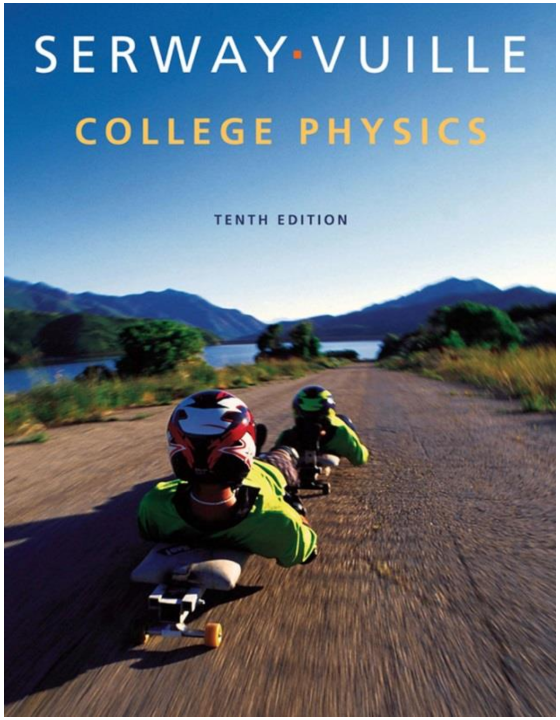

CENGAGE Learning

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Chapter 5

Energy

Forms of Energy

- Mechanical
  - Focus for now
  - May be kinetic (associated with motion) or potential (associated with position)
- Chemical
- Electromagnetic
- Nuclear
- Contained in mass

Some Energy Considerations

- Energy can be transformed from one form to another
  - The total amount of energy in the Universe never changes
  - 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 provides a link between force and energy

Work

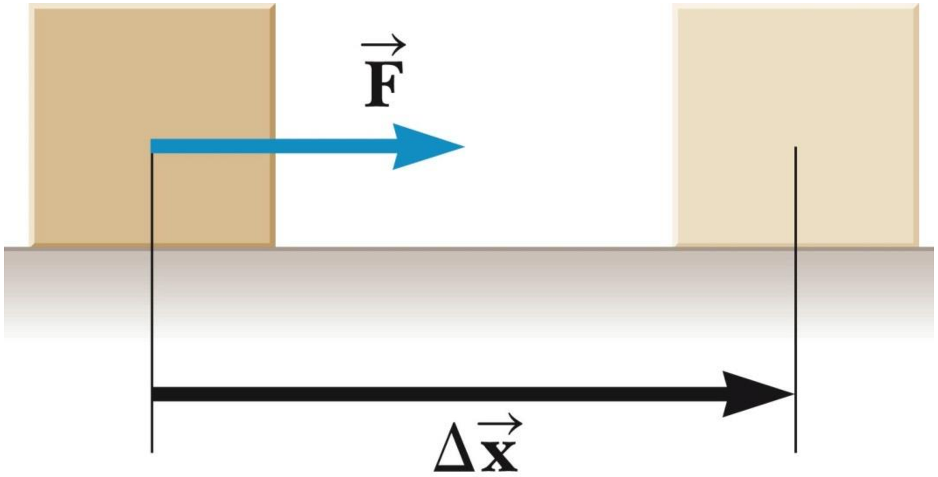
- Work has a different meaning in physics than it does in everyday usage
- The work, *W*, done by a constant force during a linear displacement along the x-axis is

$$W = F_x \, \Delta x$$

- F_x is the x-component of the force and Δx is the object's displacement

Work

- $W = F \Delta x$
  - This equation applies when the force is in the same direction as the displacement
  - $\vec{F}$ and $\Delta\vec{x}$ are in the same direction



Work, cont.

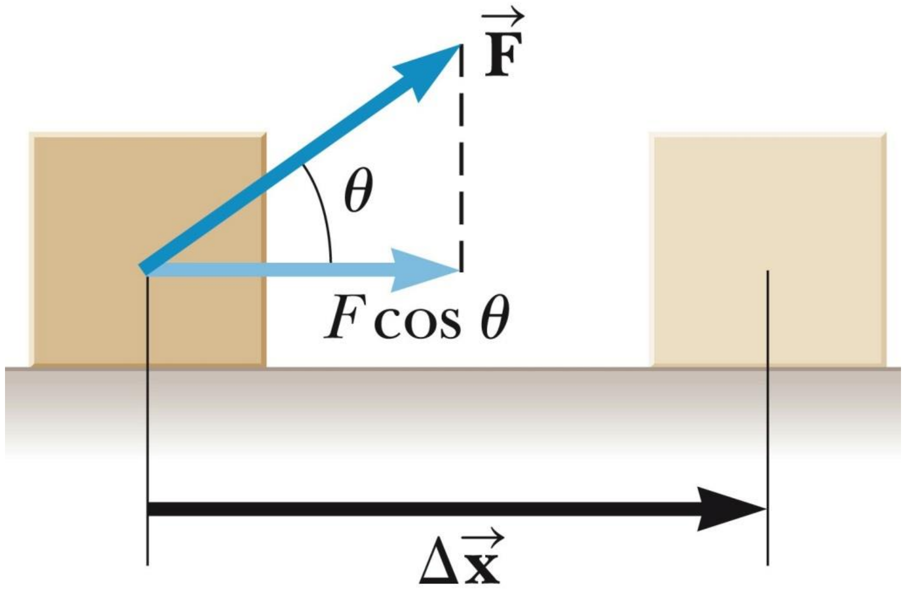
- This gives no information about
  - The time it took for the displacement to occur
  - The velocity or acceleration of the object
- Work is a scalar quantity
  - So there is no direction associated with it

Units of Work

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

Work General

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



More About Work

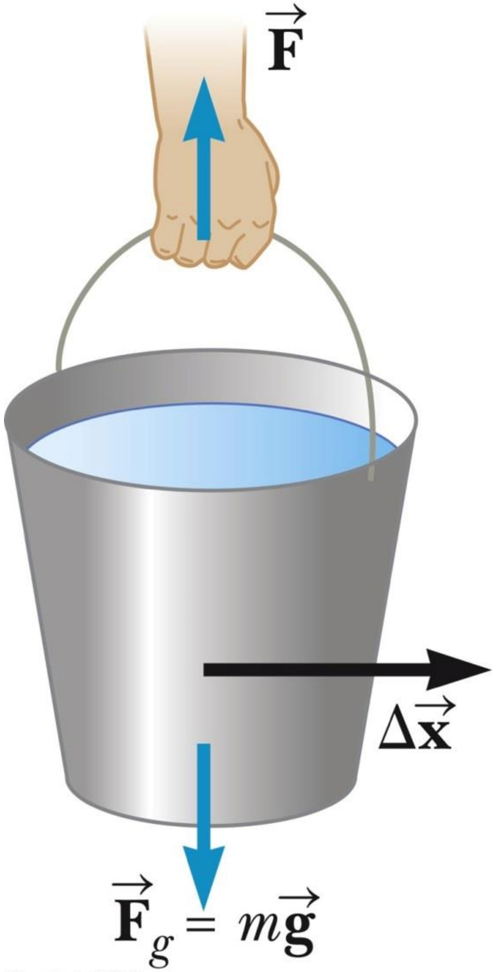
- The work done by a force is zero when the force is perpendicular to the displacement
  - $\cos 90^\circ = 0$
- If there are multiple forces acting on an object, the total work done is the algebraic sum of the amount of work done by each force

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

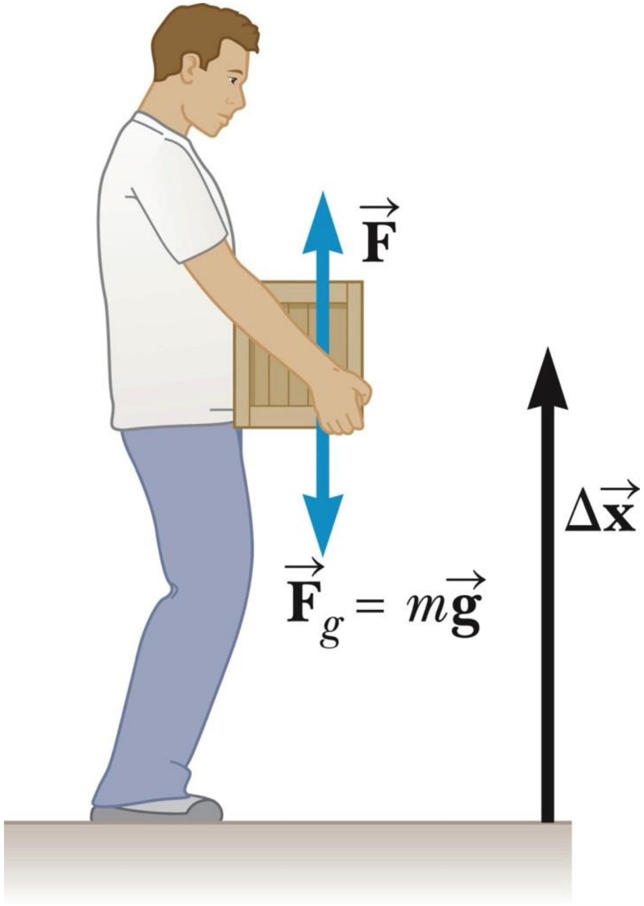
When Work is Zero

- Displacement is horizontal
- Force is vertical
- cos 90° = 0
- W = 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



Work, Final

- Work doesn't happen by itself
- Work is done *by* something in the environment, *on* the object of interest
- The forces are constant in the equations used so far
  - Varying force will be discussed later

Kinetic Energy

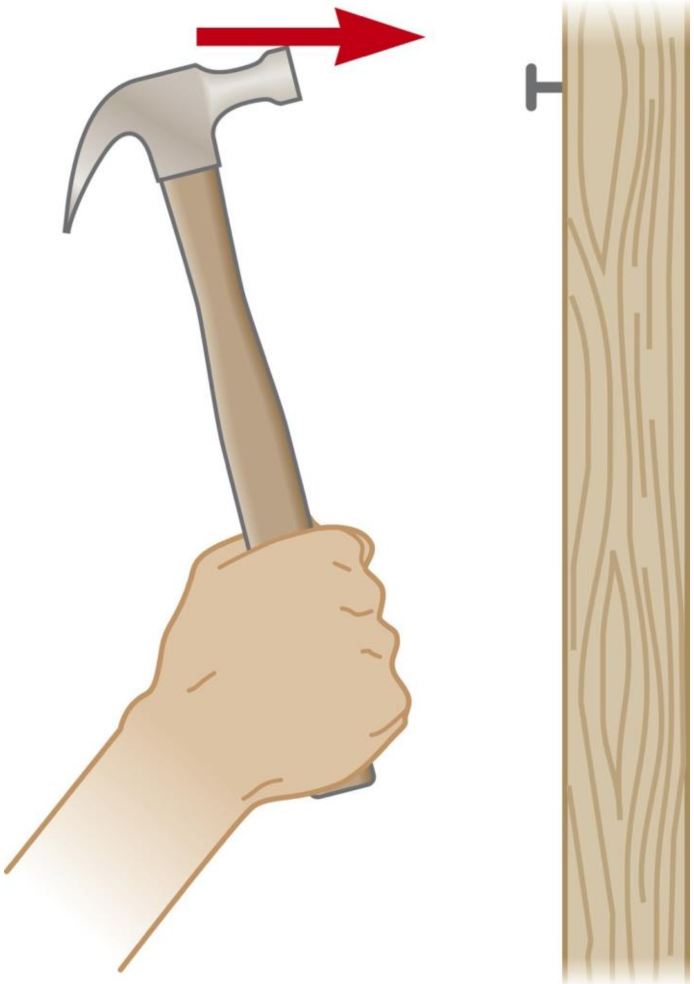
- Energy associated with the motion of an object of mass *m* moving with a speed *v*
- $KE = \frac{1}{2}mv^2$
- Scalar quantity with the same units as work
- Work is related to kinetic energy

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 the net work is positive
  - Speed will decrease if the net 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



Types of Forces

- 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

- 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

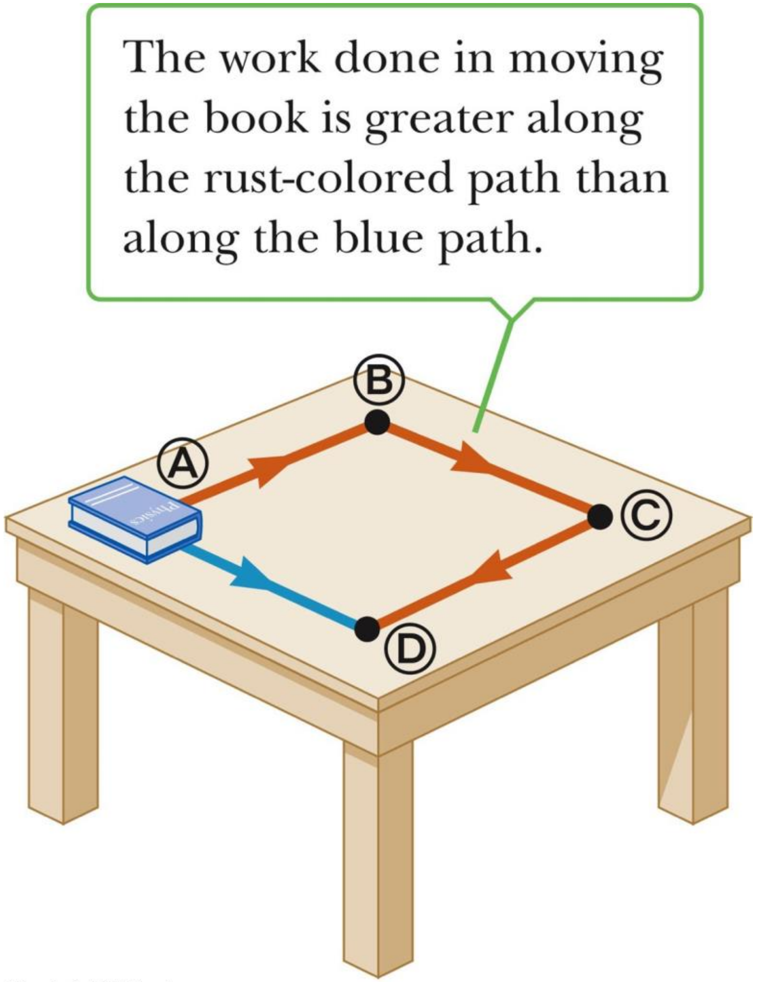
- Examples of conservative forces include:
  - Gravity
  - Spring force
  - Electromagnetic forces
- Potential energy is another way of looking at the work done by conservative forces

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

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 non-conservative force



Work-Energy Theorem Revisited

- The theorem can be expressed in terms of the work done by both conservative forces, W_c, and nonconservative forces, W_{nc}
- $W_c + W_{nc} = \Delta KE$

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 interacting via forces or processes that are internal to the system

Work and Potential Energy

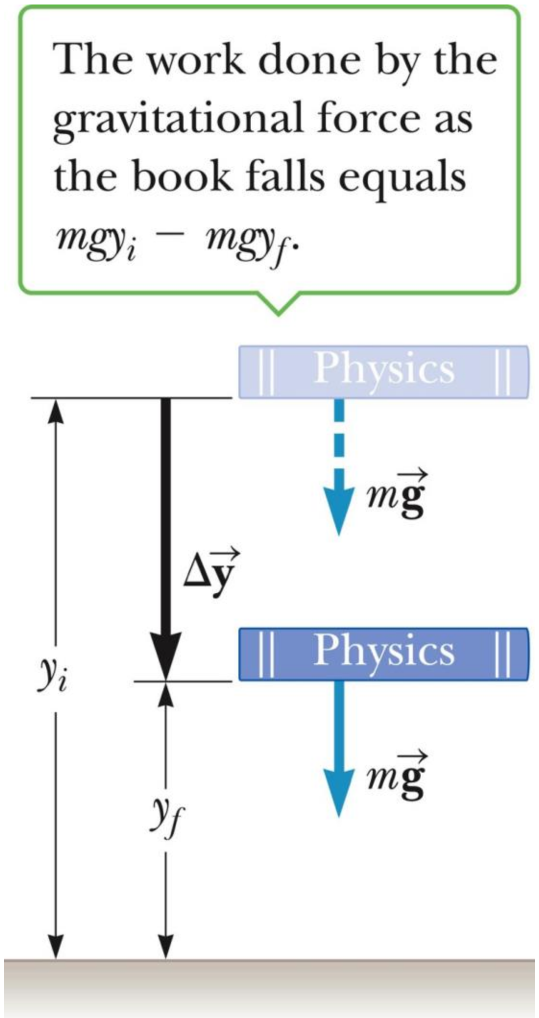
- For every conservative force a potential energy function can be found
- Evaluating the difference of the function at any two points in an object's path gives the negative of the work done by the force between those two points

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
- $W_{gravity} = -mg(y_f - y_i)$
- Units of Potential Energy are the same as those of Work and Kinetic Energy
  - Joule (J)



Work-Energy Theorem, Extended

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

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

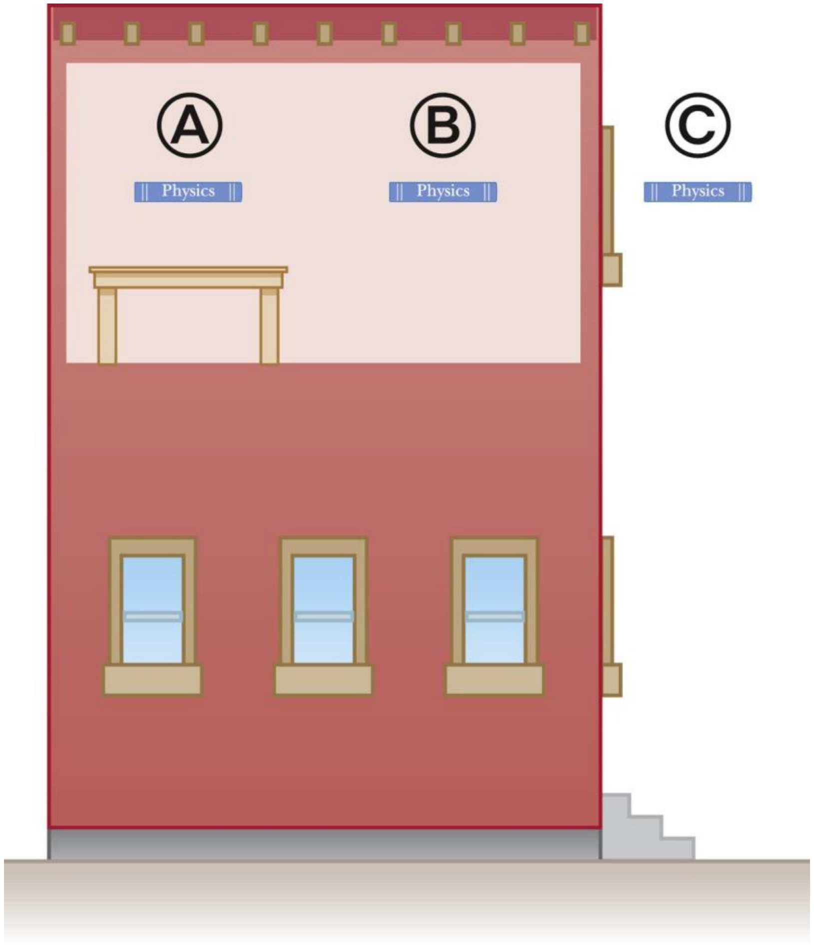
- If other conservative forces are present, potential energy functions can be developed for them and their change in that potential energy added to the right side of the equation

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
  - Once the position is chosen, it must remain fixed for the entire problem
  - Choose a convenient location for the zero reference height
    - Often the Earth's surface
    - May be some other point suggested by the problem

Reference Levels, cont

- At location A, the desk may be the convenient reference level
- At location B, the floor could be used
- At location C, the ground would be the most logical reference level
- The choice is arbitrary, though



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, although the quantities may change form
- 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
  - Include all interacting bodies
  - Verify the absence of nonconservative forces
- Select the location of zero gravitational potential energy, where $y = 0$
  - Do not change this location while solving the problem
- Select the body of interest and identify two points
  - One point should be where information is given
  - The other point should be where you want to find out something

Problem Solving, cont

- Apply the conservation of energy equation to the system
  - Identify the unknown quantity of interest
  - Immediately substitute zero values, then do the algebra before substituting the other values
- Solve for the unknown
  - Typically a speed or a position
  - Substitute known values
  - Calculate result

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
  - Do not include both work done by gravity and gravitation potential energy
- Often techniques from previous chapters will need to be employed

Potential Energy Stored in a Spring

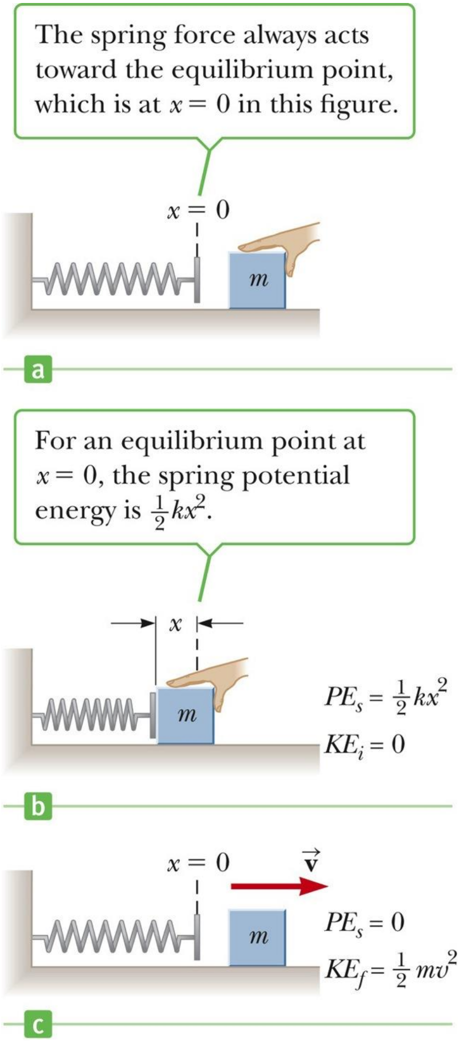
- The force used in stretching or compressing a spring is a conservative force
- Involves the *spring constant*, k
- Hooke's Law gives the force
  - $F_s = - k x$
    - F_s is the restoring force
    - F_s is in the opposite direction of x
    - k depends on how the spring was formed, the material it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

Potential Energy in a Spring

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

Spring Potential Energy, Example

- A) The spring is in equilibrium, neither stretched or compressed
- B) The spring is compressed, storing potential energy
- C) The block is released and the potential energy is transformed to kinetic energy of the block



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

- $W_{nc} = 0$
- An extended form of conservation of mechanical energy can be used
  - 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
  - Also need to define the equilibrium position of the spring

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:

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

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

- The energy can either cross a boundary or the energy is transformed into a form of non-mechanical energy such as thermal energy
  - If positive work is done on the system, energy is transferred from the environment to the system
  - If negative work is done on the system, energy is transferred from the system to the environment

Transferring Energy

- By Work
  - By applying a force
  - Produces a displacement of the system
- Heat
  - The process of transferring heat by microscopic collisions between atoms or molecules
  - For example, when a spoon rests in a cup of coffee, 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
- 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
  - Examples
    - Cooking something in your microwave oven
    - Light energy traveling from the Sun to the Earth

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

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

Instantaneous Power

- P = F v
  - Both the force and the velocity must be parallel
  - They can change with time

Power Units

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

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

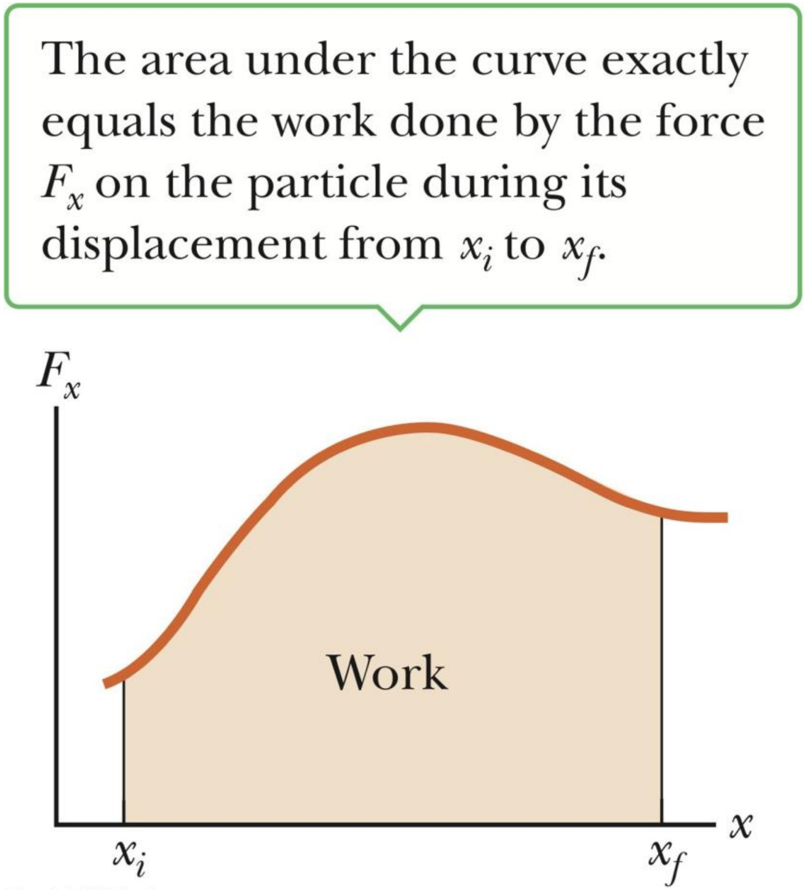
  - Can define units of work or energy in terms of units of power:
    - kilowatt hours (kWh) are often used in electric bills
    - This is a unit of energy, not power

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

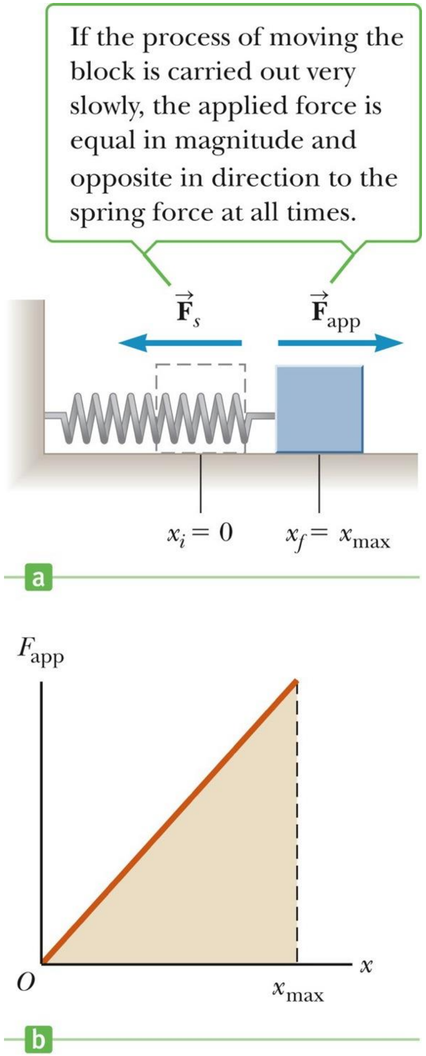
Work Done by Varying Forces

- 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_x versus x



Spring Example

- Spring is slowly stretched from 0 to x_{max}
- $\vec{F}_{applied} = -\vec{F}_s = kx$
- $$W = \frac{1}{2}kx_{max}^2$$



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 $k(x_{max})^2$ and W = PE