

# Chapter 8

Conservation of Energy

# Energy Review

## Kinetic Energy

- Associated with movement of members of a system

## Potential Energy

- Determined by the configuration of the system
- Gravitational and Elastic Potential Energies have been studied

## Internal Energy

- Related to the temperature of the system

# Types of Systems

## Non-isolated systems

- Energy can cross the system boundary in a variety of ways.
- Total energy of the system changes

## Isolated systems

- Energy does not cross the boundary of the system
- Total energy of the system is constant

## Conservation of energy

- Can be used if no non-conservative forces act within the isolated system
- Applies to biological organisms, technological systems, engineering situations, etc

## Ways to Transfer Energy Into or Out of A System

In non-isolated systems, energy crosses the boundary of the system during some time interval due to an interaction with the environment.

**Work** – transfers energy by applying a force and causing a displacement of the point of application of the force.

**Mechanical Wave** – transfers energy by allowing a disturbance to propagate through a medium.

**Heat** – the mechanism of energy transfer that is driven by a temperature difference between two regions in space.

**Matter Transfer** – matter physically crosses the boundary of the system, carrying energy with it.

**Electrical Transmission** – energy transfer into or out of a system by electric current.

**Electromagnetic Radiation** – energy is transferred by electromagnetic waves.

# Examples of Ways to Transfer Energy

Energy is transferred to the block by *work*.



a

Energy leaves the radio from the speaker by *mechanical waves*.



b

Energy transfers to the handle of the spoon by *heat*.



c

Energy enters the automobile gas tank by *matter transfer*.



d

Energy enters the hair dryer by *electrical transmission*.



e

Energy leaves the light-bulb by *electromagnetic radiation*.



f

# Conservation of Energy

## ***Energy is conserved***

- This means that energy cannot be created nor destroyed.
- If the total amount of energy in a system changes, it can only be due to the fact that energy has crossed the boundary of the system by some method of energy transfer.

## Conservation of Energy, cont.

Mathematically,  $\Delta E_{\text{system}} = \Sigma T$

- $E_{\text{system}}$  is the total energy of the system
- $T$  is the energy transferred across the system boundary by some mechanism
  - Established symbols:  $T_{\text{work}} = W$  and  $T_{\text{heat}} = Q$
  - Others just use subscripts

The primary mathematical representation of the energy version of the analysis model of the non-isolated system is given by the full expansion of the above equation.

- $\Delta K + \Delta U + \Delta E_{\text{int}} = W + Q + T_{\text{MW}} + T_{\text{MT}} + T_{\text{ET}} + T_{\text{ER}}$ 
  - $T_{\text{MW}}$  – transfer by mechanical waves
  - $T_{\text{MT}}$  – by matter transfer
  - $T_{\text{ET}}$  – by electrical transmission
  - $T_{\text{ER}}$  – by electromagnetic transmission

## Isolated System

For an isolated system,  $\Delta E_{\text{mech}} = 0$

- Remember  $E_{\text{mech}} = K + U$
- This is ***conservation of energy*** for an isolated system with no non-conservative forces acting.

If non-conservative forces are acting, some energy is transformed into internal energy.

Conservation of Energy becomes  $\Delta E_{\text{system}} = 0$

- $E_{\text{system}}$  is all kinetic, potential, and internal energies
- This is the most general statement of the isolated system model.



## Isolated System, cont.

The changes in energy can be written out and rearranged.

$$K_f + U_f = K_i + U_i$$

- Remember, this applies only to a system in which conservative forces act.

# Problem Solving Strategy – Conservation of Mechanical Energy for an Isolated System with No Non-conservative Forces

## Conceptualize

- Form a mental representation
- Imagine what types of energy are changing in the system

## Categorize

- Define the system
- It may consist of more than one object and may or may not include springs or other sources of storing potential energy.
- Determine if any energy transfers occur across the boundary of your system.
  - If there are transfers, use  $\Delta E_{\text{system}} = \Sigma T$
  - If there are no transfers, use  $\Delta E_{\text{system}} = 0$
- Determine if there are any non-conservative forces acting.
  - If not, use the principle of conservation of mechanical energy.

## Problem-Solving Strategy, 2

### Analyze

- Choose configurations to represent initial and final configuration of the system.
- For each object that changes elevation, identify the zero configuration for gravitational potential energy.
- For each object on a spring, the zero configuration for elastic potential energy is when the object is in equilibrium.
- If more than one conservative force is acting within the system, write an expression for the potential energy associated with each force.
- Write expressions for total initial mechanical energy and total final mechanical energy.
- Set them equal to each other.

## Problem-Solving Strategy, 3

### *Finalize*

- Make sure your results are consistent with your mental representation.
- Make sure the values are reasonable and consistent with everyday experience.

## Example – Ball in Free Fall

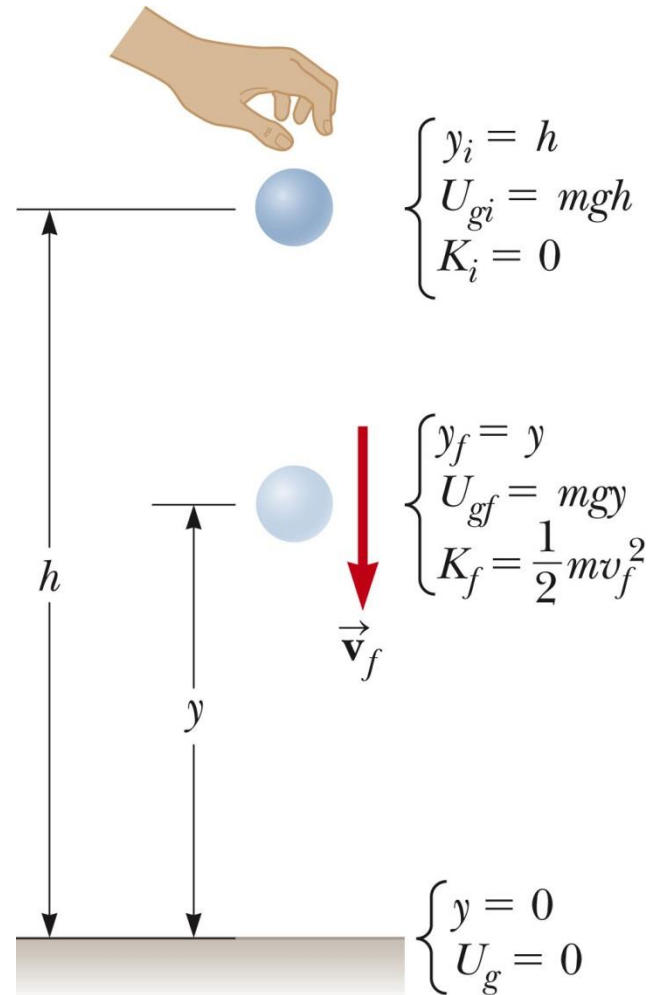
Determine the speed of the ball at a height  $y$  above the ground.

Conceptualize

- Use energy instead of motion

Categorize

- System is the ball and the Earth
- System is isolated
- Use the isolated system model
- Only force is gravitational which is conservative



## Example – Free Fall, cont.

### Analyze

- Apply the principle of Conservation of Mechanical Energy

- $K_f + U_{gf} = K_i + U_{gi}$

- $K_i = 0$ , the ball is dropped

- Solve for  $v_f$

$$v_f = \sqrt{2g(h-y)}$$

### Finalize

- The equation for  $v_f$  is consistent with the results obtained from the particle under constant acceleration model for a falling object.

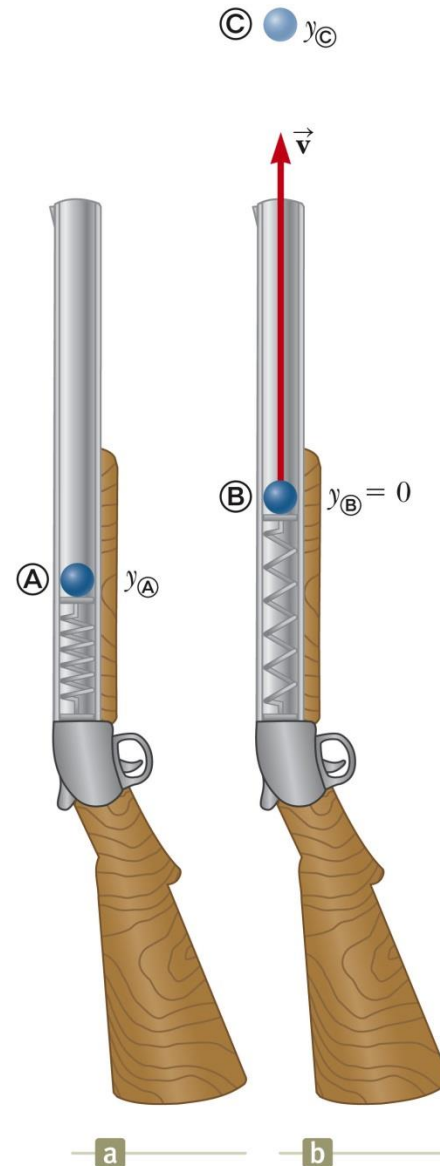
## Example – Spring Loaded Gun

### Conceptualize

- The projectile starts from rest.
- It speeds up as the spring pushes upward on it.
- As it leaves the gun, gravity slows it down.

### Categorize

- System is projectile, gun, and Earth
- Model as an isolated system with no non-conservative forces acting



## Example – Spring Gun, cont.

### Analyze

- Projectile starts from rest, so  $K_i = 0$ .
- Choose zero for gravitational potential energy where projectile leaves the spring.
- Elastic potential energy will also be 0 here.
- After the gun is fired, the projectile rises to a maximum height, where its kinetic energy is 0.

### Finalize

- Did the answer make sense?
- Note the inclusion of two types of potential energy.



## Example – Spring Gun, final

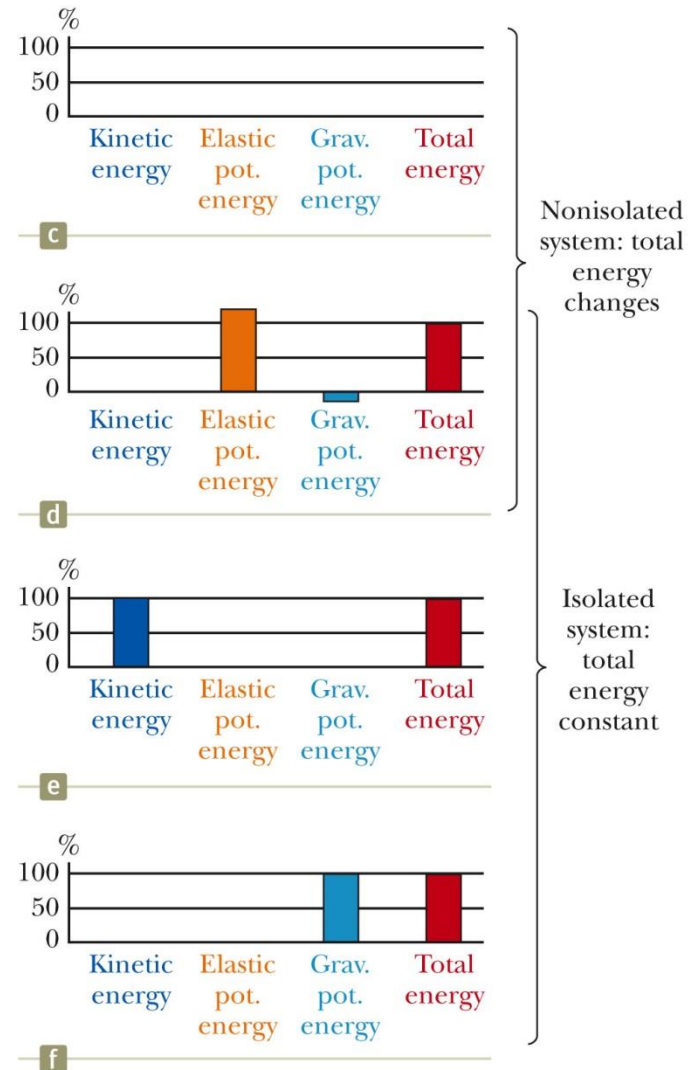
The energy of the gun-projectile-Earth system is initially zero.

The popgun is loaded by means of an external agent doing work on the system to push the spring downward.

After the popgun is loaded, elastic potential energy is stored in the spring and the gravitational potential energy is lower because the projectile is below the zero height.

As the projectile passes through the zero height, all the energy of the system is kinetic.

At the maximum height, all the energy is gravitational potential.



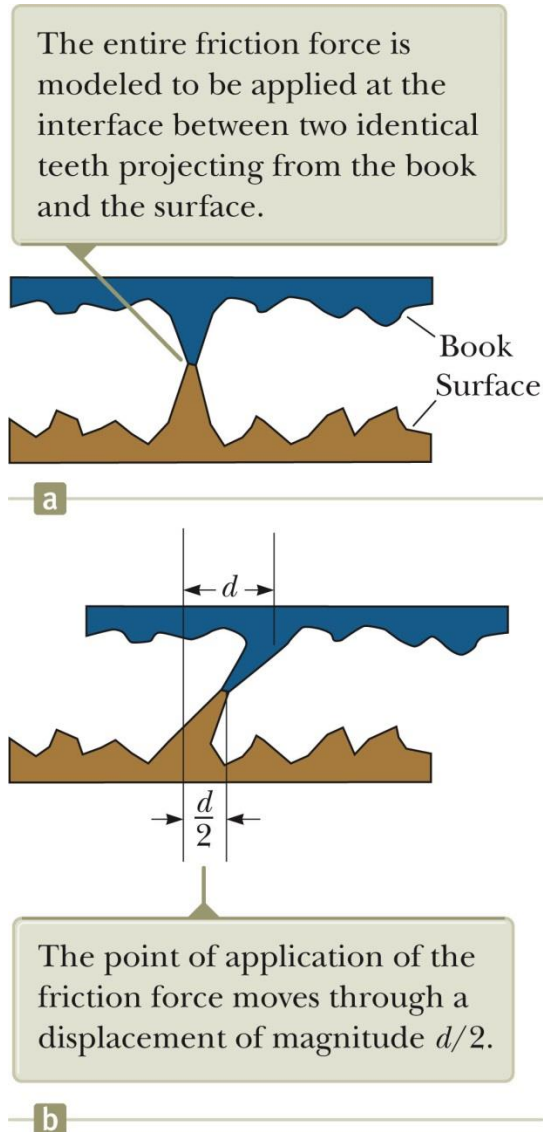
# Kinetic Friction

Kinetic friction can be modeled as the interaction between identical teeth.

The frictional force is spread out over the entire contact surface.

The displacement of the point of application of the frictional force is not calculable.

Therefore, the work done by the frictional force is not calculable.



## Work – Kinetic Energy Theorem

Is valid for a particle or an object that can be modeled as an object

When a friction force acts, you cannot calculate the work done by friction.

However, Newton's Second Law is still valid even though the work-kinetic energy theorem is not.

## Work and Energy With Friction

In general, if friction is acting in a system:

- $\Delta K = \Sigma W_{\text{other forces}} - f_k d$
- This is a modified form of the work – kinetic energy theorem.
  - Use this form when friction acts on an object.
- If friction is zero, this equation becomes the same as Conservation of Mechanical Energy.

A friction force transforms kinetic energy in a system to internal energy.

The increase in internal energy of the system is equal to its decrease in kinetic energy.

- $\Delta E_{\text{int}} = f_k d$

In general, this equation can be written as  $\Sigma W_{\text{other forces}} = W = \Delta K + \Delta E_{\text{int}}$

This represents the non-isolated system model for a system within which a non-conservative force acts.

## Example – Block on Rough Surface

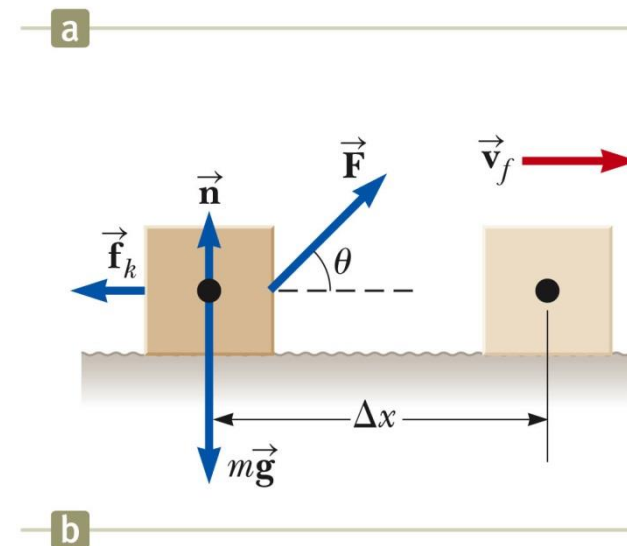
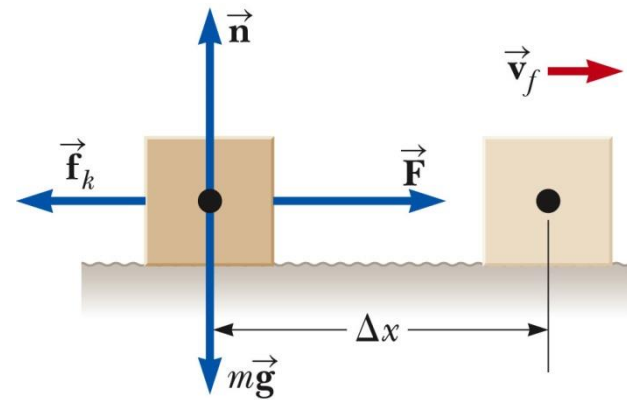
The block is pulled by a constant force over a rough horizontal surface.

Conceptualize

- The rough surface applies a friction force on the block.
- The friction force is in the direction opposite to the applied force.

Categorize

- Model the block-surface system as non-isolated with a non-conservative force acting.



## Example – Rough Surface cont.

### Analyze

- Neither the normal nor gravitational forces do work on the system.
- Vertical direction – apply particle in equilibrium model.
  - Find the magnitude of the friction force.

### Solve for final speed

### Finalize

- Less than value found in example without friction.
- There was an increase in the internal energy of the block-system surface.

## Example – Block-spring System

### The problem

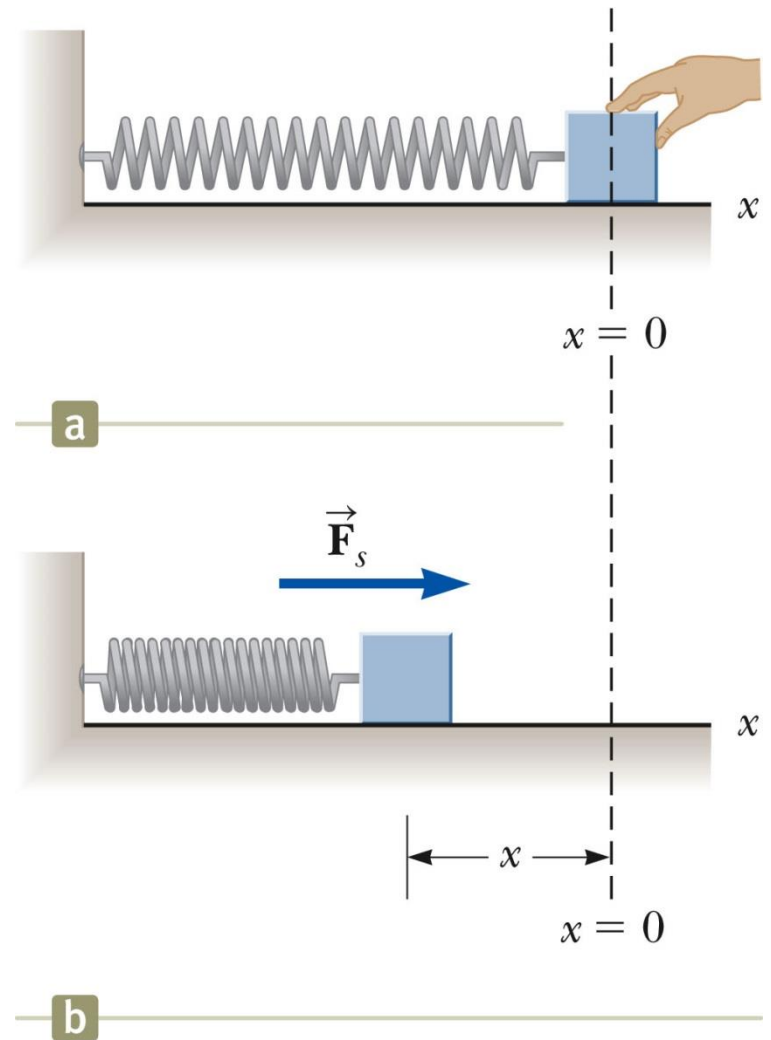
- The mass is attached to a spring, the spring is compressed and then the mass is released.
- A constant friction force acts (part B of example 8.6).

### Conceptualize

- The block will be pushed by the spring and move off with some speed.

### Categorize

- Block and surface is the system
- System is non-isolated
- There is a non-conservative force (friction) acting.



## Example – Spring-block, cont.

Analyze

- $K_f = K_i - f_k d + W_s$
- $K_f = \frac{1}{2} m v_f^2$

Finalize

- Think about the result
- Compare it to the result without friction



## Adding Changes in Potential Energy

If friction acts within an isolated system

$$\Delta E_{\text{mech}} = \Delta K + \Delta U = -f_k d$$

- $\Delta U$  is the change in all forms of potential energy

If non-conservative forces act within a non-isolated system and the external influence on the system is by means of work.

$$\Delta E_{\text{mech}} = -f_k d + \Sigma W_{\text{other forces}}$$

This equation represents the non-isolated system model for a system that possesses potential energy and within which a non-conservative force acts and can be rewritten as

$$\Sigma W_{\text{other forces}} = W = \Delta K + \Delta U + \Delta E_{\text{int}}$$

# Problem Solving Strategy with Non-conservative Forces

## *Conceptualize*

- Form a mental representation of what is happening.

## *Categorize*

- Define the system .
  - May consist of more than one object
- Determine if any non-conservative forces are present.
  - If not, use principle of conservation of mechanical energy.
- Determine if any work is done across the boundary of your system by forces other than friction.

## Problem Solving, cont

### *Analyze*

- Identify the initial and final conditions of the system.
- Identify the configuration for zero potential energy.
  - Include gravitational potential energy and spring elastic potential energy points .
- If there is more than one conservative force, write an expression for the potential energy associated with each force.
- Establish a mathematical representation of the problem.
- Solve for the unknown.

### *Finalize*

- Make sure your results are consistent with your mental representation.
- Make sure the values of your results are reasonable and consistent with everyday experience.

## Example – Ramp with Friction

Problem: the crate slides down the rough ramp

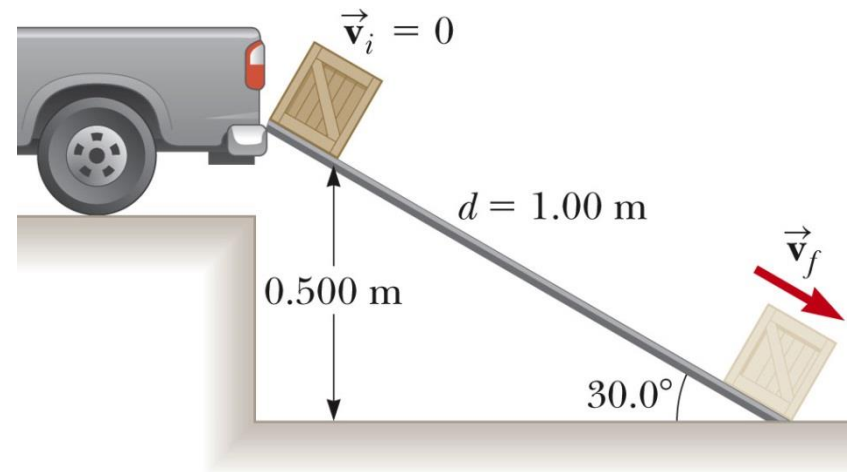
- Find speed at bottom

Conceptualize

- Energy considerations

Categorize

- Identify the crate, the surface, and the Earth as the system.
- Isolated system with non-conservative force acting



## Example – Ramp, cont.

### Analyze

- Let the bottom of the ramp be  $y = 0$
- At the top:  $E_i = K_i + U_{gi} = 0 + mgy_i$
- At the bottom:  $E_f = K_f + U_{gf} = \frac{1}{2} m v_f^2 + mgy_f$
- Then  $\Delta E_{\text{mech}} = E_f - E_i = -f_k d$
- Solve for  $v_f$

### Finalize

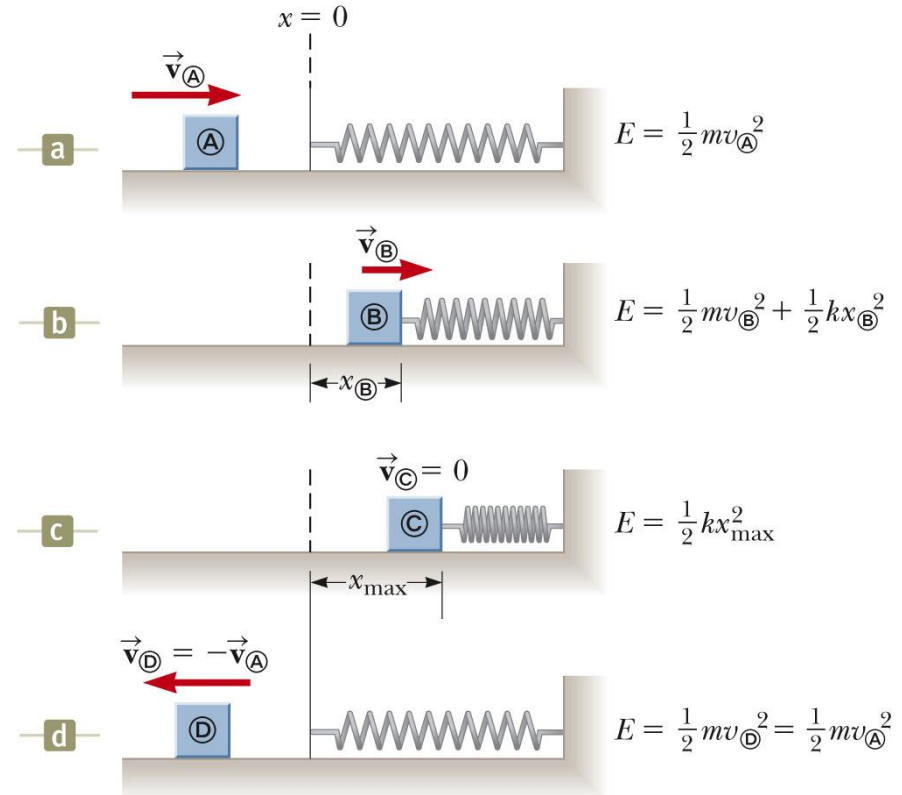
- Could compare with result if ramp was frictionless
- The internal energy of the system increased.

## Example – Spring Block Collision

Without friction, the energy continues to be transformed between kinetic and elastic potential energies and the total energy remains the same.

If friction is present, the energy decreases.

- $\Delta E_{\text{mech}} = -f_k d$



## Example – Spring Mass, 2

### Conceptualize

- All motion takes place on a horizontal plane.
  - So no changes in gravitational potential energy

### Categorize

- The system is the block and the system.
- Without friction, it is an isolated system with no non-conservative forces.

### Analyze

- Before the collision, the total energy is kinetic.
- When the spring is totally compressed, the kinetic energy is zero and all the energy is elastic potential.
- Total mechanical energy is conserved

## Problem – Spring Mass 3

Finalize

- Decide which root has physical meaning.

Now add friction

- Categorize
  - Now is isolated with non-conservative force
- Analyze
  - Use  $\Delta E_{\text{mech}} = -f_k d$
  - Solve for  $x$
- Finalize
  - The value is less than the case for no friction
    - As expected



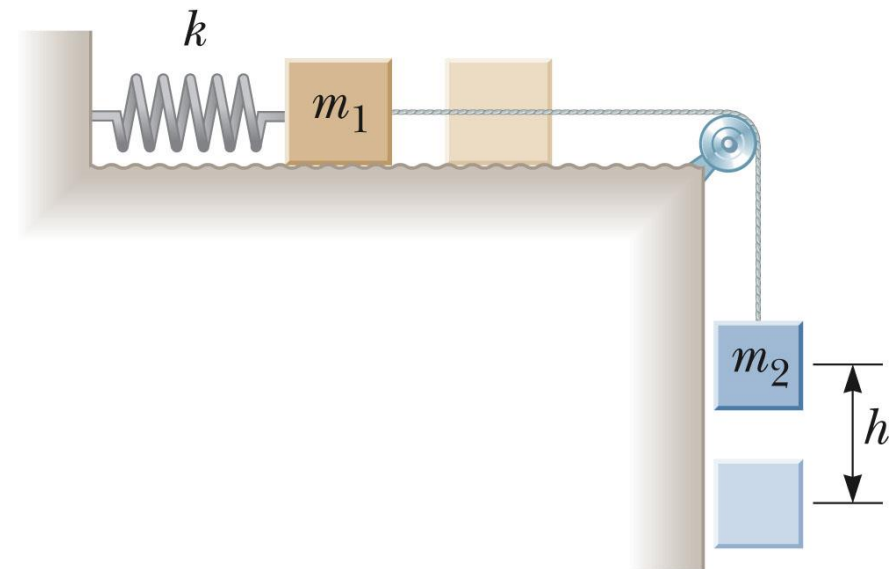
## Example – Connected Blocks in Motion

### Conceptualize

- Configurations of the system when at rest are good candidates for initial and final points.

### Categorize

- The system consists of the two blocks, the spring, the surface, and the Earth.
- System is isolated with a non-conservative force acting
- Model the sliding block as a particle in equilibrium in the vertical direction.



## Example – Blocks, cont.

### Analyze

- Gravitational and elastic potential energies are involved.
  - Changes in gravitational potential energy are associated only with the falling block.
- The kinetic energy is zero if our initial and final configurations are at rest.
- The spring undergoes a change in elastic potential energy.
- The coefficient of kinetic energy can be measured.

### Finalize

- This allows a method for measuring the coefficient of kinetic energy.
- Remember you can always begin with equation 8.2 and delete or expand terms as appropriate.

# Energy Bars for the Connected Objects Example

Initially (a) there is nothing moving in the system, therefore the kinetic energy is zero.

The total energy is potential

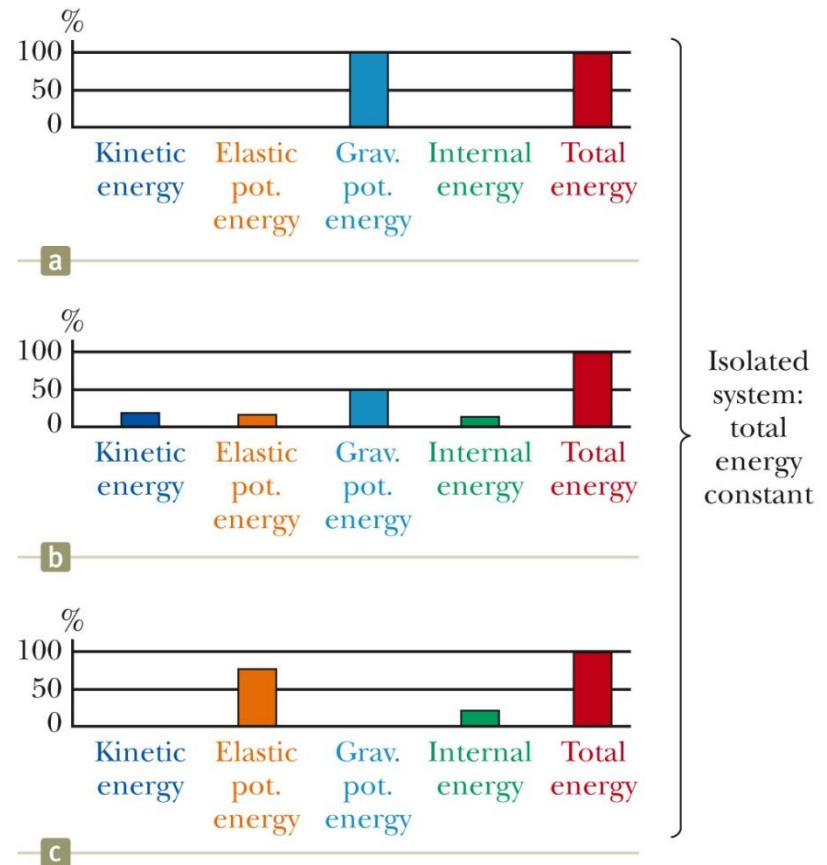
In (b), all four types of energy are present.

The system has gained kinetic energy, elastic potential energy and internal energy.

In (c), the gravitational potential and kinetic energies are both zero.

The spring is stretched to its maximum amount.

Internal energy has increased as one block continued to move over the surface.



# Power

Power is the time rate of energy transfer.

The *instantaneous power* is defined as

$$P \equiv \frac{dE}{dt}$$

Using work as the energy transfer method, this can also be written as

$$P_{avg} = \frac{W}{\Delta t}$$

## Instantaneous Power and Average Power

The instantaneous power is the limiting value of the average power as  $\Delta t$  approaches zero.

$$P = \lim_{\Delta t \rightarrow 0} \frac{W}{\Delta t} = \frac{dW}{dt} = \vec{\mathbf{F}} \cdot \frac{d\vec{\mathbf{r}}}{dt} = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}$$

This expression for power is valid for any means of energy transfer.

## Units of Power

The SI unit of power is called the watt.

- $1 \text{ watt} = 1 \text{ joule} / \text{second} = 1 \text{ kg} \cdot \text{m}^2 / \text{s}^3$

A unit of power in the US Customary system is horsepower.

- $1 \text{ hp} = 746 \text{ W}$

Units of power can also be used to express units of work or energy.

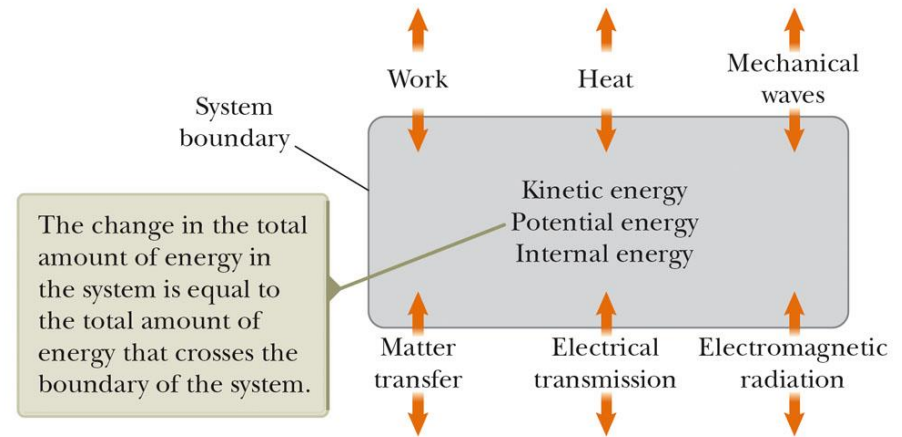
- $1 \text{ kWh} = (1000 \text{ W})(3600 \text{ s}) = 3.6 \times 10^6 \text{ J}$

## Problem Solving Summary – Non-isolated System

The most general statement describing the behavior of a non-isolated system is the conservation of energy equation.

$$\Delta E_{\text{system}} = \Sigma T$$

This equation can be expanded or have terms deleted depending upon the specific situation.



## Problem Solving Summary – Isolated System

The total energy of an isolated system is conserved

$$\Delta E_{\text{system}} = 0$$

If no non-conservative forces act within the isolated system, the mechanical energy of the system is conserved.

$$\Delta E_{\text{mech}} = 0$$

