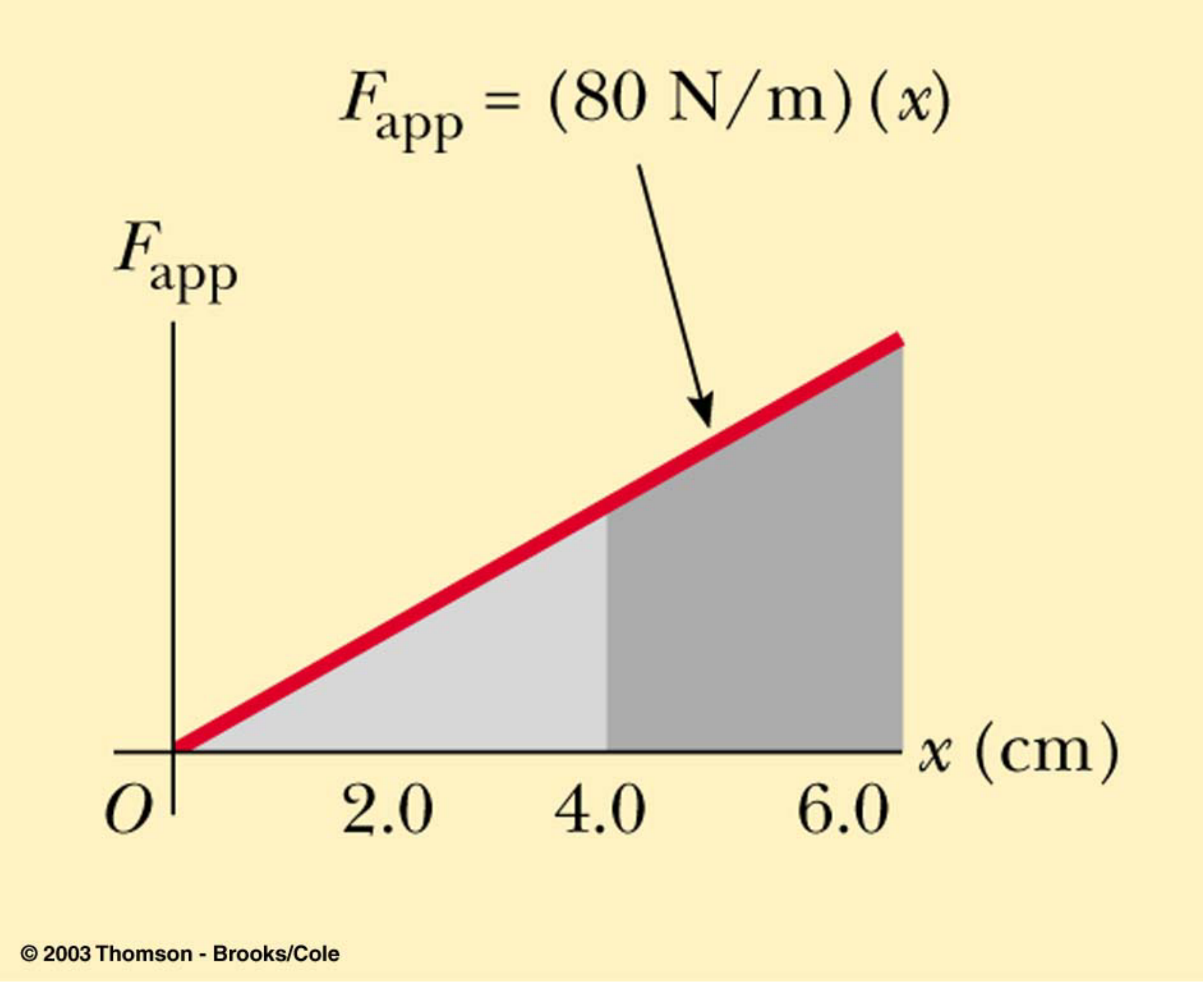


Calculation Method



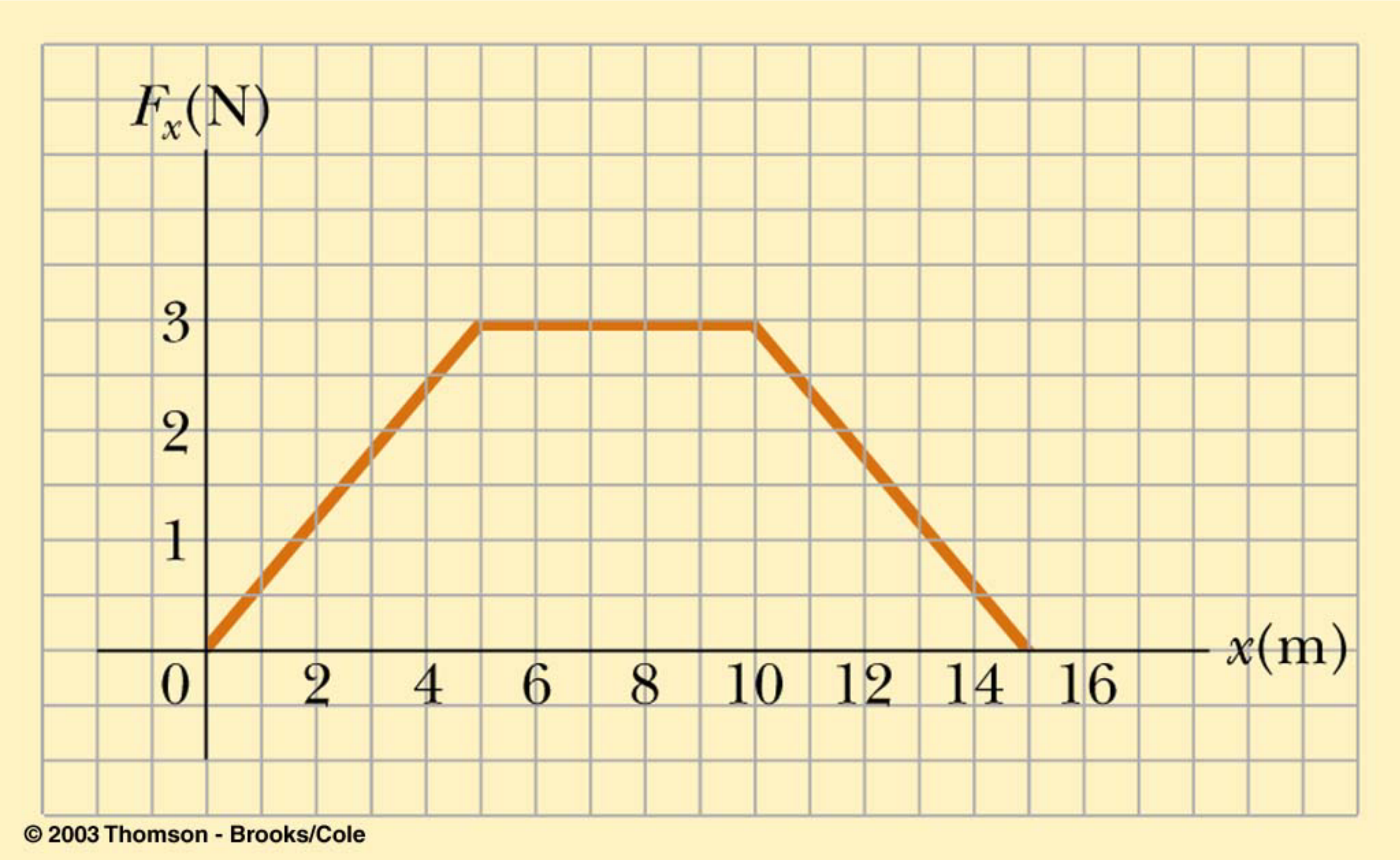
Work done by varying forces example 1

How much work was done?



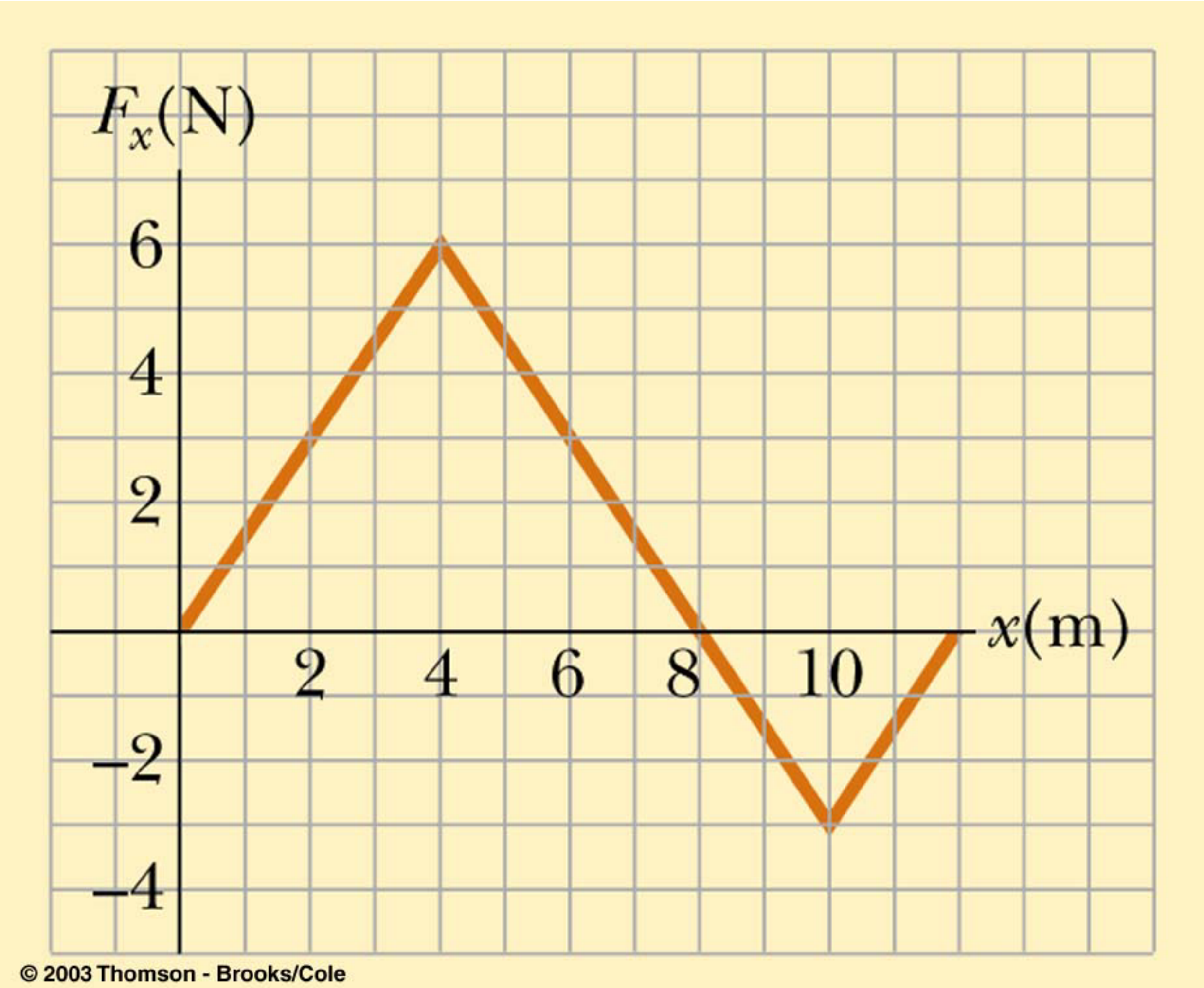
Work done by varying forces example 2

How much work was done?



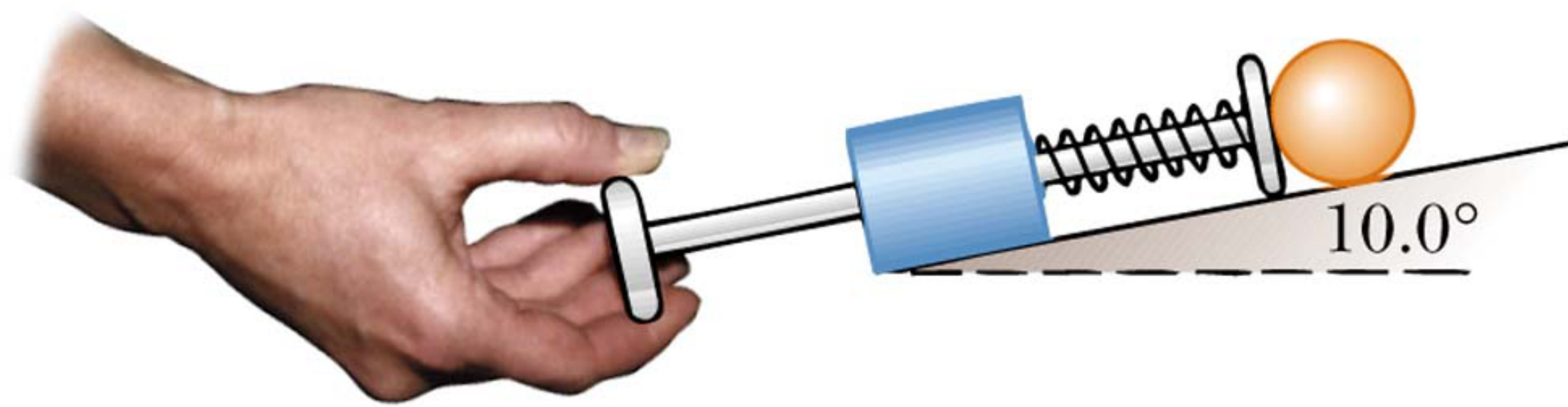
Work done by varying forces example 3

How much work was done?



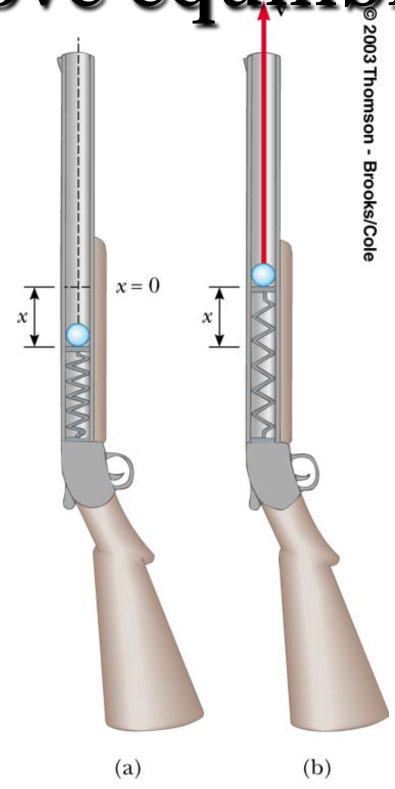
Work done by varying forces example 4

A 10 kg ball rolls from the top of 2 meter incline drawn below. The ball comes in contact with the spring 10cm up the incline. If the spring constant is 400 N/M how much does the spring get compressed.



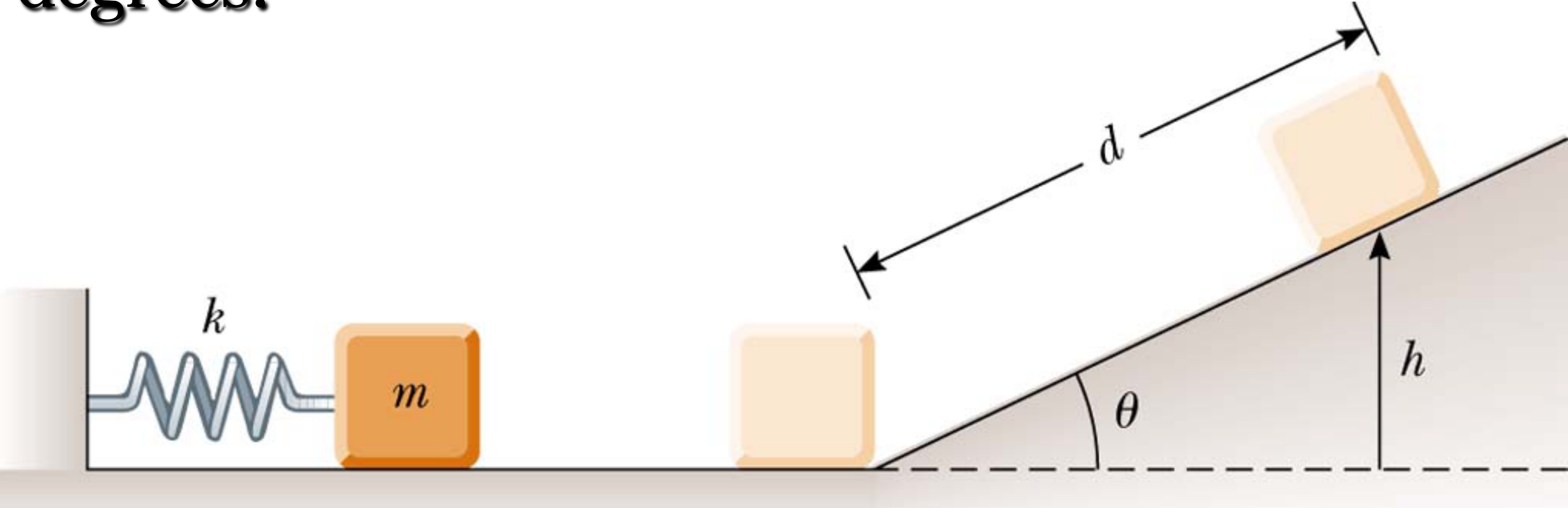
Work done by varying forces example 5

A 500 g ball if fired vertically out of a toy gun. The spring has a spring constant of 200 N/m. If the spring is compressed 10cm. How high does the ball travel above equilibrium point?



Work done by varying forces example 5

A 5 kg block is compressed 15cm on a spring that has a spring constant of 250 N/m. How far up the incline does the block travel is there is no friction and the incline has an angle for 20 degrees.



Work done by varying forces example 6

A 20 kg block is released from 1m and lands on a spring with force constant 400N/M. How much is the spring compressed before it starts to move the block back up?