Chapter 10: Energy and Work

LOOKING AHEAD ►

The goals of Chapter 10 are to introduce the concept of energy and to learn a new problem-solving strategy based on conservation of energy.

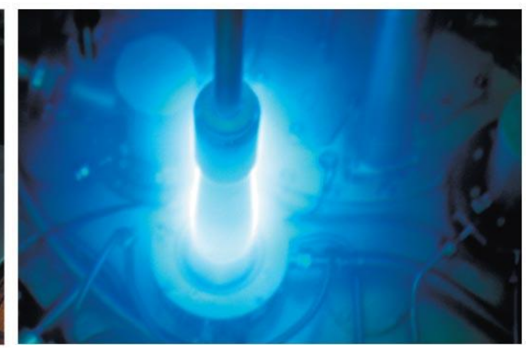
Forms of Energy

Mechanical Energy

Thermal Energy

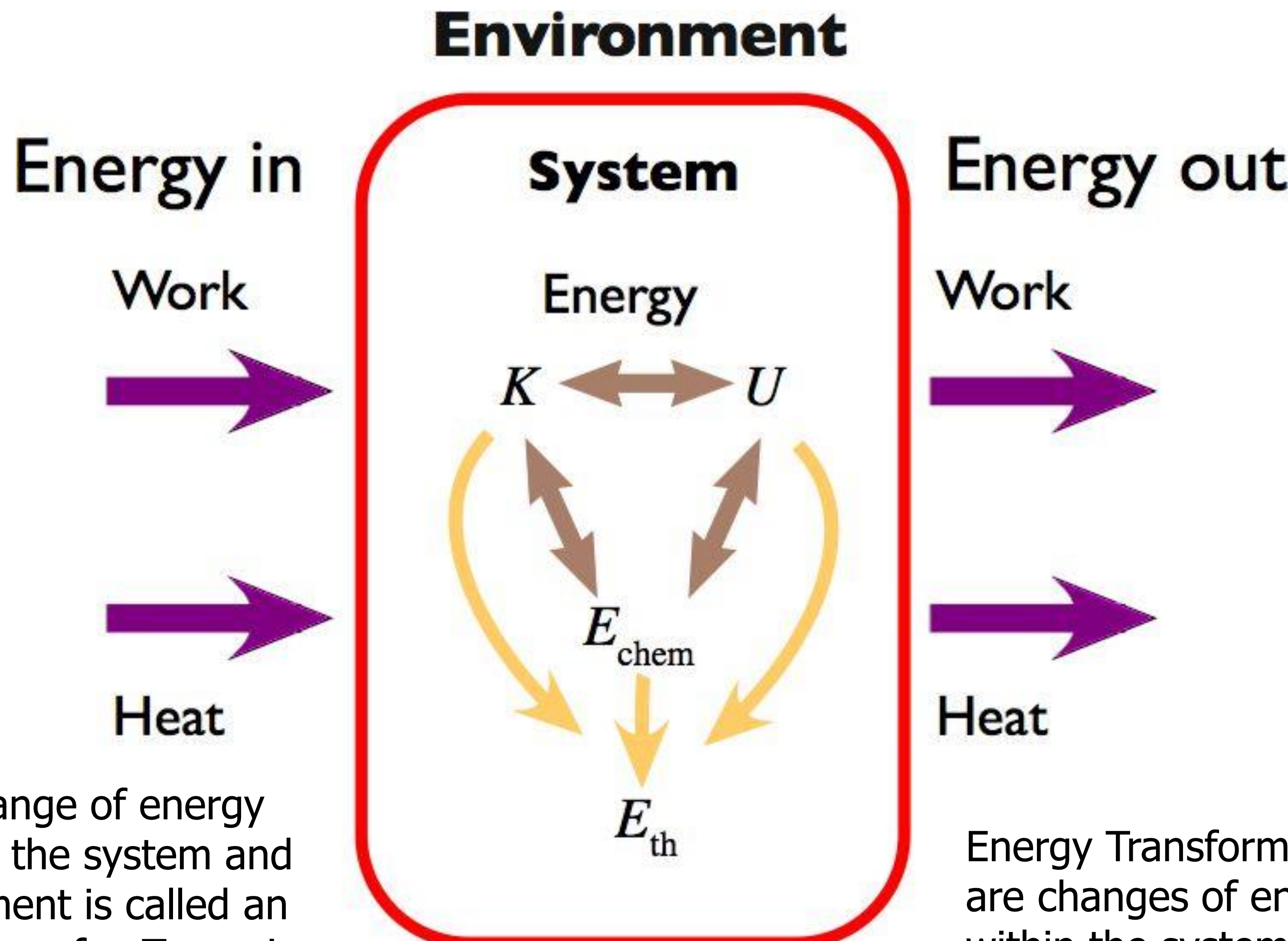
Other forms include

E_{chem}



$E_{nuclear}$

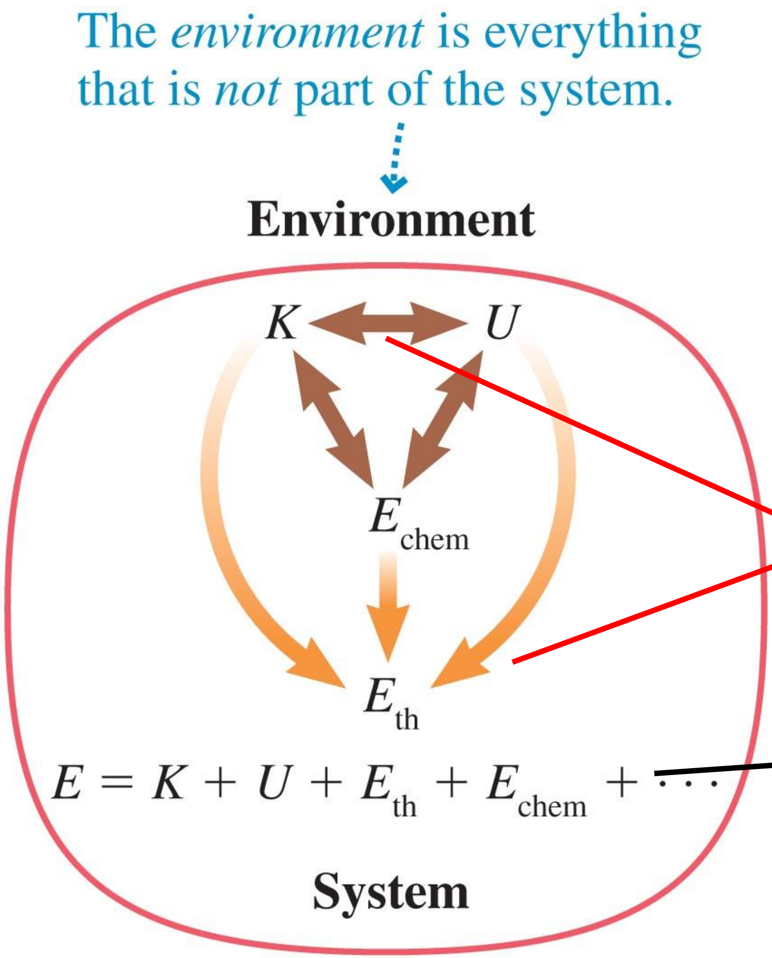
The Basic Energy Model



An exchange of energy between the system and environment is called an energy transfer. Two primary energy transfer processes: work and heat (APP2).

Energy Transformations are changes of energy within the system from one form to another.

Energy Transformations



Kinetic energy K = energy of motion

Potential energy U = energy of position

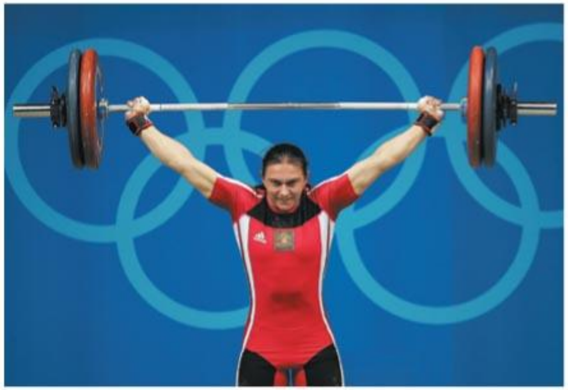
Thermal energy E_{th} = energy associated with temperature

System energy $E = K + U + E_{th} + E_{chem} + \ldots$

Energy can be <u>transformed</u> within the system without loss.

Energy is a property of a <u>system</u>.

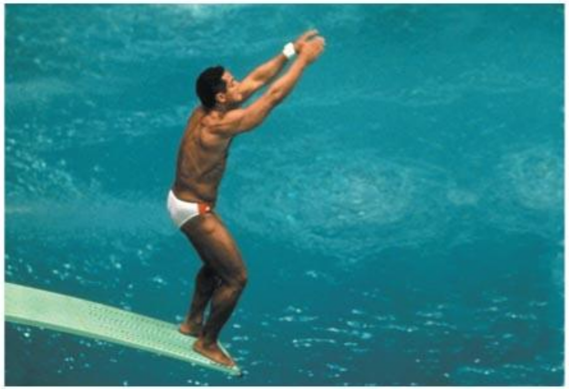
Some Energy Transformations



$E_{\text{chem}} \rightarrow U_g$

$K \rightarrow E_{\text{th}}$

$E_{\text{chem}} \rightarrow E_{th}$



$U_s \rightarrow K \rightarrow U_g$

Transferring Energy

Energy can be *transferred* into a system by pushing on it, a process called **work.**

The bobsledders do work on the sled, *transferring* energy to it and causing it to speed up.

Transforming Energy

Energy of one kind can change into energy of a different kind. These **energy transformations** are what make the world an interesting place.

As this race car skids to a stop, its kinetic energy is being *transformed* into thermal energy, making the tires hot enough to smoke.

Question:

If a system is *isolated*, the total energy of the system

A. increases constantly.
B. decreases constantly.
C. is constant.
D. depends on work into the system.
E. depends on work out of the system.

Answer

If a system is *isolated*, the total energy of the system

A. increases constantly.
B. decreases constantly.
C. is constant.
D. depends on work into the system.
E. depends on work out of the system.

The Law of Conservation of Energy

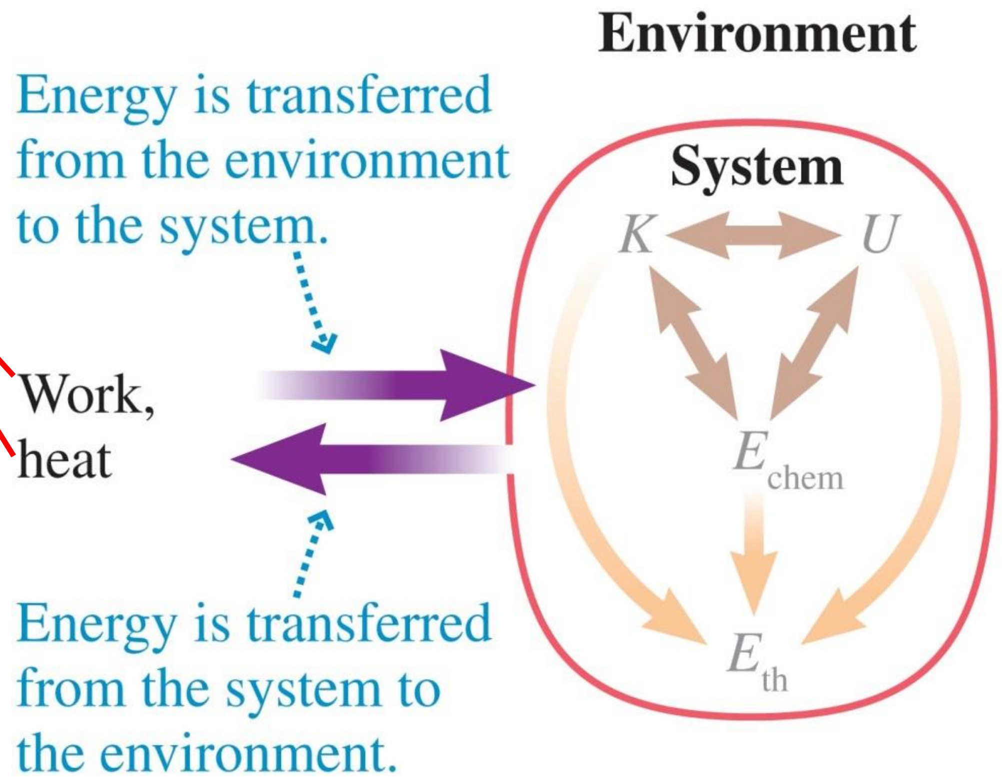
One of the most fundamental laws of physics, the **law of conservation of energy** states that the total energy of an isolated system is a constant.

How fast are these water sliders moving at the bottom? How fast does the rock fly out of the slingshot? We'll use conservation of energy and the before-and-after analysis introduced in Chapter 9 to solve these kinds of problems.

Energy Transfers

These <u>change</u> the energy of the system.

Interactions with the environment.



Work is the mechanical transfer of energy to or from a system via pushes and pulls.

Energy Transfers: Work

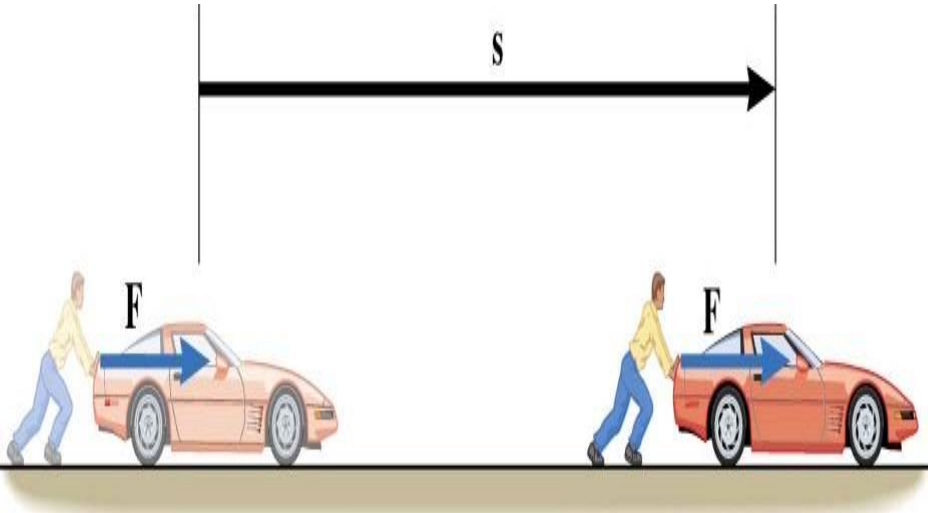
$W \rightarrow K$

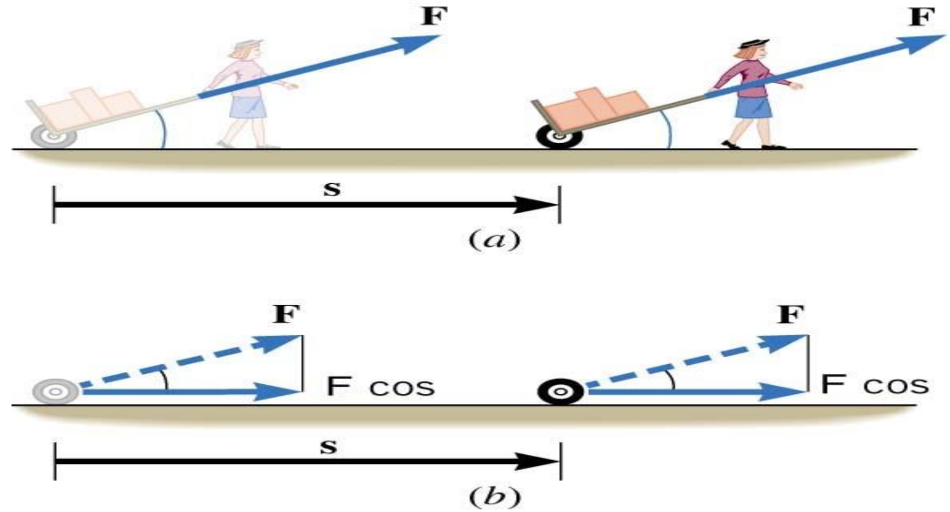
$W \rightarrow E_{th}$

$W \rightarrow U_s$

W = **F·d** (Units: N·m = Joule)

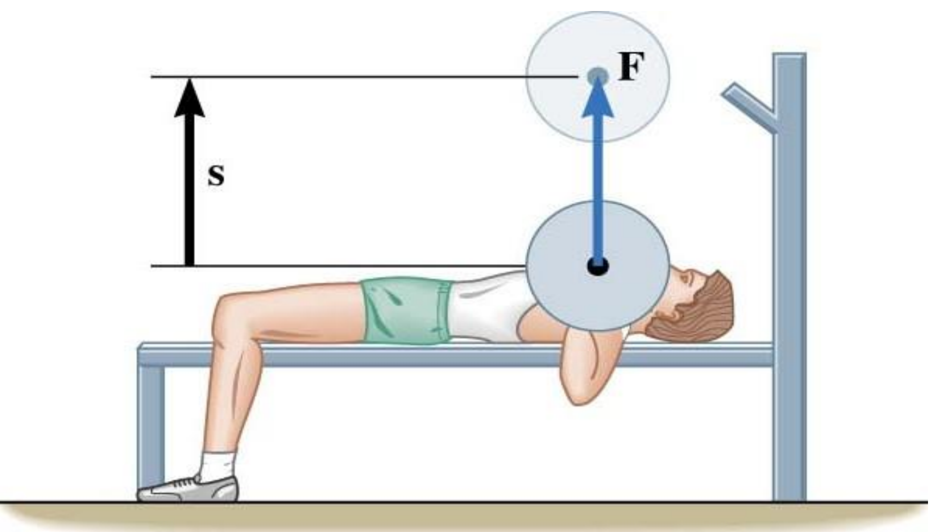
where F and d (displacement) are parallel to one another



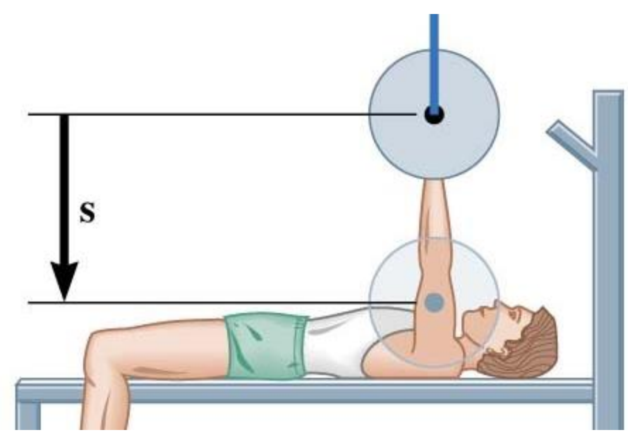


$W = F \cdot d$

$W = (F \cdot \cos\theta)\, d$



positive work



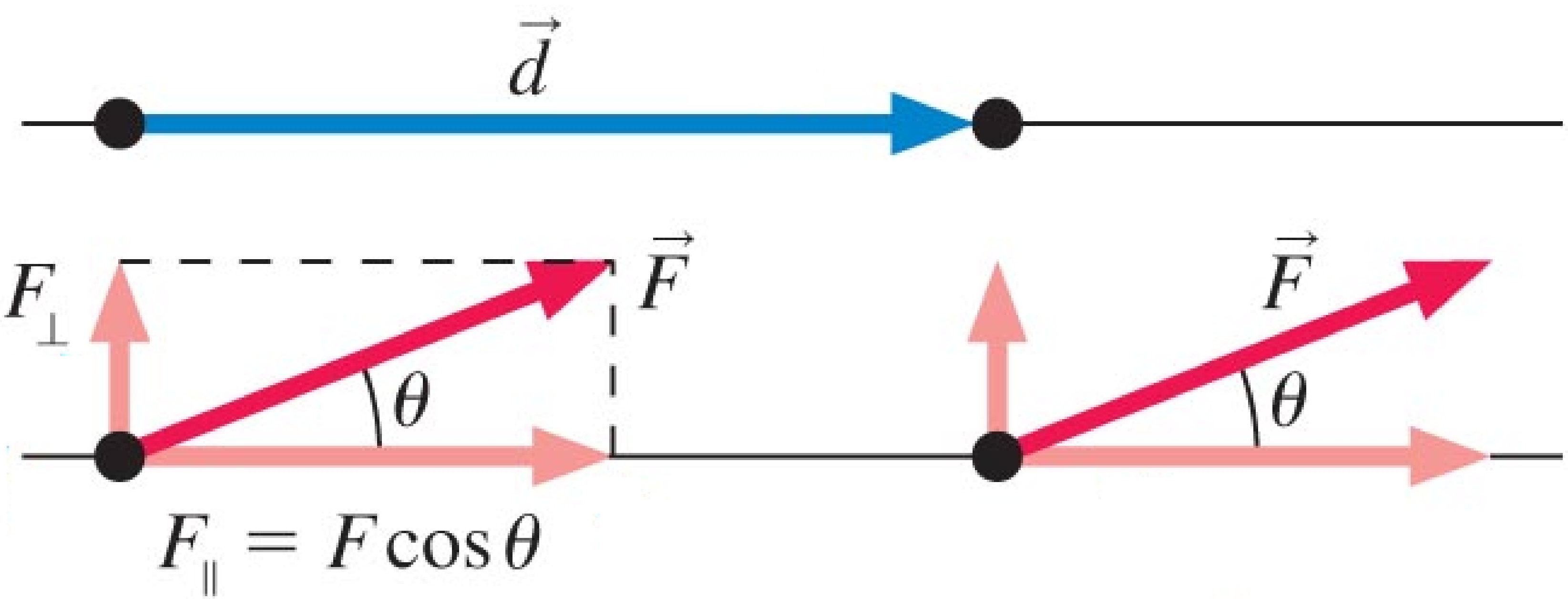
negative work

Work Done by Force at an Angle to Displacement

Recall: Force and Displacement have to be parallel for work to be done.

$$W = F_{\parallel} d = F d \cos\theta$$

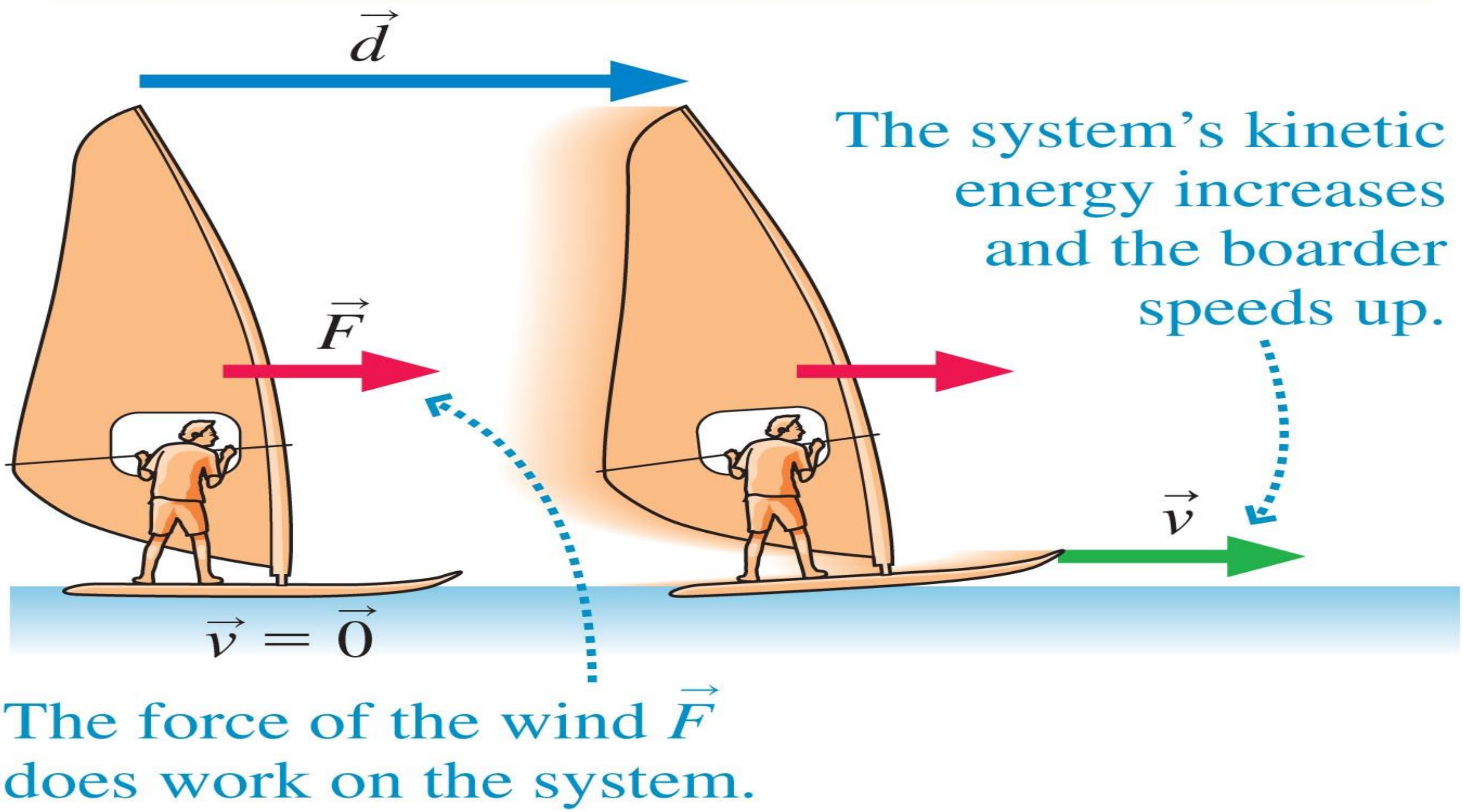
Work done by a constant force $\vec{F}$ at an angle θ to the displacement $\vec{d}$



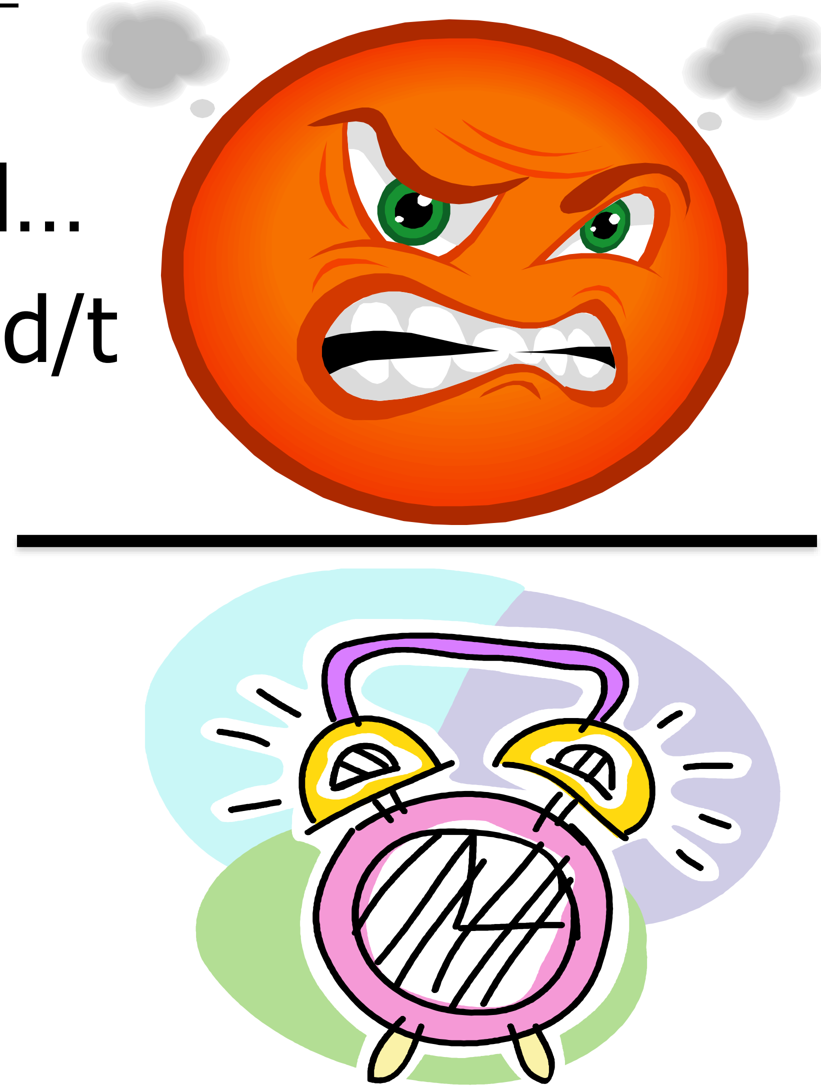
Work

$$W = Fd$$

Work done by a constant force $\vec{F}$ in the direction of a displacement $\vec{d}$



- Work makes you mad…
- Power makes you *mad* **<u>over</u>** *time*…
- Get it?
- Work makes you m·a·d…
- Power makes you m·a·d/t



Energy Equations

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

Kinetic energy of an object of mass m moving with speed v

$$U_g = mgy$$

Gravitational potential energy of an object of mass m at height y (assuming $U_g = 0$ when the object is at $y = 0$)

$$U_s = \frac{1}{2}kx^2$$

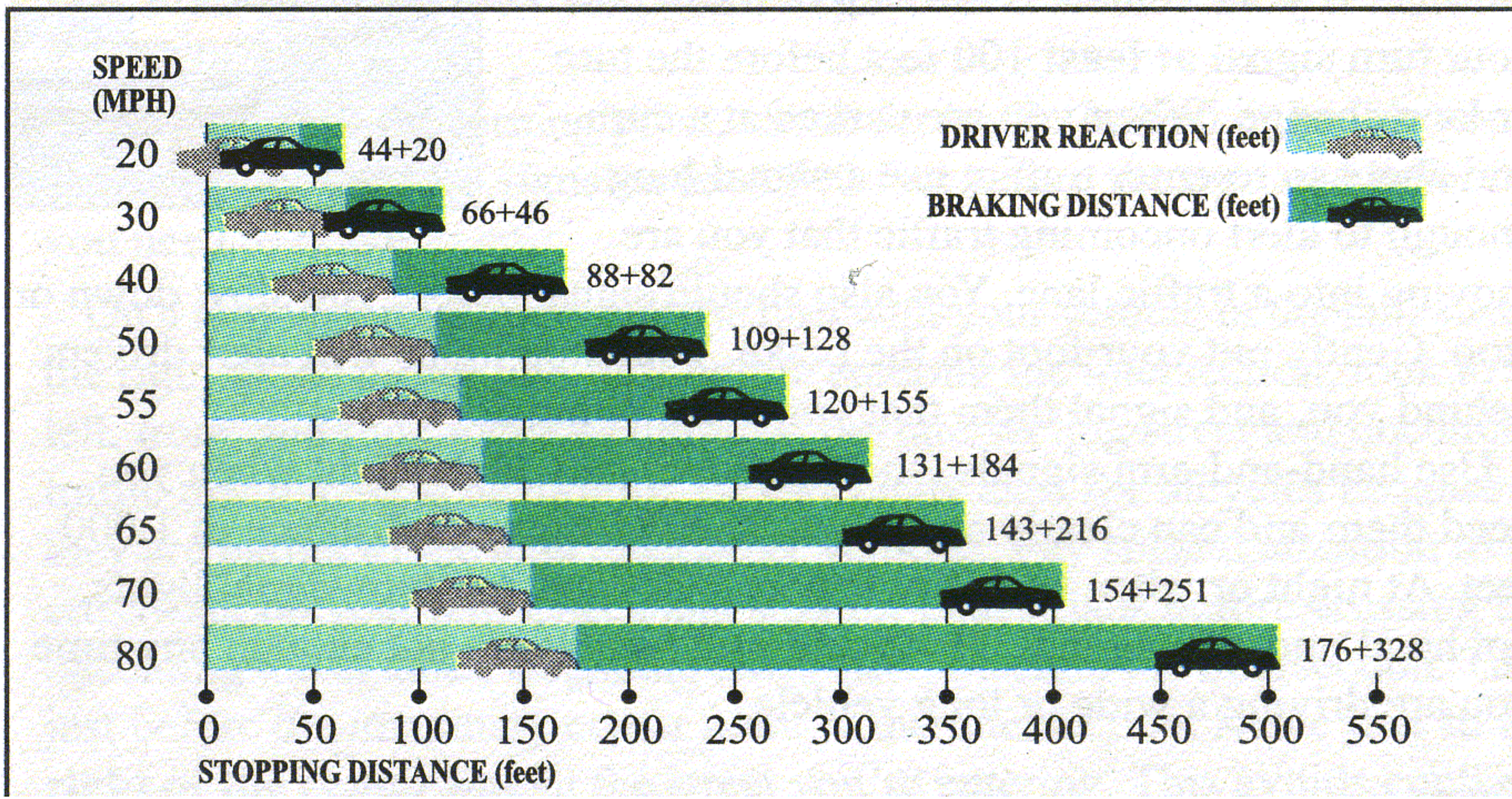
Elastic potential energy of a spring displaced a distance x from equilibrium (assuming $U_s = 0$ when the end of the spring is at $x = 0$)

Kinetic Energy

- $KE = ½\ m(v)^2$ (Translational Kinetic Energy)
- Looking at this equation, what does KE depend on?
- Mass and Speed. KE is called energy of motion.
- Work can change KE (work energy theorem.) $W = \Delta KE$
- $F \bullet d = ½\ m\ v_f^2 - ½\ m\ v_i^2$

Drivers Ed Question…While driving, if you double your speed, how much more distance is needed to stop?

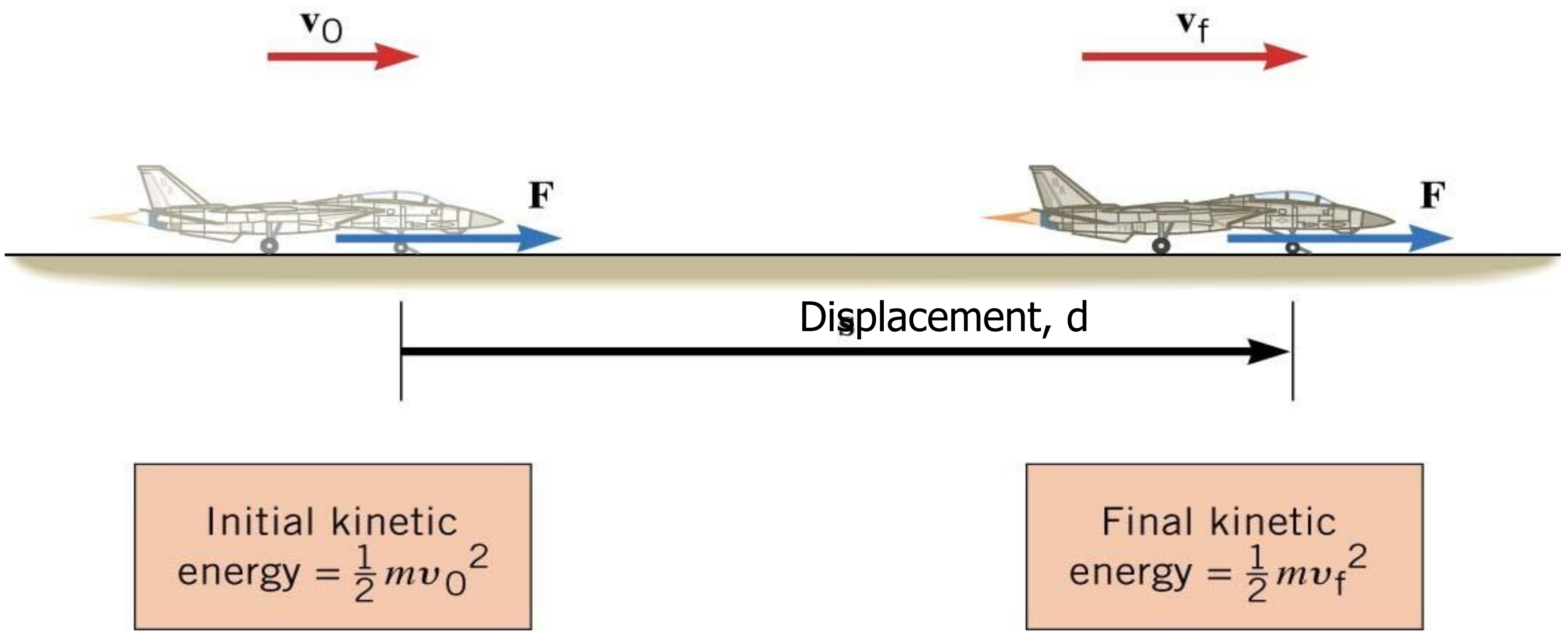
(You will not be tested on distances in this table)



Drivers Ed Question…While driving, if you double your speed, how much more distance is needed to stop?

- $W = \Delta KE$
- $F \bullet d = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$
- $F \bullet d = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$
- $F \bullet d = 0 - \frac{1}{2} m v_i^2$
- $d \propto v_i^2$
- $\therefore (2v_i)^2 \rightarrow 4d$
- **Doubling $\mathbf{v_i}$**, or $2x\, v_i$, will result in a $\mathbf{2^2}x$ d or **4*x* greater distance** needing to stop!

Relating Work to Kinetic Energy



- A constant net external force Σ**F** acts over a displacement **d** and does work on the plane.
- As a result of the work done, the plane's kinetic energy changes.

Work-Energy Theorem

- The total energy of a system changes by the amount of work done on it.
- When a net force performs work on an object, the result could be a change in the kinetic energy of the object.
- If the work done by the net force is *positive*, the kinetic energy of the object *increases*.
- If the work done by the net force is *negative*, the kinetic energy of the object *decreases*.
- If the work done by the net force is *zero*, the kinetic energy of the object remains the same, or *unchanged*.
- $W = \Delta KE = Ke_f - KE_i$

Kinetic Energy

- Kinetic Energy can be solely translational K… $K = ½\ m\ v^2$
- Kinetic Energy can be solely rotational K…

$$K = \frac{1}{2} I\omega^2$$

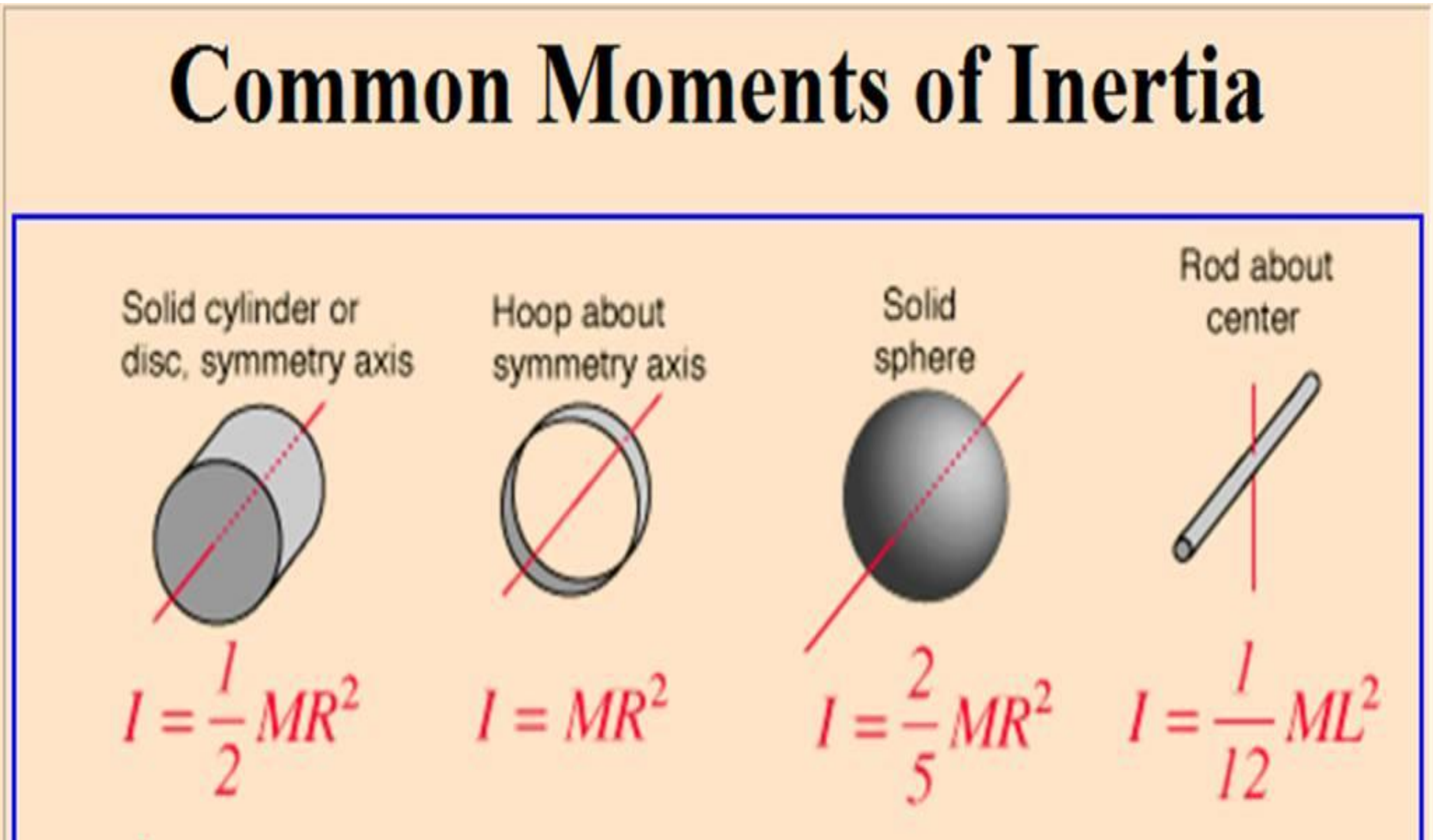
- Or Kinetic Energy can be a combination of both… ball rolling down a ramp.

Rotational Kinetic Energy

$$K = \frac{1}{2} I\omega^2$$

Variable	Translational	Angular
Displacement	$s = r\theta$	$\theta = \frac{s}{r}$
Velocity	$v = r\omega$	$\omega = \frac{v}{r}$
Acceleration	$a = r\alpha$	$\alpha = \frac{a}{r}$
Time	t	t
Force/Torque	$F_{net} = ma$	$\tau_{net} = I\alpha$
Momentum	$p = mv$	$L = I\omega$
Kinetic Energy	$KE = \frac{1}{2}mv^2$	$KE = \frac{1}{2}I\omega^2$

I = Moment of Inertia,
M = Mass, R = radius

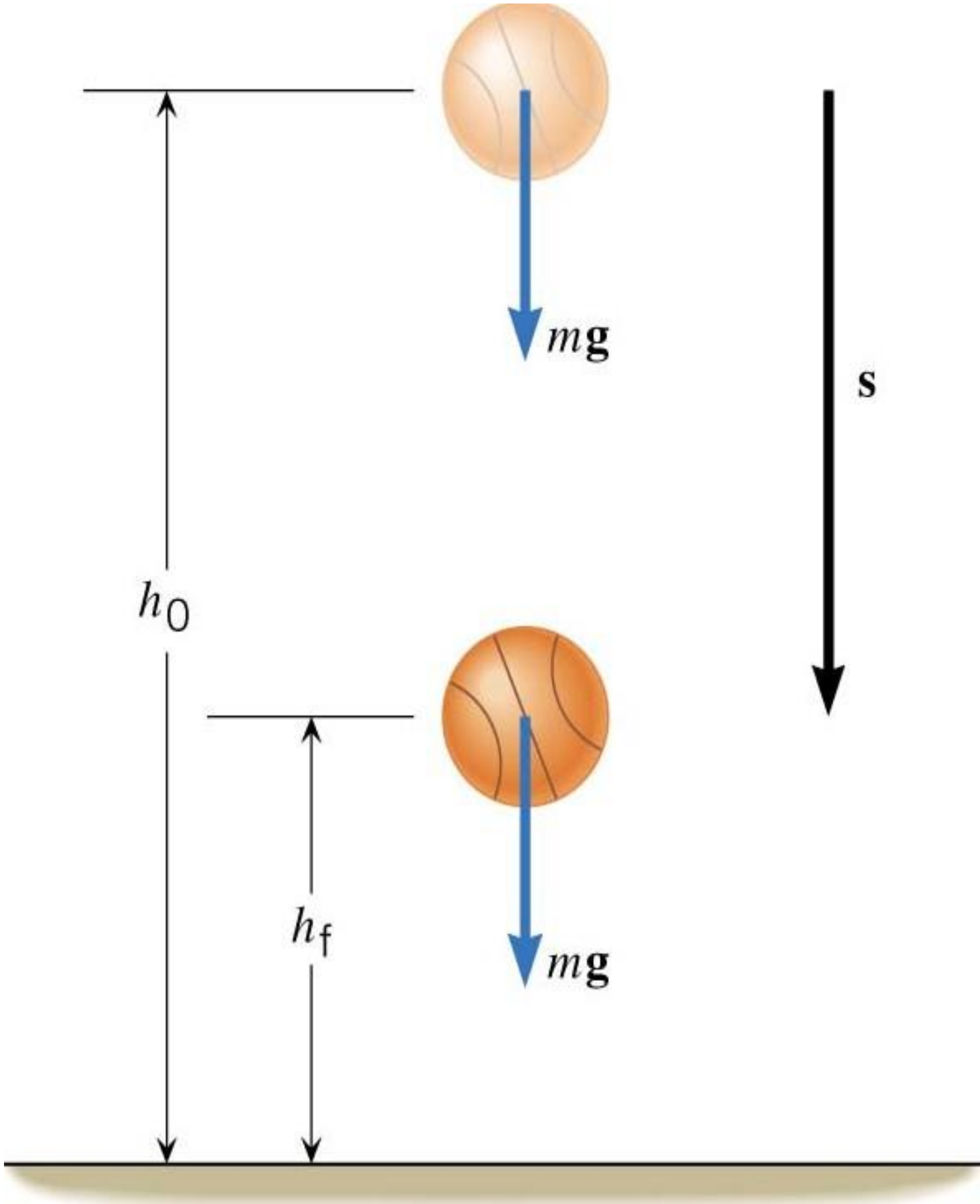


Gravitational PE

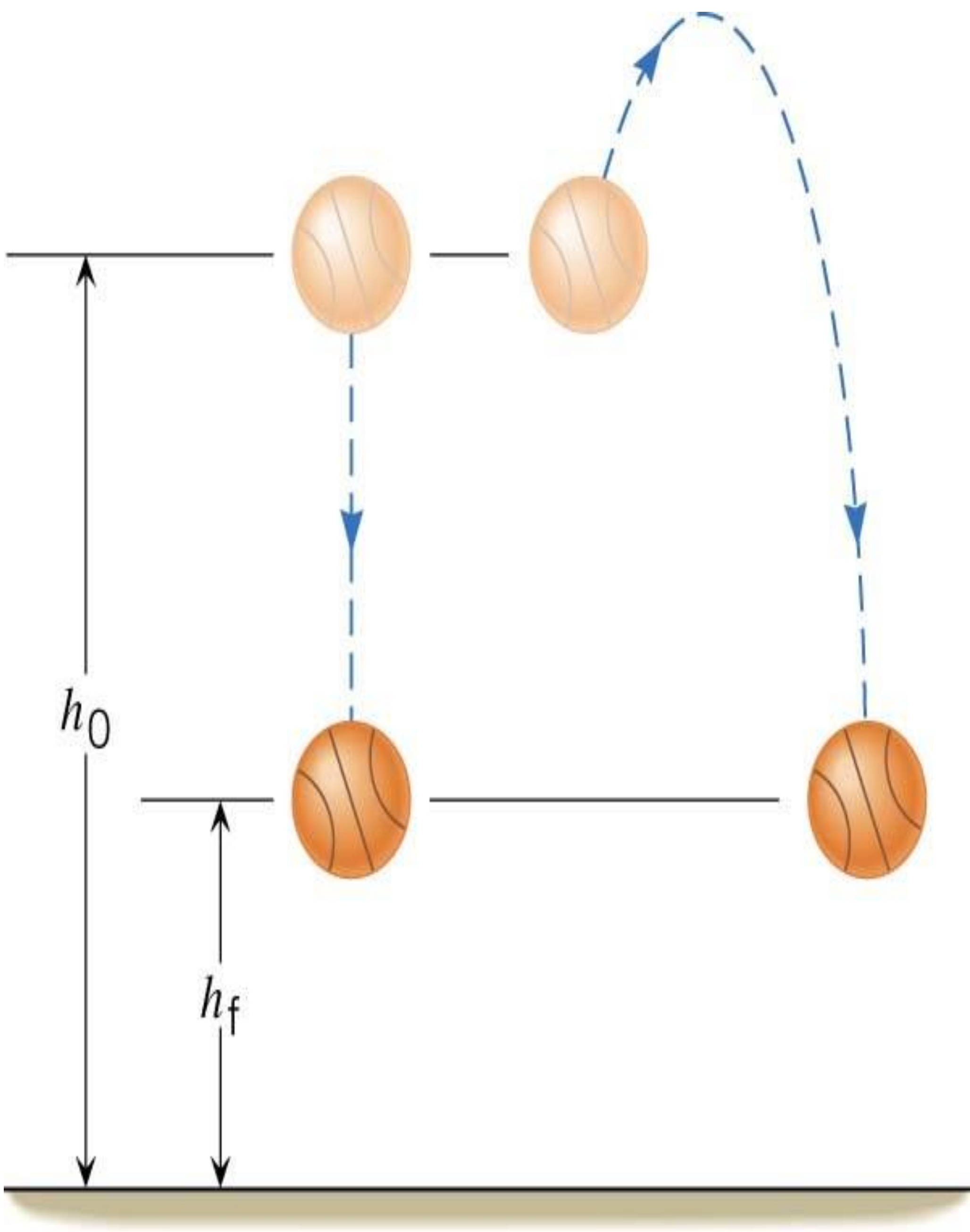
- The total energy of a system changes by the amount of work done on it. (Work-Energy Theorem)
- U_g = GPE = $ma_g\Delta h$
- What does GPE depend on?
- Mass, acceleration due to gravity & height.
- GPE is called *energy of location* or position.
- ΔGPE does not care about that path taken, just the change in height.
- W= ΔGPE = $ma_g\Delta h$

Work done by the force of gravity

- Gravity exerts a force m**g** on the basketball. Work is done *by* the gravitational force as the basketball falls from a height of h_o to a height of h_f (relative to the earth's surface).
- $d = h_o - h_f$
- $W_g = F_g d = mg (h_o - h_f)$

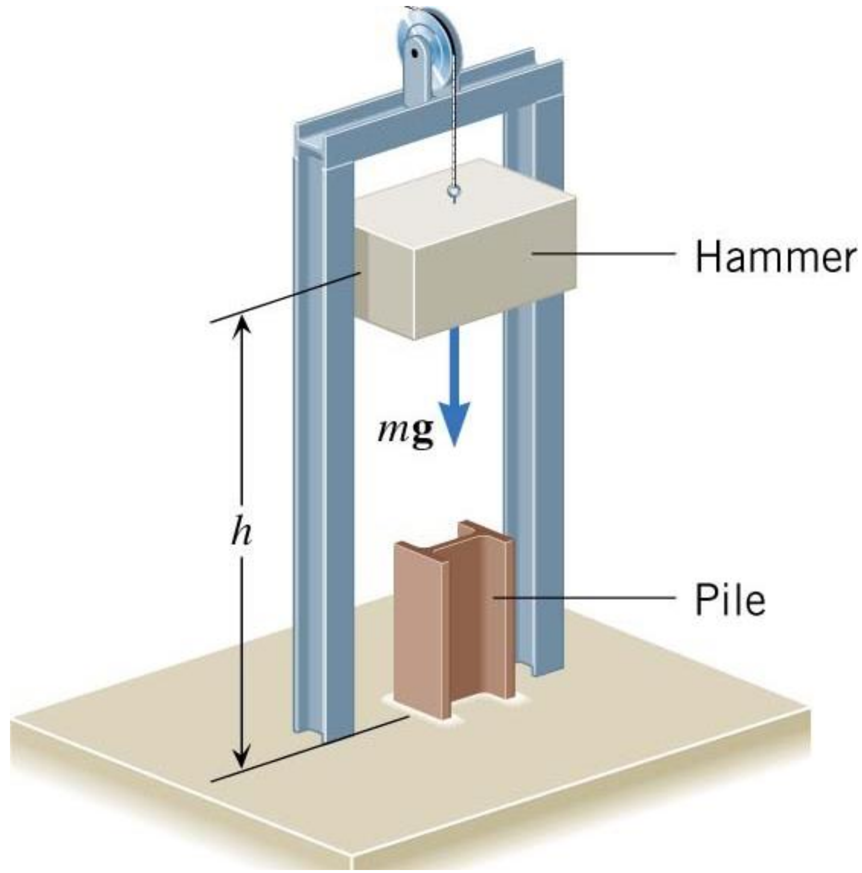


- An object can move along different paths in going from an initial height h_o to a final height of h_f. In each case, the work done by the gravitational force is the same, since the change in vertical distance is the same.
- $d = h_o - h_f$
- $W_g = F_g d = mg (h_o - h_f)$
- Note: ΔU_g does not depend on path taken.



Gravitational Potential Energy

- An object possessing energy by virtue of its position relative to earth is said to have gravitational potential energy.
- The hammer has the potential to do the work of driving the pile into the ground.
- $U_g = PE_g = mgh$
- $W_g = mg\,(\Delta h) = \Delta U_g$



Conservation of Energy

- Energy cannot be created nor destroyed, but energy can change from one form into another.
- $\Delta E = \Delta U_g + \Delta KE + \Delta U_s = W$
- For an isolated system, W = 0, or the total energy of an *isolated system* remains constant (is conserved).
- $\Delta E = \Delta GPE + \Delta KE = W = 0$ (isolated system)
- Or another way to write it would be…
- $E_{final} = E_{initial}$

Question

If you raise an object to a greater height, you are increasing

A. kinetic energy.
B. heat.
C. potential energy.
D. chemical energy.
E. thermal energy.

Answer

If you raise an object to a greater height, you are increasing

A. kinetic energy.
B. heat.
C. potential energy.
D. chemical energy.
E. thermal energy.

Checking Understanding

A skier is moving down a slope at a constant speed. What energy transformation is taking place?

A. $K \rightarrow U_g$

B. $U_g \rightarrow E_{th}$

C. $U_s \rightarrow U_g$

D. $U_g \rightarrow K$

E. $K \rightarrow E_{th}$

Answer

A skier is moving down a slope at a constant speed. What energy transformation is taking place?

A. $K \rightarrow U_g$

B. $\mathbf{U_g \rightarrow E_{th}}$

C. $U_s \rightarrow U_g$

D. $U_g \rightarrow K$

E. $K \rightarrow E_{th}$

Checking Understanding

A child is on a playground swing, motionless at the highest point of his arc. As he swings back down to the lowest point of his motion, what energy transformation is taking place?

A. $K \rightarrow U_{\mathrm{g}}$

B. $U_{\mathrm{g}} \rightarrow E_{\mathrm{th}}$

C. $U_{\mathrm{s}} \rightarrow U_{\mathrm{g}}$

D. $U_{\mathrm{g}} \rightarrow K$

E. $K \rightarrow E_{\mathrm{th}}$

Answer

A child is on a playground swing, motionless at the highest point of his arc. As he swings back down to the lowest point of his motion, what energy transformation is taking place?

A. $K \rightarrow U_g$

B. $U_g \rightarrow E_{th}$

C. $U_s \rightarrow U_g$

D. $U_g \rightarrow K$

E. $K \rightarrow E_{th}$

The Work-Energy Equation

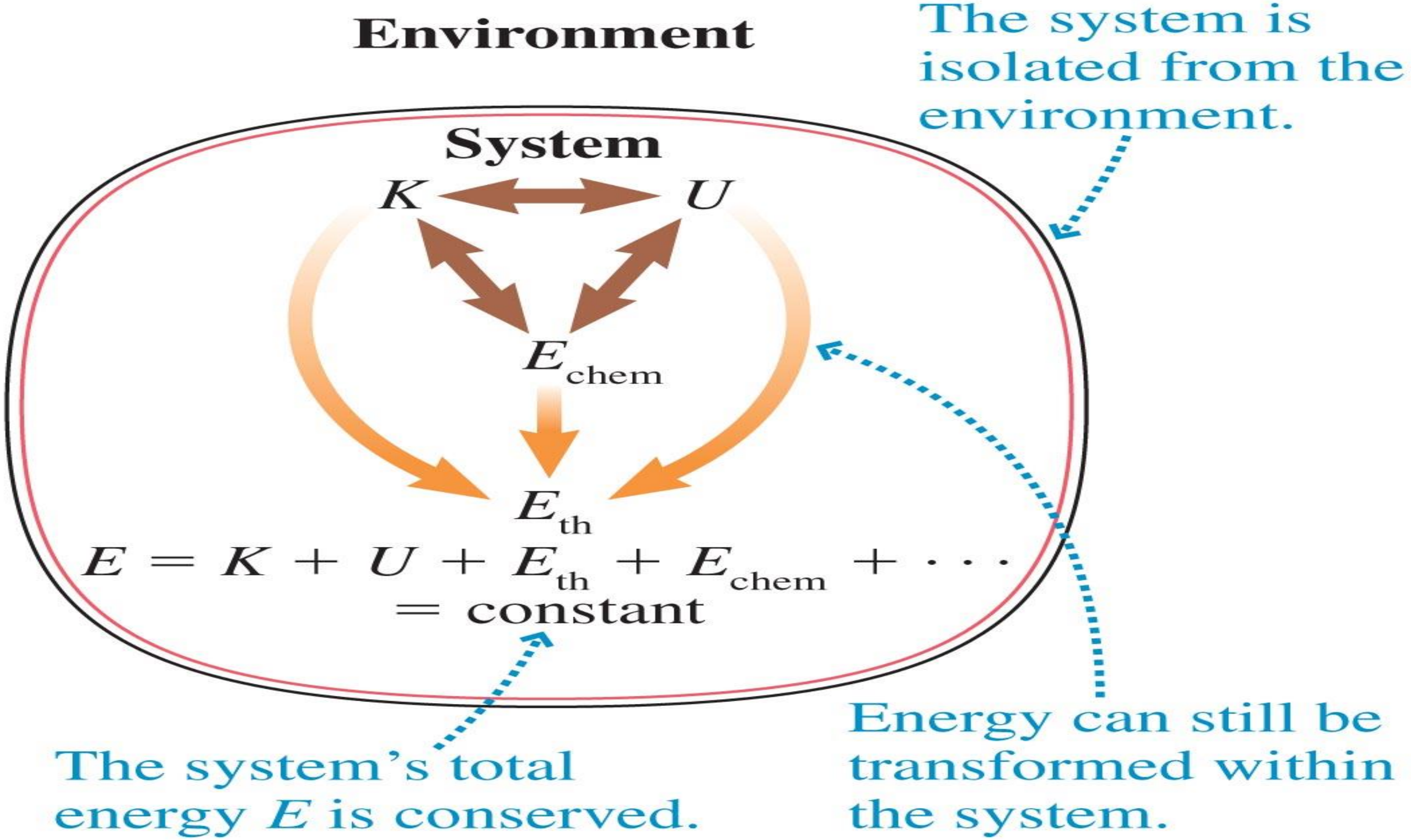
The work-energy equation The total energy of a system changes by the amount of work done on it:

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = W$$

The Law of Conservation of Energy

Law of conservation of energy The total energy of an isolated system remains constant:

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = 0$$



The Basic Equation

$$K_f + U_f + \Delta E_{th} = K_i + U_i$$

A few things to note:

- Work can be positive (work in) or negative (work out)
- We are, for now, ignoring heat.
- Thermal energy is…special. When energy changes to thermal energy, this change is irreversible.

PROBLEM-SOLVING STRATEGY 10.1

Conservation of energy problems

PREPARE Referring to Table 10.2, choose your system so that it is isolated. Draw a before-and-after visual overview, as was outlined in Tactics Box 9.1. Note the known quantities, and identify what you're trying to find.

SOLVE There are two important situations:

- If the system is isolated *and* there's no friction, the mechanical energy is conserved:

$$K_f + (U_g)_f + (U_s)_f = K_i + (U_g)_i + (U_s)_i$$

- If the system is isolated but there is friction within the system, the total energy is conserved:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{th} = K_i + (U_g)_i + (U_s)_i$$

Depending on the problem, you'll need to calculate the initial and/or final values of these energies; you can then solve for the unknown energies, and from these any unknown speeds (from K), heights (from U_g and U_s), or displacements or friction forces (from $\Delta E_{th} = f_k \Delta x$).

ASSESS Check the signs of your energies. Kinetic energy is always positive, as is the change in thermal energy. Check that your result has the correct units, is reasonable, and answers the question.

Exercise 23

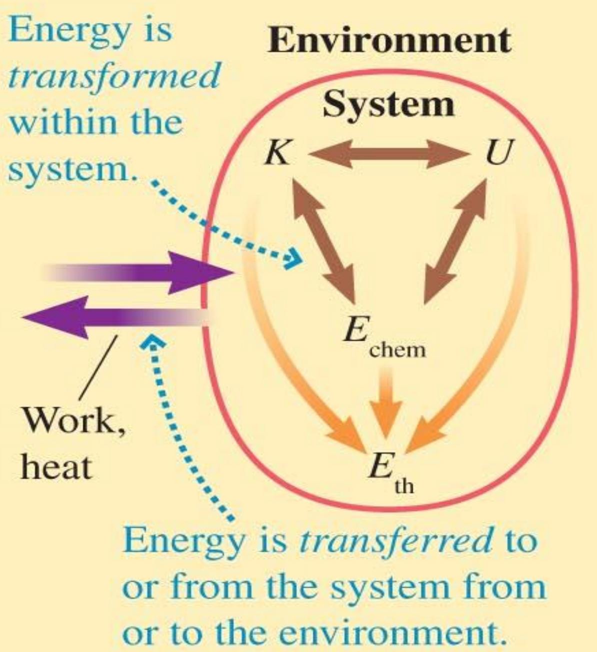
Summary

Basic Energy Model

Within a system, energy can be **transformed** between various forms.

Energy can be **transferred** into or out of a system in two basic ways:

- **Work:** The transfer of energy by mechanical forces.
- **Heat:** The nonmechanical transfer of energy from a hotter to a colder object.



Conservation of Energy

When work W is done on a system, the system's total energy changes by the amount of work done. In mathematical form, this is the **work-energy equation:**

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = W$$

A system is **isolated** when no energy is transferred into or out of the system. This means the work is zero, giving the **law of conservation of energy:**

$$\Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = 0$$

Summary

Solving Energy Conservation Problems

PREPARE Choose your system so that it's isolated. Draw a before-and-after visual overview.

SOLVE

- If the system is isolated and there's no friction, then mechanical energy is conserved:

$$K_f + (U_g)_f + (U_s)_f = K_i + (U_g)_i + (U_s)_i$$

- If the system is isolated but there's friction present, then the total energy is conserved:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{th} = K_i + (U_g)_i + (U_s)_i$$

ASSESS Kinetic energy is always positive, as is the change in thermal energy.