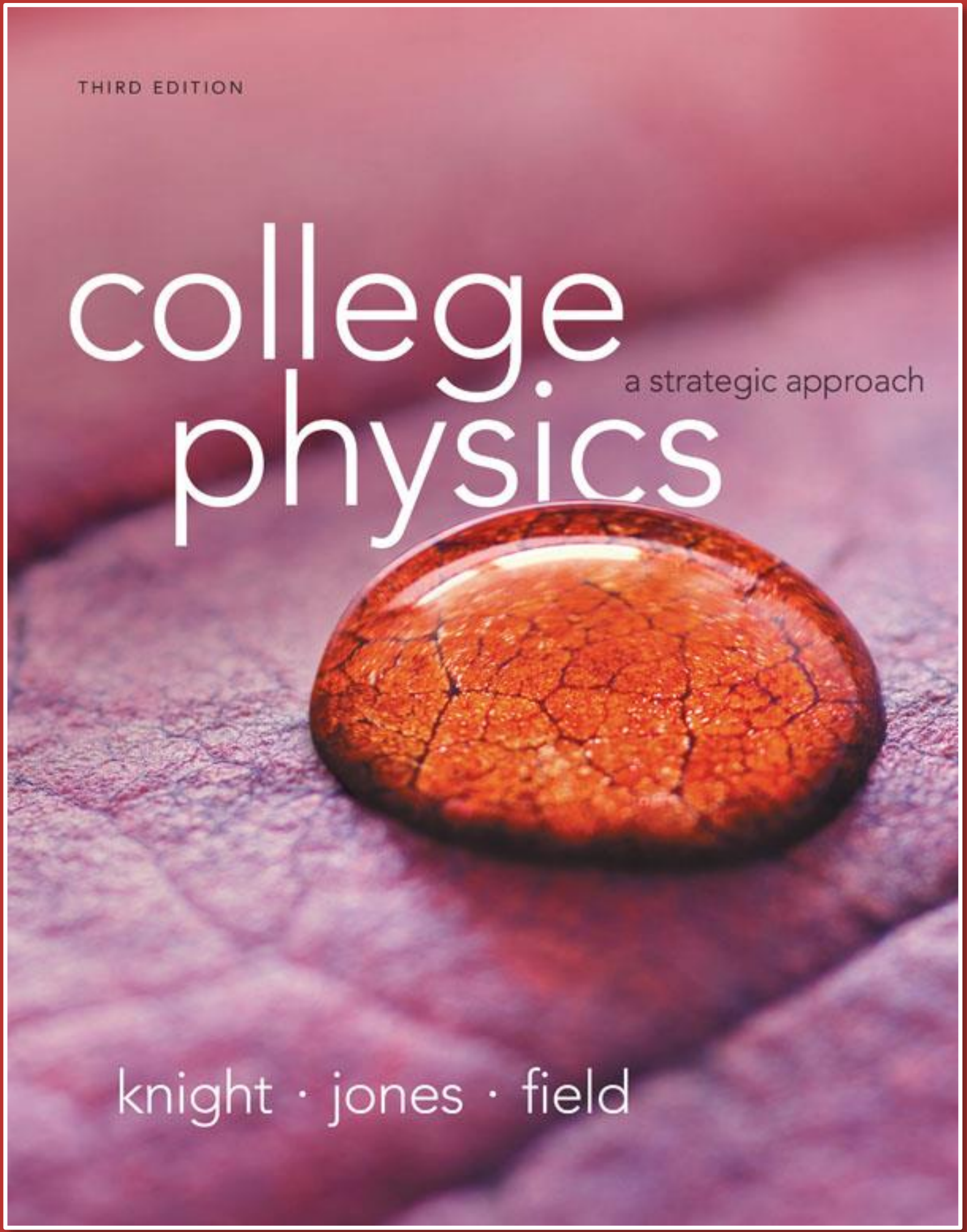


Lecture Presentation

Chapter 10

Energy and Work

Suggested Videos for Chapter 10

- **Prelecture Videos**
  - *Forms of Energy*
  - *Conservation of Energy*
  - *Work and Power*

- **Class Videos**
  - *The Basic Energy Model*
  - *Breaking Boards*

- **Video Tutor Solutions**
  - *Energy and Work*

- **Video Tutor Demos**
  - *Canned Food Race*
  - *Chin Basher?*

Suggested Simulations for Chapter 10

- **ActivPhysics**
  - *5.1–5.7*
  - *6.1, 6.2, 6.5, 6.8, 6.9*
  - *7.11–7.13*
- **PhETs**
  - *Energy Skate Park*
  - *The Ramp*

Chapter 10 Energy and Work

Chapter Goal: To introduce the concept of energy and to learn a new problem-solving strategy based on conservation of energy.

Chapter 10 Preview

Looking Ahead: Forms of Energy

- This dolphin has lots of **kinetic energy** as it leaves the water. At its highest point its energy is mostly **potential energy**.

- You'll learn about several of the most important forms of energy—kinetic, potential, and thermal.

Chapter 10 Preview

Looking Ahead: Work and Energy

- As the band is stretched, energy is *transferred* to it as **work**. This energy is then *transformed* into kinetic energy of the rock.

- You'll learn how to calculate the work done by a force, and how this work is related to the change in a system's energy.

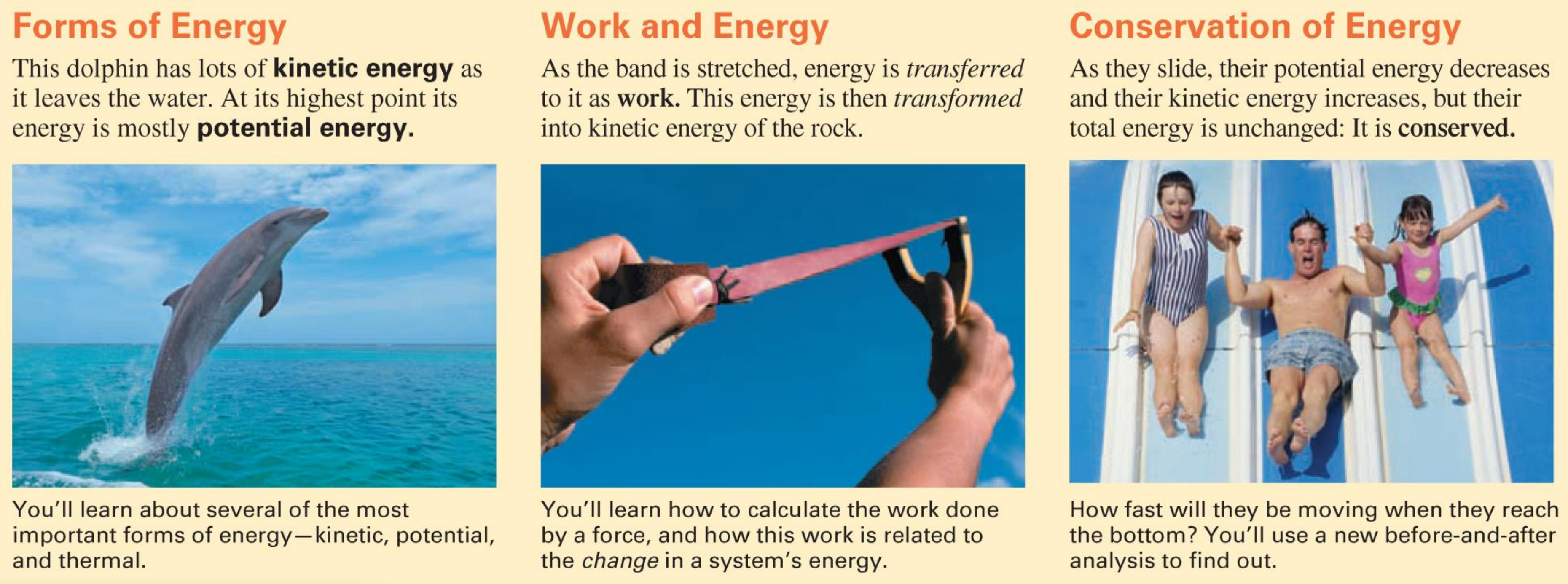
Chapter 10 Preview

Looking Ahead: Conservation of Energy

- As they slide, their potential energy decreases and their kinetic energy increases, but their total energy is unchanged: It is **conserved**.

- How fast will they be moving when they reach the bottom? You'll use a new before-and-after analysis to find out.

Chapter 10 Preview
Looking Ahead



Forms of Energy

This dolphin has lots of **kinetic energy** as it leaves the water. At its highest point its energy is mostly **potential energy.**

You'll learn about several of the most important forms of energy—kinetic, potential, and thermal.

Work and Energy

As the band is stretched, energy is *transferred* to it as **work.** This energy is then *transformed* into kinetic energy of the rock.

You'll learn how to calculate the work done by a force, and how this work is related to the *change* in a system's energy.

Conservation of Energy

As they slide, their potential energy decreases and their kinetic energy increases, but their total energy is unchanged: It is **conserved.**

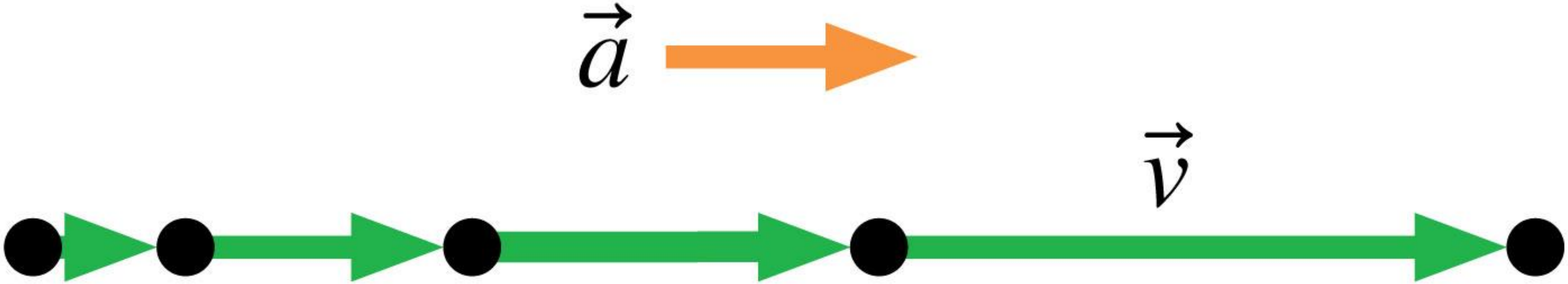
How fast will they be moving when they reach the bottom? You'll use a new before-and-after analysis to find out.

Text: p. 283

Chapter 10 Preview

Looking Back: Motion with Constant Acceleration

In Chapter 2 you learned how to describe the motion of a particle that has a constant acceleration. In this chapter, you'll use the constant-acceleration equations to connect work and energy.



A particle's final velocity is related to its initial velocity, its acceleration, and its displacement by

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\Delta x$$

Chapter 10 Preview

Stop to Think

A car pulls away from a stop sign with a constant acceleration. After traveling 10 m, its speed is 5 m/s. What will its speed be after traveling 40 m?

A. 10 m/s
B. 20 m/s
C. 30 m/s
D. 40 m/s

Reading Question 10.1

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

A. Increases constantly.
B. Decreases constantly.
C. Is constant.
D. Depends on the work into the system.
E. Depends on the work out of the system.

Reading Question 10.1

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

A. Increases constantly.
B. Decreases constantly.
✓ C. Is constant.
D. Depends on the work into the system.
E. Depends on the work out of the system.

Reading Question 10.2

Which of the following is an energy transfer?

A. Kinetic energy
B. Work
C. Potential energy
D. Chemical energy
E. Thermal energy

Reading Question 10.2

Which of the following is an energy transfer?

A. Kinetic energy

✓ B. Work

C. Potential energy

D. Chemical energy

E. Thermal energy

Reading Question 10.3

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.

Reading Question 10.3

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.

Reading Question 10.4

If you hold a heavy weight over your head, the work you do

A. Is greater than zero.
B. Is zero.
C. Is less than zero.
D. Is converted into chemical energy.
E. Is converted into potential energy.

Reading Question 10.4

If you hold a heavy weight over your head, the work you do

A. Is greater than zero.
✓ B. Is zero.
C. Is less than zero.
D. Is converted into chemical energy.
E. Is converted into potential energy.

Reading Question 10.5

The unit of work is

A. The watt.
B. The poise.
C. The hertz.
D. The pascal.
E. The joule.

Reading Question 10.5

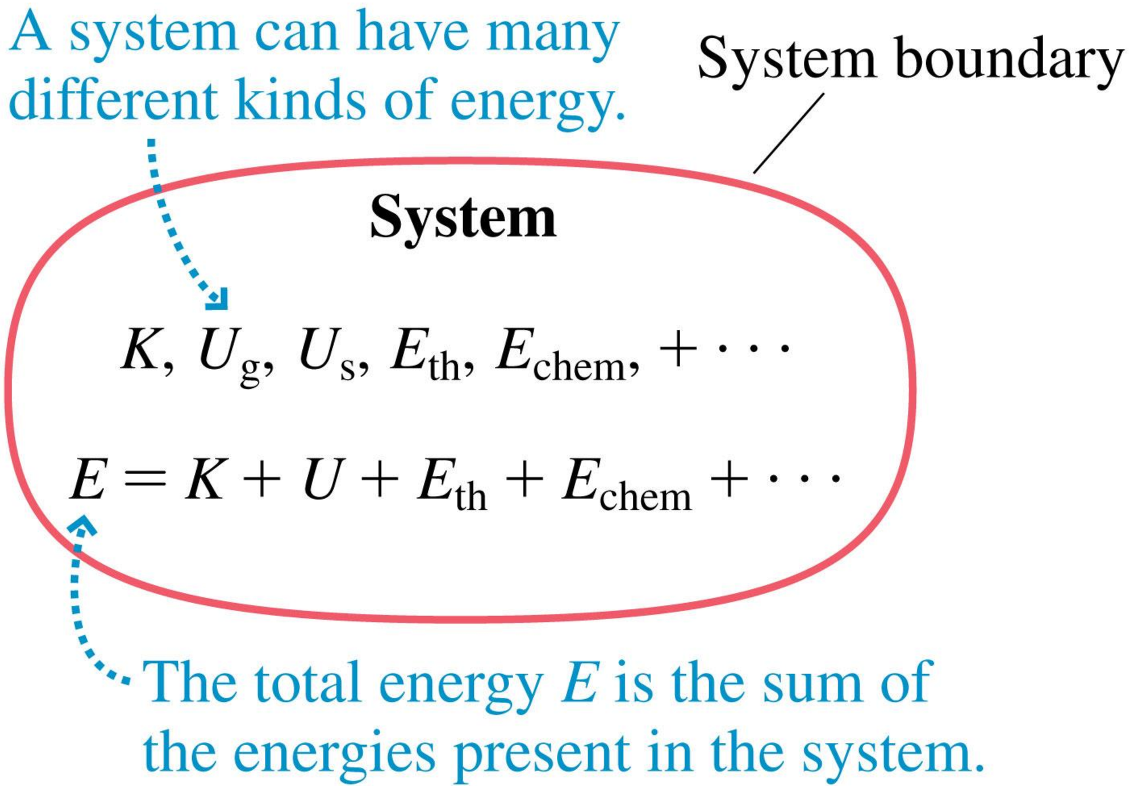
The unit of work is

A. The watt.
B. The poise.
C. The hertz.
D. The pascal.
✓ E. The joule.

Section 10.1 The Basic Energy Model

The Basic Energy Model

Every system in nature has a quantity we call its **total energy** E.


A system can have many different kinds of energy.

System boundary

System

$K, U_g, U_s, E_{th}, E_{chem}, + \cdots$

$E = K + U + E_{th} + E_{chem} + \cdots$

The total energy E is the sum of the energies present in the system.

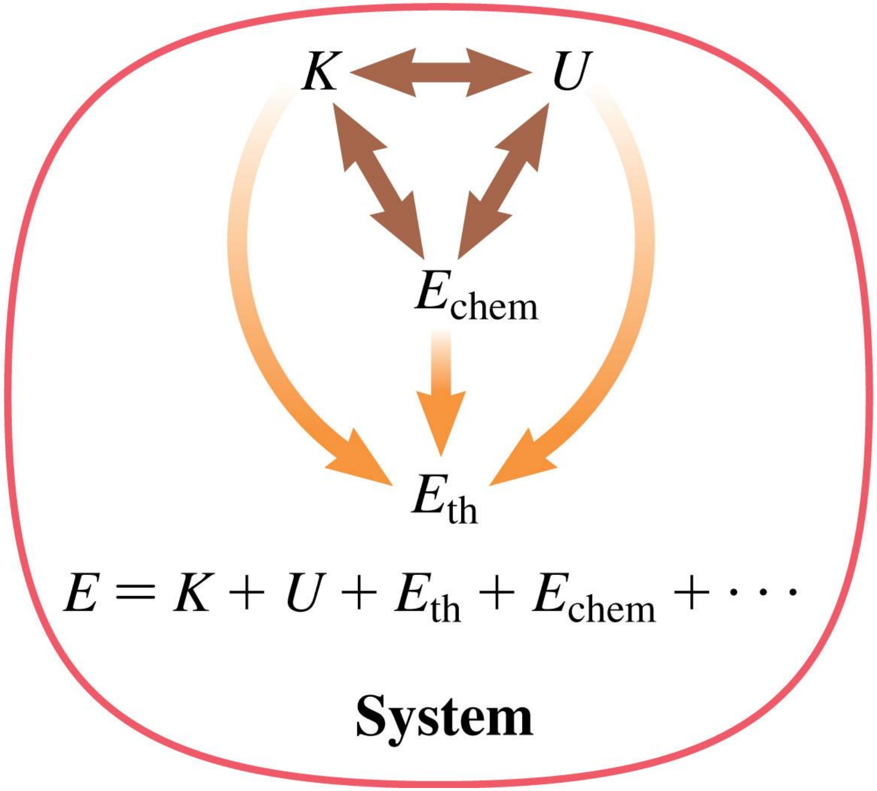
Forms of Energy

Some important forms of energy are

- *Kinetic energy* K: energy of motion.
- *Gravitational potential energy* U_g: stored energy associated with an object's height above the ground.
- *Elastic or spring potential energy* U_s: energy stored when a spring or other elastic object is stretched.
- *Thermal energy* E_{th}: the sum of the kinetic and potential energies of all the molecules in an object.
- *Chemical energy* E_{chem}: energy stored in the bonds between molecules.
- *Nuclear energy* $E_{nuclear}$: energy stored in the mass of the nucleus of an atom.

Energy Transformations

Energy of one kind can be *transformed* into energy of another kind within a system.



Energy Transformations

The weightlifter converts chemical energy in her body into gravitational potential energy of the barbell.

Elastic potential energy of the springboard is converted into kinetic energy. As the diver rises into the air, this kinetic energy is transformed into gravitational potential energy.

QuickCheck 10.1

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

A. $K \rightarrow U_{\text{g}}$
B. $U_{\text{g}} \rightarrow K$
C. $E_{\text{th}} \rightarrow K$
D. $U_{\text{g}} \rightarrow E_{\text{th}}$
E. $K \rightarrow E_{\text{th}}$

QuickCheck 10.1

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

A. $K \rightarrow U_g$

✓ B. $U_g \rightarrow K$

C. $E_{th} \rightarrow K$

D. $U_g \rightarrow E_{th}$

E. $K \rightarrow E_{th}$

QuickCheck 10.2

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

A. $K \rightarrow U_g$
B. $U_g \rightarrow K$
C. $E_{th} \rightarrow K$
D. $U_g \rightarrow E_{th}$
E. $K \rightarrow E_{th}$

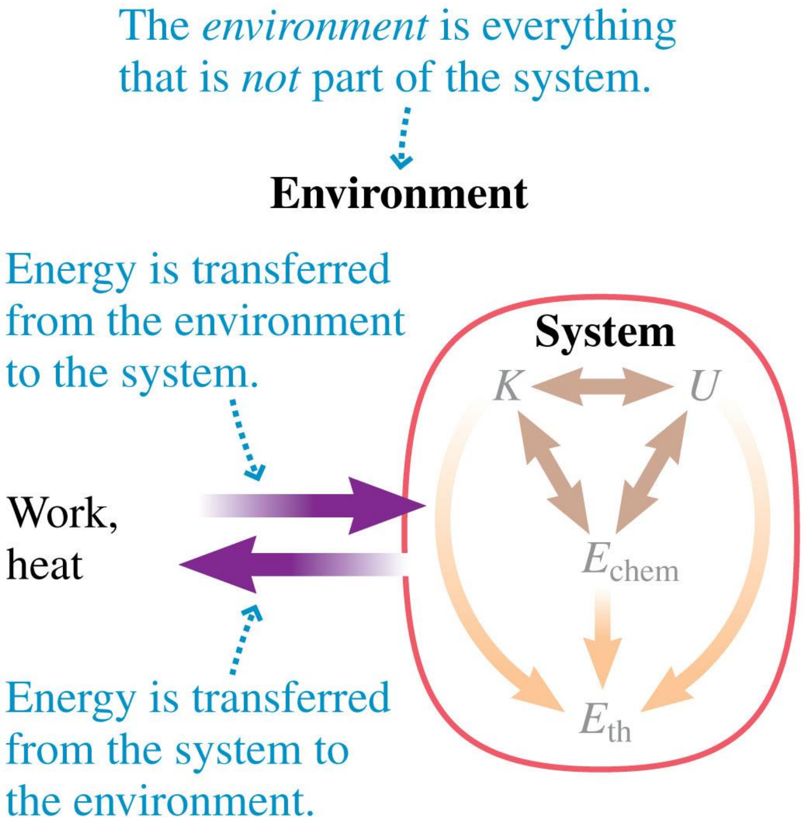
QuickCheck 10.2

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

A. $K \rightarrow U_g$
B. $U_g \rightarrow K$
C. $E_{th} \rightarrow K$
✓ D. $U_g \rightarrow E_{th}$
E. $K \rightarrow E_{th}$

Energy Transfers and Work

- Energy can be *transferred* between a system and its environment through work and heat.
- **Work** is the mechanical transfer of energy to or from a system by pushing or pulling on it.
- **Heat** is the nonmechanical transfer of energy between a system and the environment due to a temperature difference between the two.



The *environment* is everything that is *not* part of the system.

Energy is transferred from the environment to the system.

Energy is transferred from the system to the environment.

Energy Transfers and Work

The athlete does **work** on the shot, giving it kinetic energy, K.

The hand does **work** on the match, giving it thermal energy, E_{th}.

The boy does **work** on the slingshot, giving it elastic potential energy, U_s.

QuickCheck 10.3

A tow rope pulls a skier up the slope at constant speed. What energy transfer (or transfers) is taking place?

A. $W \rightarrow U_g$
B. $W \rightarrow K$
C. $W \rightarrow E_{th}$
D. Both A and B.
E. Both A and C.

QuickCheck 10.3

A tow rope pulls a skier up the slope at constant speed. What energy transfer (or transfers) is taking place?

A. $W \rightarrow U_{\text{g}}$
B. $W \rightarrow K$
C. $W \rightarrow E_{\text{th}}$
D. Both A and B.
✓ E. Both A and C.

The Work-Energy Equation

- Work represents energy that is transferred into or out of a system.
- The total energy of a system changes by the amount of work done on it.

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

- Work can increase or decrease the energy of a system.
- If no energy is transferred into or out of a system, that is an **isolated system**.

QuickCheck 10.4

A crane lowers a girder into place at constant speed. Consider the work W_g done by gravity and the work W_T done by the tension in the cable. Which is true?

A. $W_g > 0$ and $W_T > 0$
B. $W_g > 0$ and $W_T < 0$
C. $W_g < 0$ and $W_T > 0$
D. $W_g < 0$ and $W_T < 0$
E. $W_g = 0$ and $W_T = 0$

QuickCheck 10.4

A crane lowers a girder into place at constant speed. Consider the work W_g done by gravity and the work W_T done by the tension in the cable. Which is true?

- A. $W_g > 0$ and $W_T > 0$
- ✓ B. $W_g > 0$ and $W_T < 0$
- C. $W_g < 0$ and $W_T > 0$
- D. $W_g < 0$ and $W_T < 0$
- E. $W_g = 0$ and $W_T = 0$

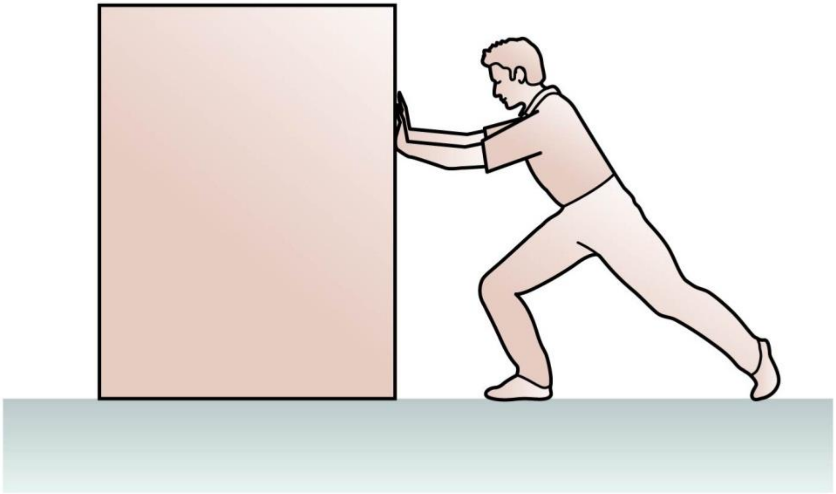
The downward force of gravity is in the direction of motion $\Rightarrow$ positive work.

The upward tension is in the direction opposite the motion $\Rightarrow$ negative work.

QuickCheck 10.5

Robert pushes the box to the left at constant speed. In doing so, Robert does _______ work on the box.

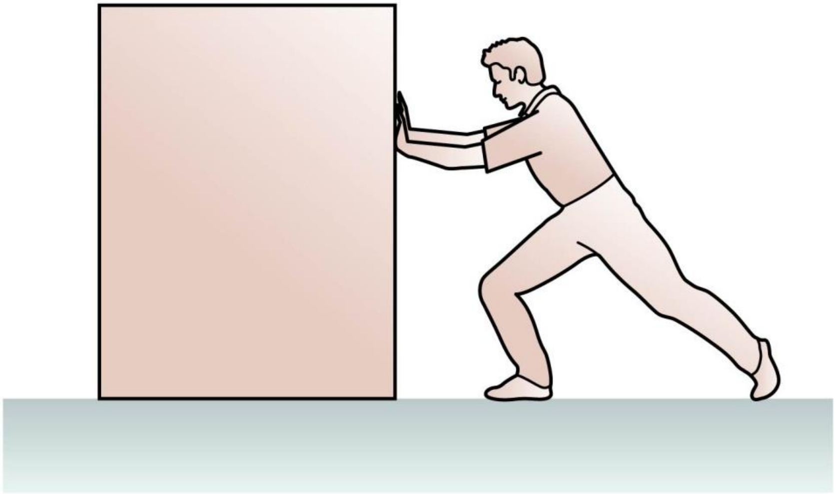
A. positive
B. negative
C. zero



QuickCheck 10.5

Robert pushes the box to the left at constant speed. In doing so, Robert does _______ work on the box.

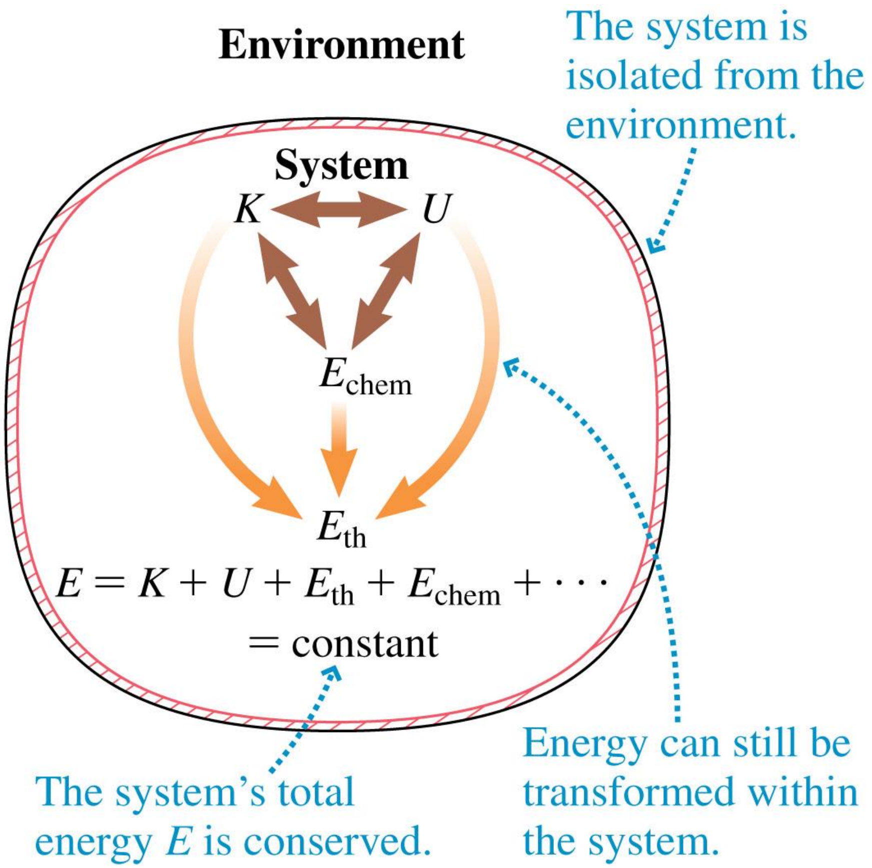
- ✓ A. positive
- B. negative
- C. zero



Force is in the direction of displacement ⇒ positive work

The Law of Conservation of Energy

The total energy of an isolated system remains constant.



$$E = K + U + E_{\text{th}} + E_{\text{chem}} + \cdots$$
$$= \text{constant}$$

The system is isolated from the environment.

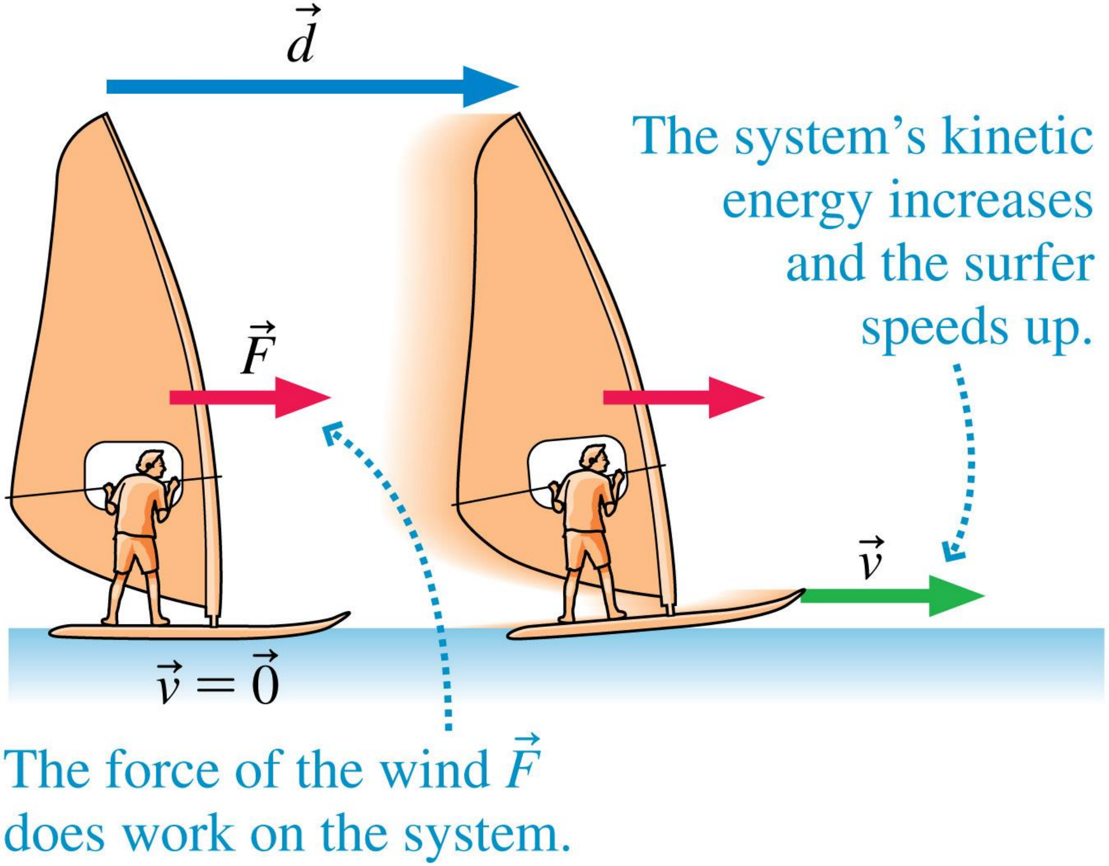
Energy can still be transformed within the system.

The system's total energy E is conserved.

Section 10.2 Work

Work

Work is done on a system by **external forces**: forces from outside the system.



Calculating Work

$$W = Fd$$

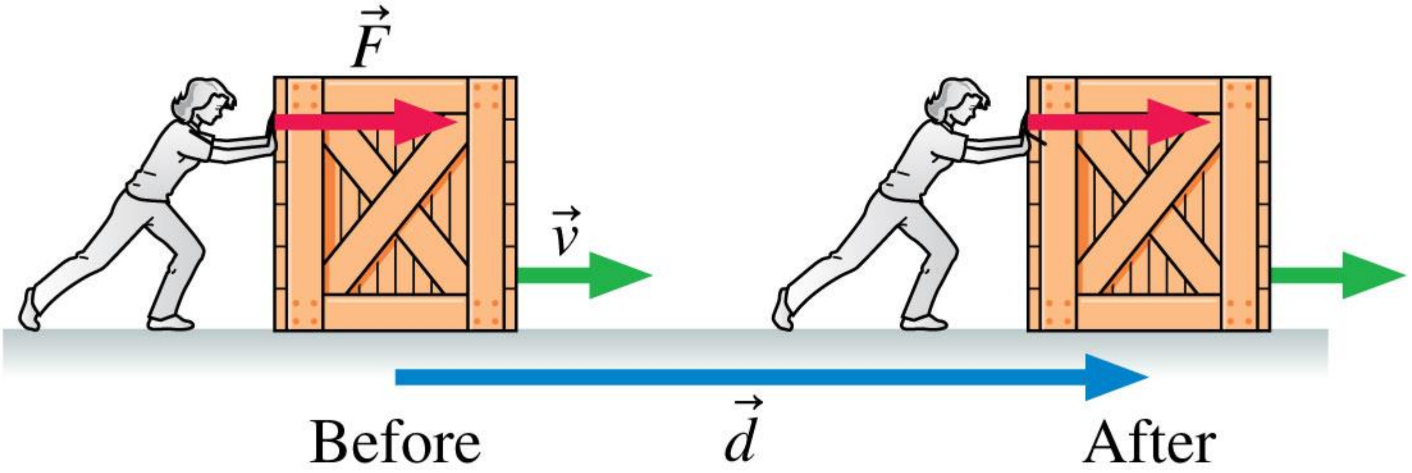
Work done by a constant force $\vec{F}$ in the direction of a displacement $\vec{d}$

- Although both the force and the displacement are vectors, work is a scalar.
- The unit of work (and energy) is:

$$1 \text{ joule} = 1 \text{ J} = 1 \text{ N} \cdot \text{m}$$

Example 10.1 Work done in pushing a crate

Sarah pushes a heavy crate 3.0 m along the floor at a constant speed. She pushes with a constant horizontal force of magnitude 70 N. How much work does Sarah do on the crate?



Known

$F = 70\text{ N}$
$d = 3.0\text{ m}$
$v = \text{constant}$

Find

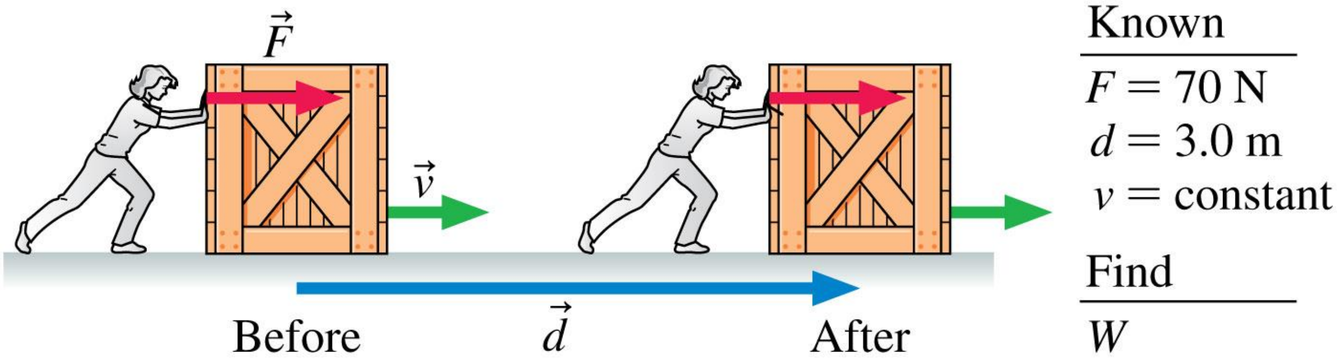
W

Example 10.1 Work done in pushing a crate (cont.)

PREPARE We begin with the before-and-after visual overview in FIGURE 10.6. Sarah pushes with a constant force in the direction of the crate's motion, so we can use Equation 10.5 to find the work done.

SOLVE The work done by Sarah is

$$W = Fd = (70\ \text{N})(3.0\ \text{m}) = 210\ \text{J}$$



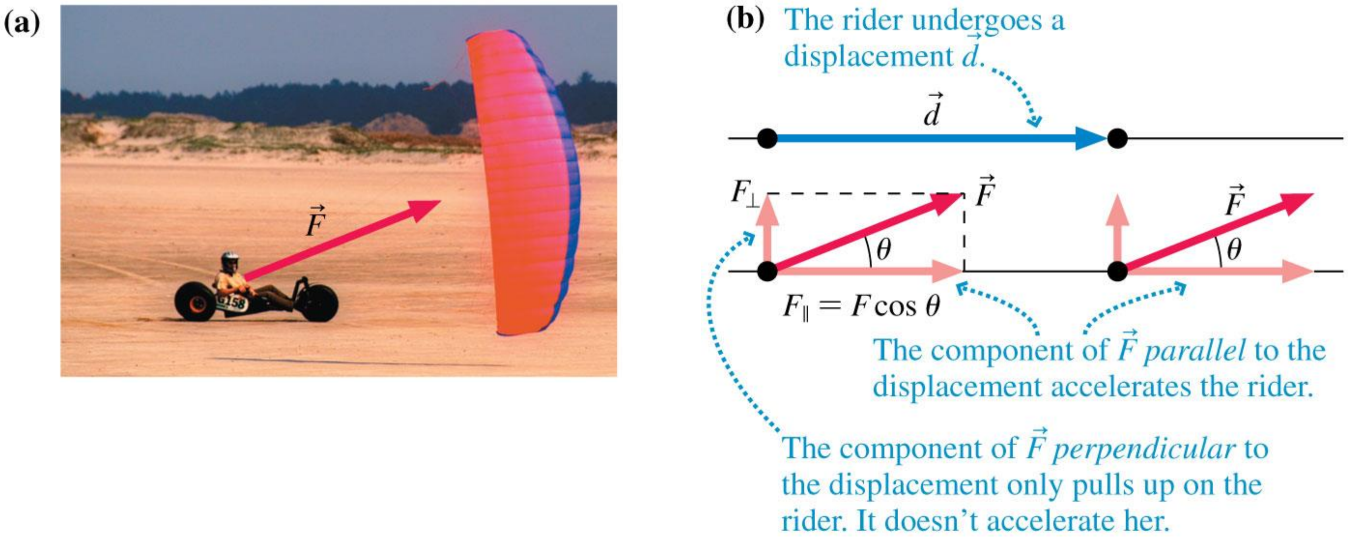
By pushing on the crate Sarah increases its kinetic energy, so it makes sense that the work done is positive.

Force at an Angle to the Displacement

- Only the component of a force in the direction of displacement does work.

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

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



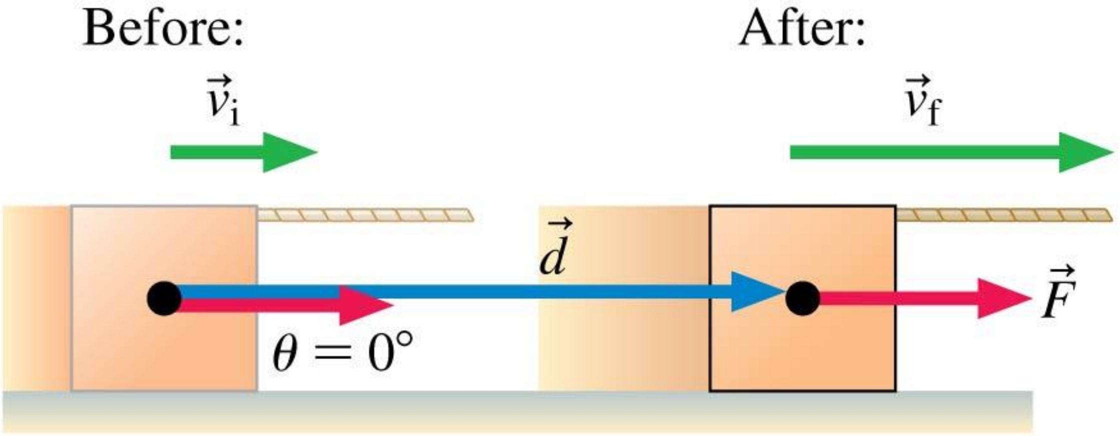
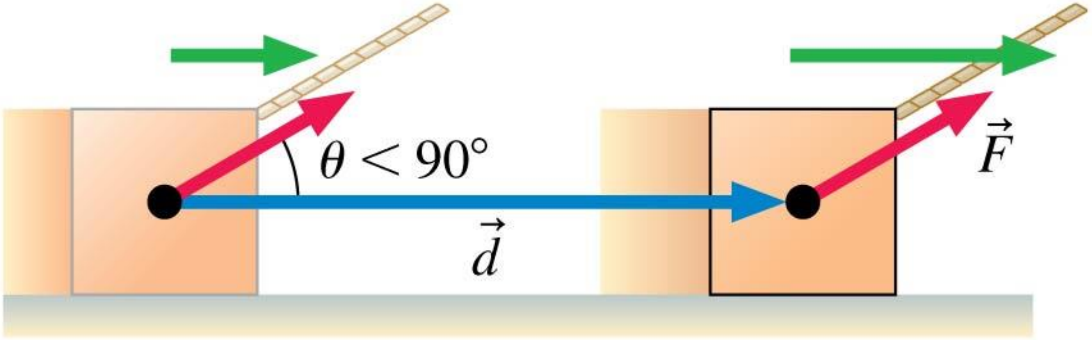
The rider undergoes a displacement $\vec{d}$.

The component of $\vec{F}$ *parallel* to the displacement accelerates the rider.

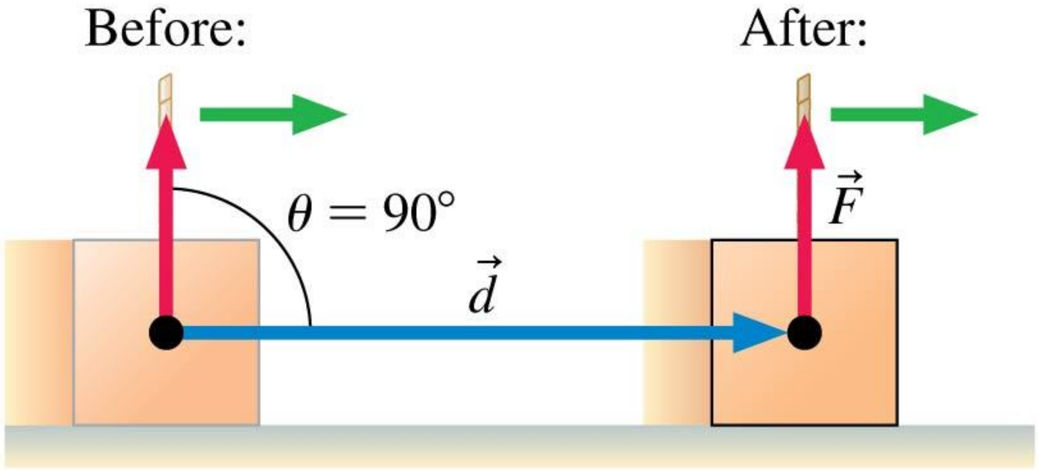
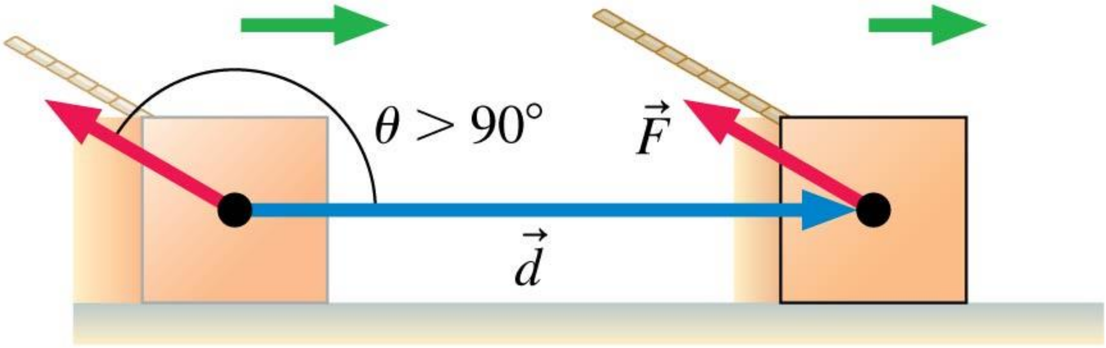
The component of $\vec{F}$ *perpendicular* to the displacement only pulls up on the rider. It doesn't accelerate her.

- If the force is at an angle θ to the displacement, the component of the force, F, that does work is $F\cos\theta$.

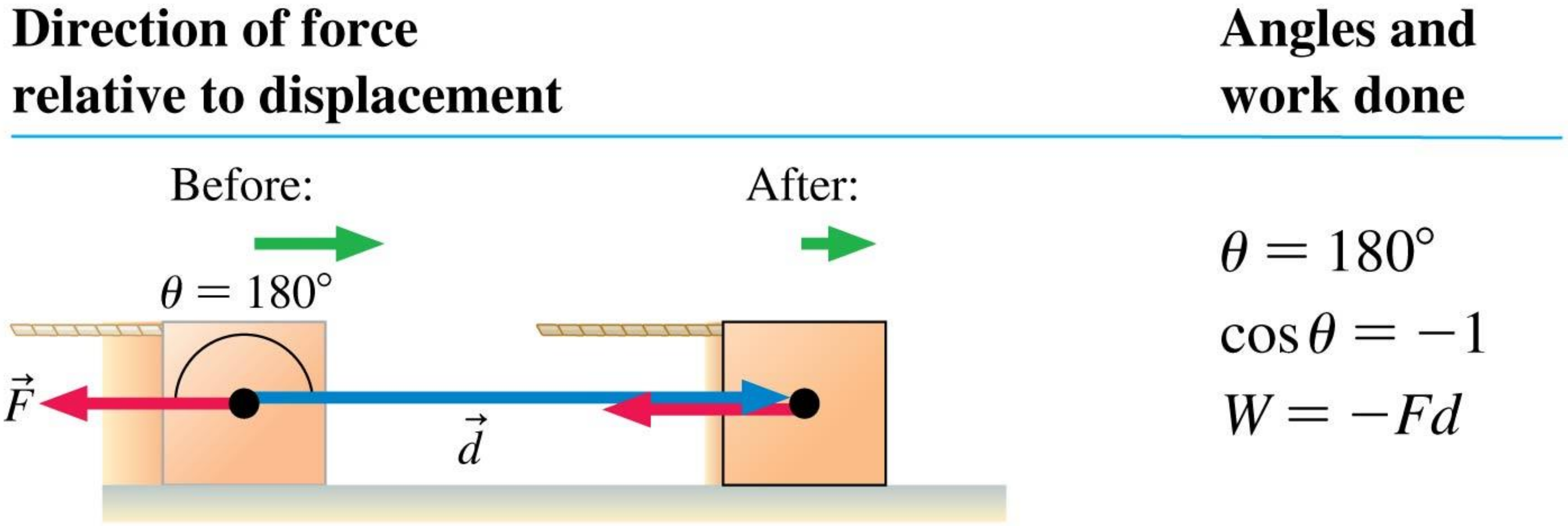
Force at an Angle to the Displacement

Direction of force relative to displacement	**Angles and work done**
	$\theta = 0°$ $\cos\theta = 1$ $W = Fd$
	$\theta < 90°$ $W = Fd\cos\theta$

Force at an Angle to the Displacement

Direction of force relative to displacement	**Angles and work done**
	$\theta = 90°$ $\cos\theta = 0$ $W = 0$
	$\theta > 90°$ $W = Fd\cos\theta$

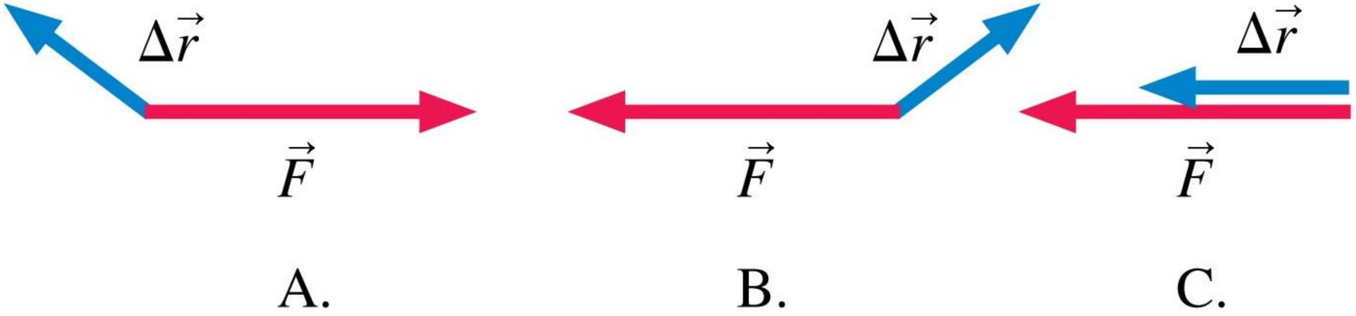
Force at an Angle to the Displacement



The sign of W is determined by the angle θ between the force and the displacement.

QuickCheck 10.6

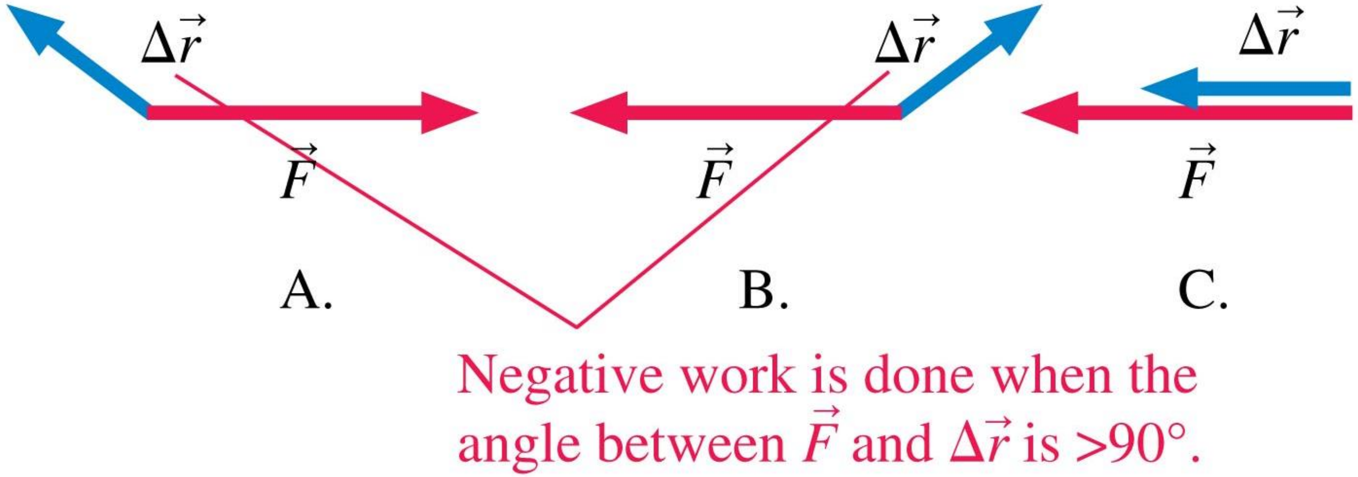
A constant force $\vec{F}$ pushes a particle through a displacement $\Delta\vec{r}$. In which of these three cases does the force do negative work?



D. Both A and B.
E. Both A and C.

QuickCheck 10.6

A constant force $\vec{F}$ pushes a particle through a displacement $\Delta\vec{r}$. In which of these three cases does the force do negative work?



✔ D. Both A and B.

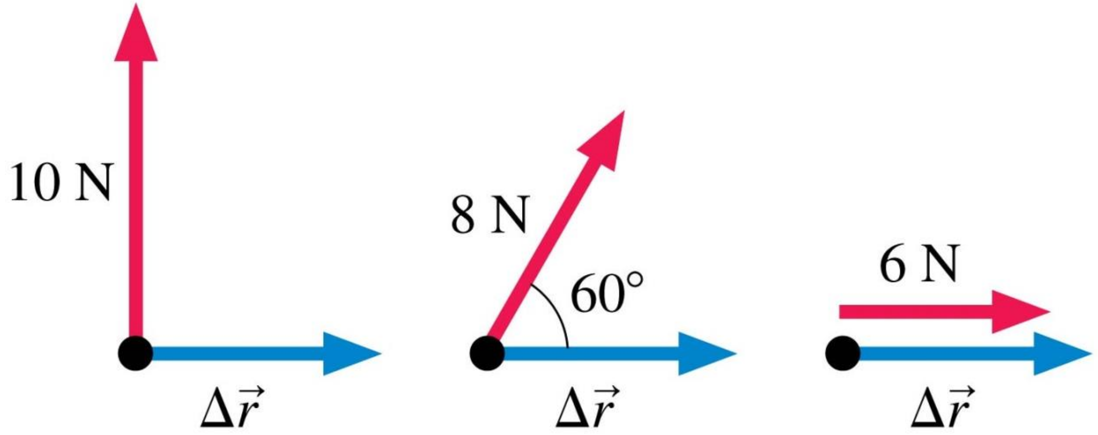
E. Both A and C.

QuickCheck 10.7

Which force below does the most work? All three displacements are the same.

A. The 10 N force.
B. The 8 N force
C. The 6 N force.
D. They all do the same work.

sin60° = 0.87
cos60° = 0.50

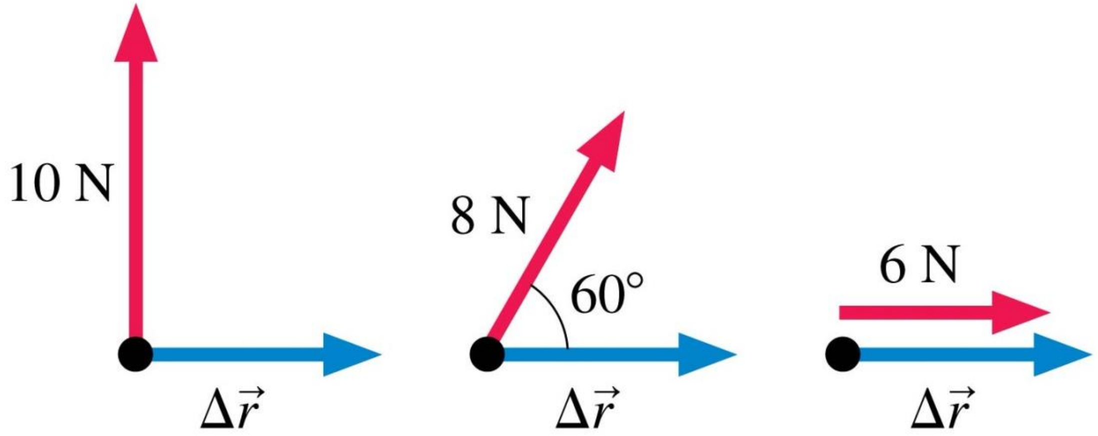


QuickCheck 10.7

Which force below does the most work? All three displacements are the same.

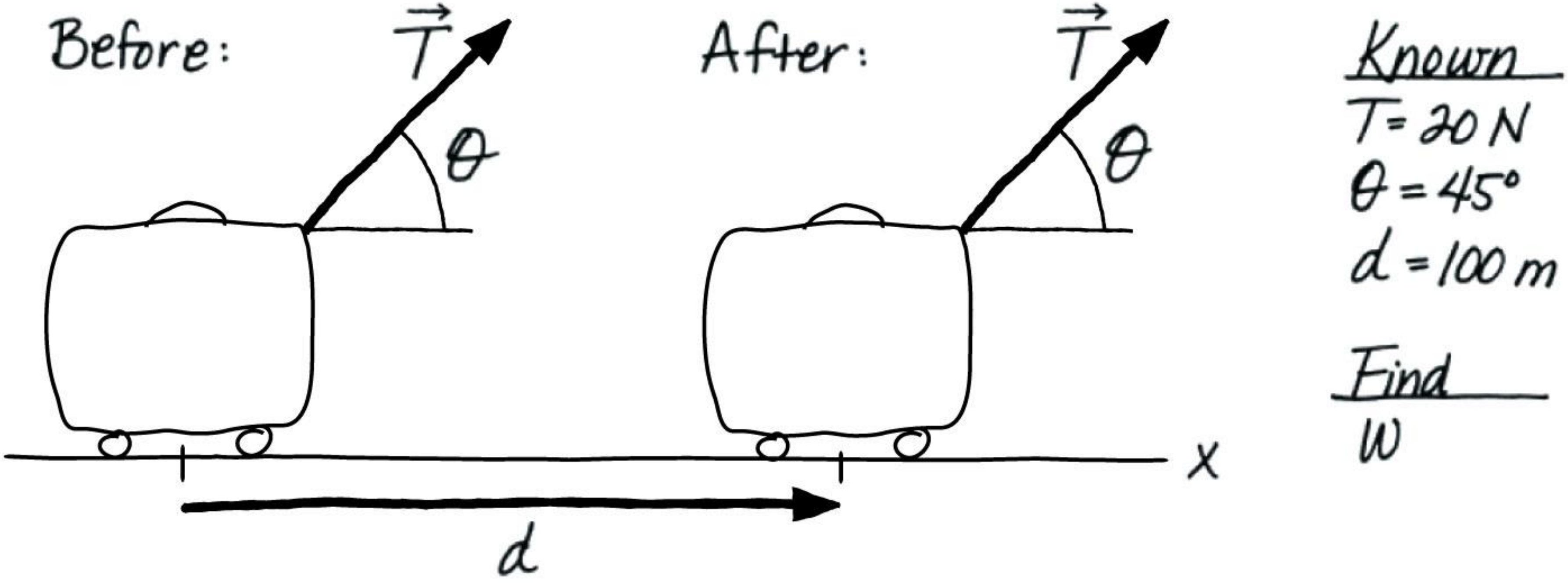
A. The 10 N force.
B. The 8 N force
✓ C. The 6 N force.
D. They all do the same work.

$\sin 60° = 0.87$
$\cos 60° = 0.50$



Example 10.2 Work done in pulling a suitcase

A strap inclined upward at a 45° angle pulls a suitcase through the airport. The tension in the strap is 20 N. How much work does the tension do if the suitcase is pulled 100 m at a constant speed?



Example 10.2 Work done in pulling a suitcase (cont.)

PREPARE FIGURE 10.8 shows a visual overview. Since the suitcase moves at a constant speed, there must be a rolling friction force (not shown) acting to the left.

SOLVE We can use Equation 10.6 , with force $F = T$, to find that the tension does work:

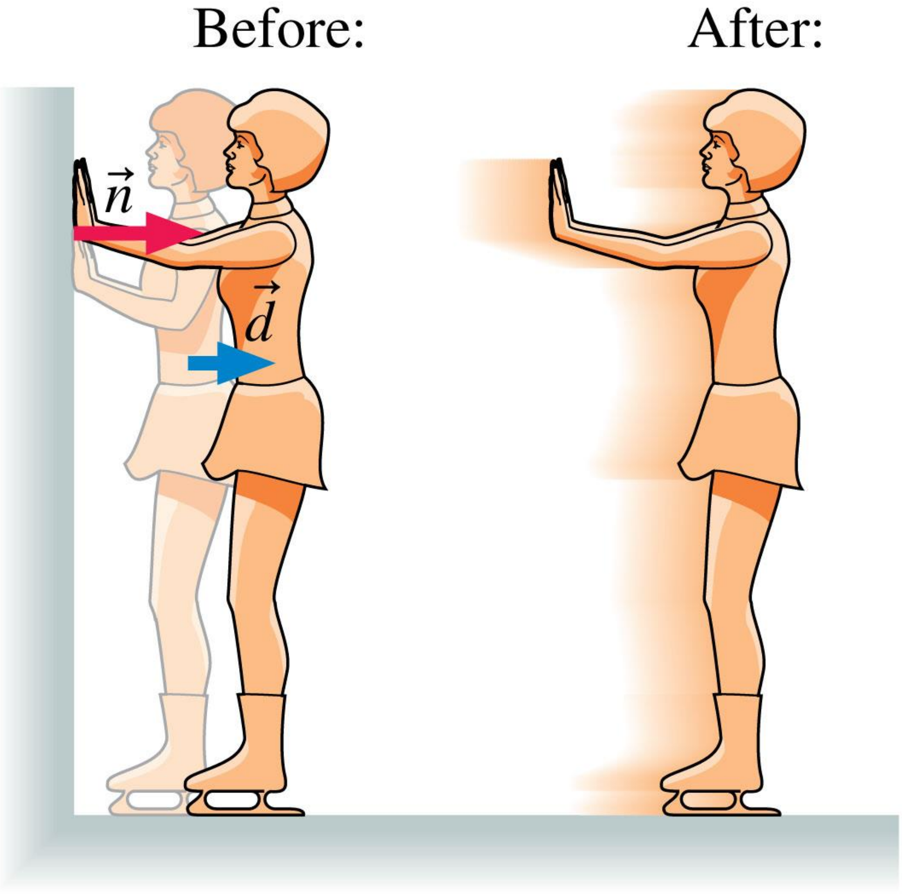
$$W = Td \cos \theta = (20 \text{ N})(100 \text{ m})\cos 45^\circ = 1400 \text{ J}$$

The tension is needed to do work on the suitcase even though the suitcase is traveling at a constant speed to overcome friction. So it makes sense that the work is positive. The work done goes entirely into increasing the thermal energy of the suitcase and the floor.

Forces That Do No Work

A force does no work on an object if

- The object undergoes no displacement.
- The force is perpendicular to the displacement.
- The part of the object on which the force acts undergoes no displacement (even if other parts of the object do move).



Text: p. 291

QuickCheck 10.8

I swing a ball around my head at constant speed in a circle with circumference 3 m. What is the work done on the ball by the 10 N tension force in the string during one revolution of the ball?

A. 30 J
B. 20 J
C. 10 J
D. 0 J

QuickCheck 10.8

I swing a ball around my head at constant speed in a circle with circumference 3 m. What is the work done on the ball by the 10 N tension force in the string during one revolution of the ball?

A. 30 J
B. 20 J
[✓ C. 10 J]
D. 0 J

Section 10.3 Kinetic Energy

Kinetic Energy

- Kinetic energy is energy of motion.
- Kinetic energy can be in two forms: **translational**, for motion of an object along a path; and **rotational**, for the motion of an object around an axis.

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

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

$$K_{\text{rot}} = \frac{1}{2}I\omega^2$$

Rotational kinetic energy of an object with moment of inertia I and angular velocity ω

QuickCheck 10.9

Ball A has half the mass and eight times the kinetic energy of ball B. What is the speed ratio v_A/v_B?

A. 16
B. 4
C. 2
D. 1/4
E. 1/16

QuickCheck 10.9

Ball A has half the mass and eight times the kinetic energy of ball B. What is the speed ratio v_A/v_B?

A. 16

✓ B. 4

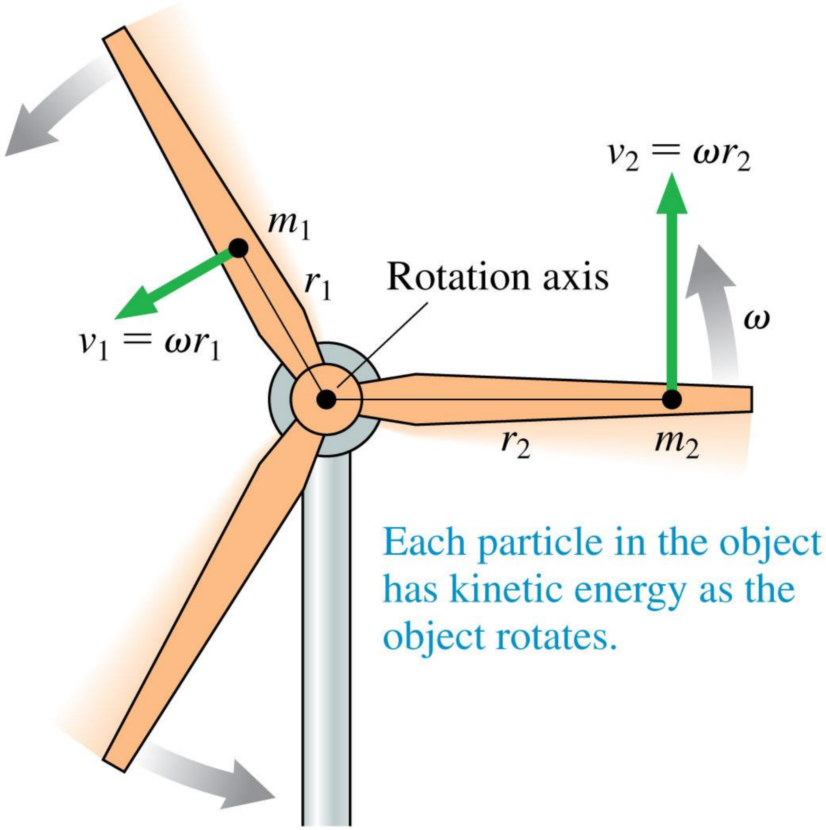
C. 2

D. 1/4

E. 1/16

Rotational Kinetic Energy

- Rotational kinetic energy is a way of expressing the sum of the kinetic energy of all the parts of a rotating object.
- In rotational kinetic energy, the moment of inertia takes the place of mass and the angular velocity takes the place of linear velocity.



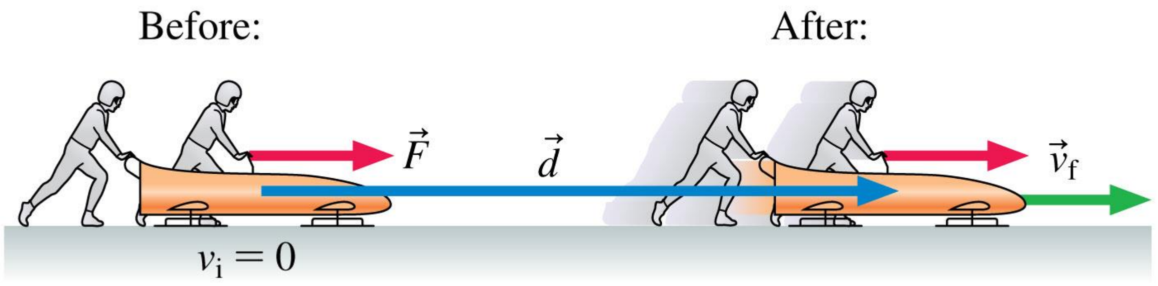
Each particle in the object has kinetic energy as the object rotates.

Example 10.5 Speed of a bobsled after pushing

A two-man bobsled has a mass of 390 kg. Starting from rest, the two racers push the sled for the first 50 m with a net force of 270 N. Neglecting friction, what is the sled's speed at the end of the 50 m?

Example 10.5 Speed of a bobsled after pushing (cont.)

PREPARE Because friction is negligible, there is no change in the sled’s thermal energy. And, because the sled’s height is constant, its gravitational potential energy is unchanged as well. Thus the work-energy equation is simply $\Delta K = W$. We can therefore find the sled’s final kinetic energy, and hence its speed, by finding the work done by the racers as they push on the sled. The figure lists the known quantities and the quantity v_f that we want to find.



Known

$m = 390$ kg $F = 270$ N
$d = 50$ m $v_i = 0$ m/s

Find: v_f

The work done by the pushers increases the sled’s kinetic energy.

Example 10.5 Speed of a bobsled after pushing (cont.)

SOLVE From the work-energy equation, Equation 10.3, the change in the sled's kinetic energy is $\Delta K = K_f - K_i = W$. The sled's final kinetic energy is thus

$$K_f = K_i + W$$

Using our expressions for kinetic energy and work, we get

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + Fd$$

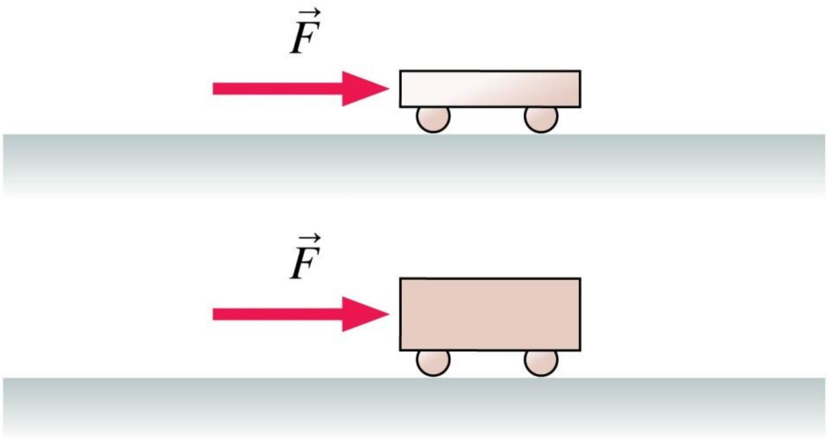
Because $v_i = 0$, the work-energy equation reduces to $\frac{1}{2}mv_f^2 = Fd$.

We can solve for the final speed to get

$$v_f = \sqrt{\frac{2Fd}{m}} = \sqrt{\frac{2(270 \text{ N})(50 \text{ m})}{390 \text{ kg}}} = 8.3 \text{ m/s}$$

QuickCheck 10.10

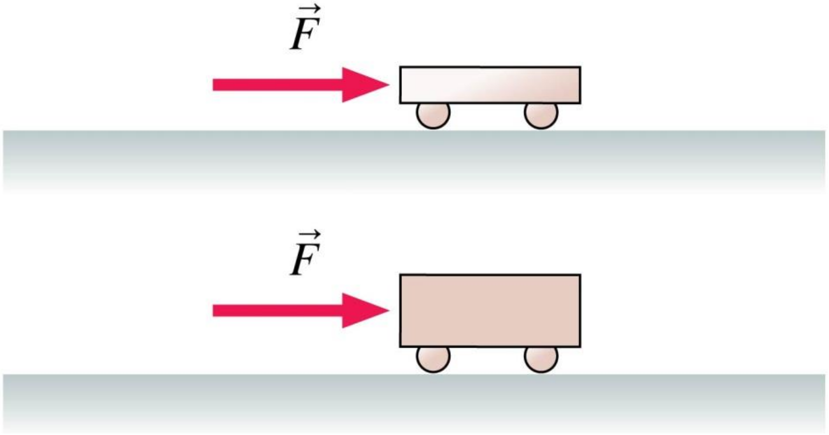
A light plastic cart and a heavy steel cart are both pushed with the same force for a distance of 1.0 m, starting from rest. After the force is removed, the kinetic energy of the light plastic cart is _________ that of the heavy steel cart.



A. greater than
B. equal to
C. less than
D. Can’t say. It depends on how big the force is.

QuickCheck 10.10

A light plastic cart and a heavy steel cart are both pushed with the same force for a distance of 1.0 m, starting from rest. After the force is removed, the kinetic energy of the light plastic cart is _________ that of the heavy steel cart.



A. greater than

✓ B. equal to

C. less than

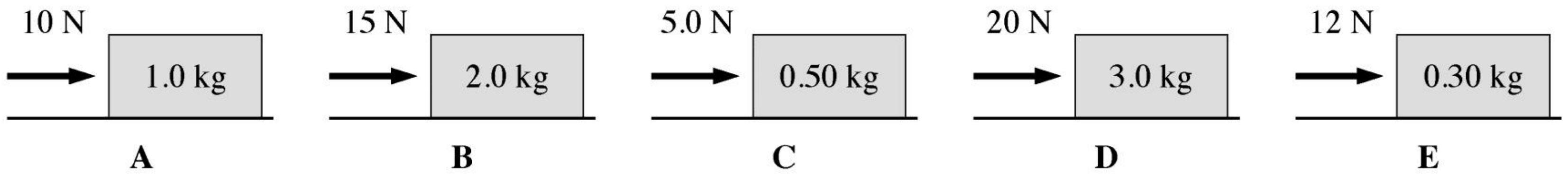
D. Can't say. It depends on how big the force is.

Same force, same distance $\Rightarrow$ same work done

Same work $\Rightarrow$ change of kinetic energy

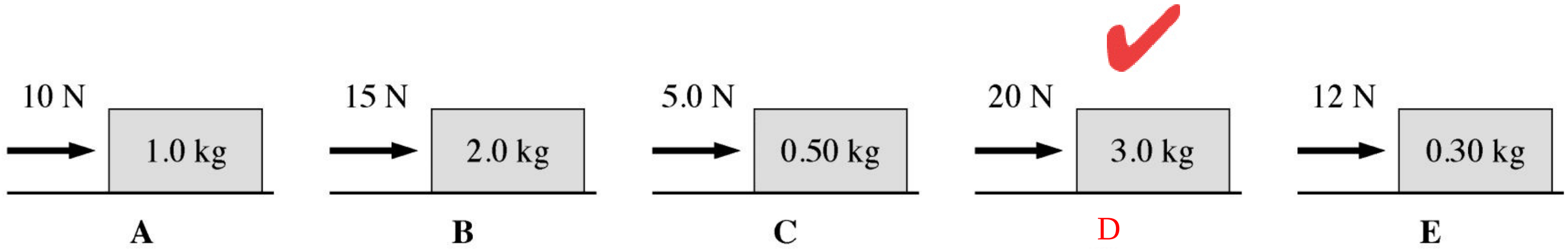
QuickCheck 10.11

Each of the boxes shown is pulled for 10 m across a level, frictionless floor by the force given. Which box experiences the greatest change in its kinetic energy?



QuickCheck 10.11

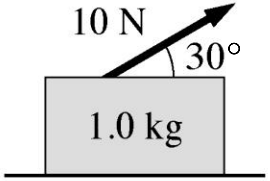
Each of the boxes shown is pulled for 10 m across a level, frictionless floor by the force given. Which box experiences the greatest change in its kinetic energy?



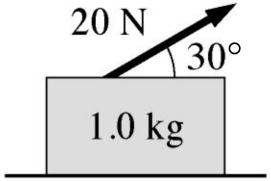
Work-energy equation: $\Delta K = W = Fd$. All have same d, so largest work (and hence largest ΔK) corresponds to largest force.

QuickCheck 10.12

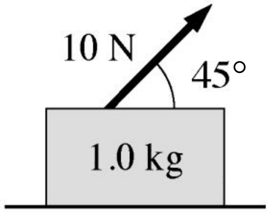
Each of the 1.0 kg boxes starts at rest and is then is pulled for 2.0 m across a level, frictionless floor by a rope with the noted force at the noted angle. Which box has the highest final speed?



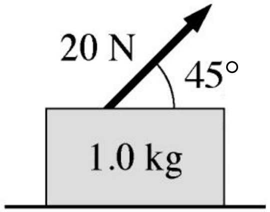
A



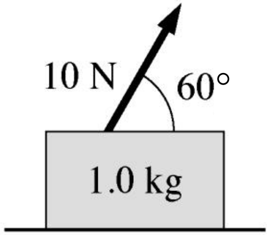
B



C



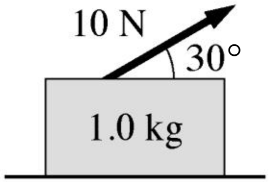
D



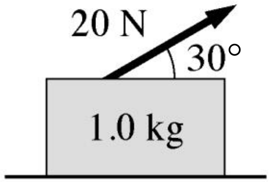
E

QuickCheck 10.12

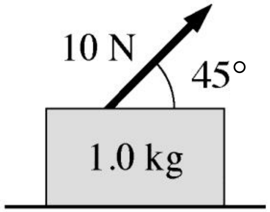
Each of the 1.0 kg boxes starts at rest and is then is pulled for 2.0 m across a level, frictionless floor by a rope with the noted force at the noted angle. Which box has the highest final speed?



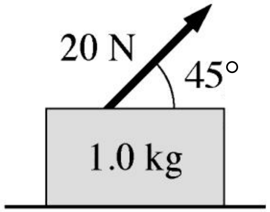
A



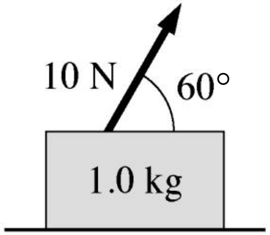
[✓ B]



C



D



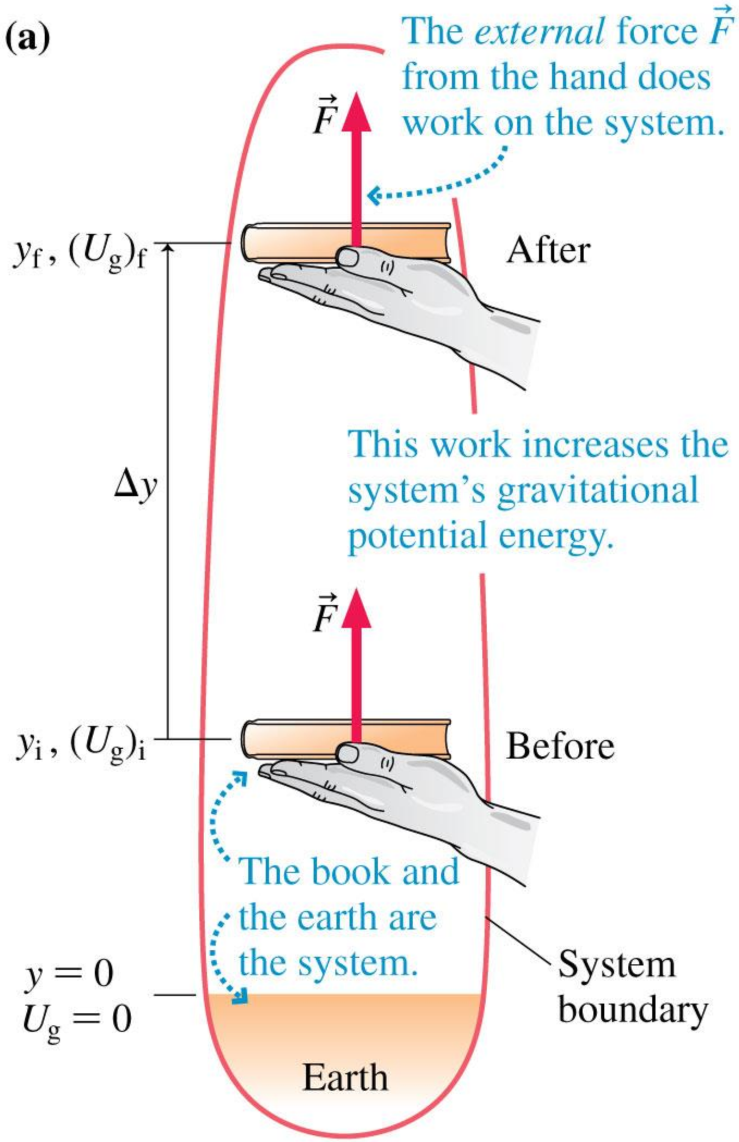
E

Section 10.4 Potential Energy

Potential Energy

- Potential energy is stored energy that can be readily converted to other forms of energy, such as kinetic or thermal energy.
- Forces that can store useful energy are **conservative forces**:
  - Gravity
  - Elastic forces
- Forces such as friction that cannot store useful energy are **nonconservative forces**.

Gravitational Potential Energy



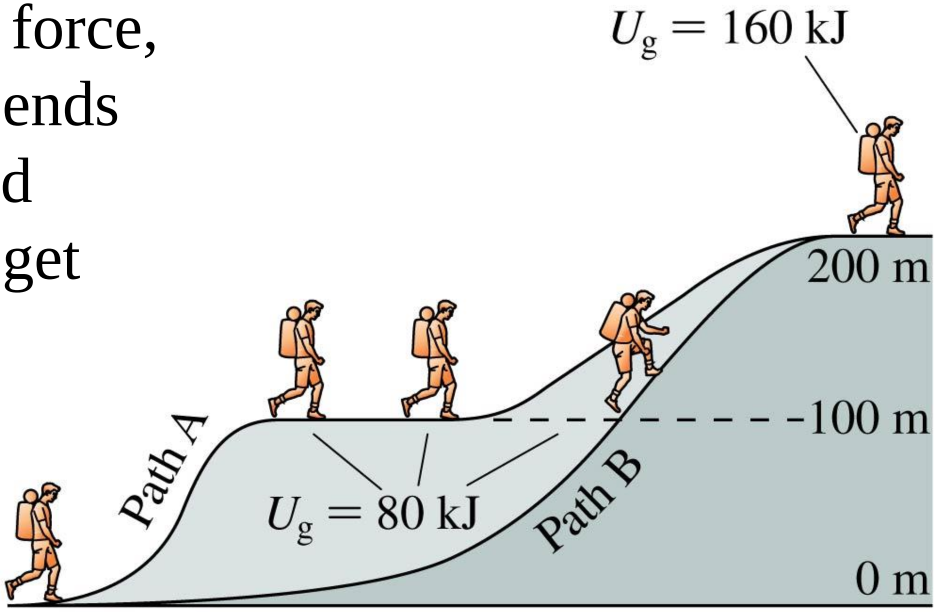
The change in gravitational potential energy is proportional to the change in its height.

Gravitational Potential Energy

$$U_g = mgy$$

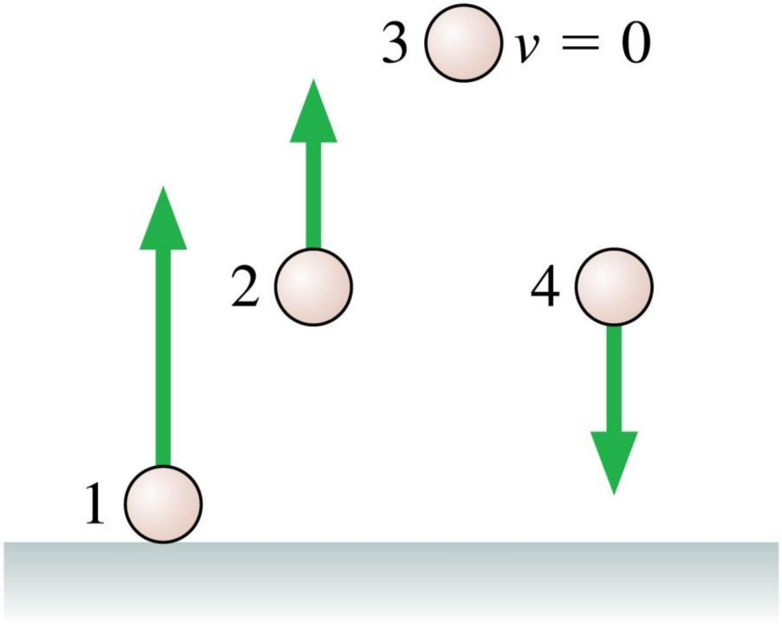
Gravitational potential energy of an object of mass m at height y (assuming $U_g = 0$ when the object is at $y = 0$)

- We can choose the reference level where gravitational potential energy $U_g = 0$ since only changes in U_g matter.
- Because gravity is a conservative force, gravitational potential energy depends only on the height of an object and not on the path the object took to get to that height.



QuickCheck 10.13

Rank in order, from largest to smallest, the gravitational potential energies of the balls.

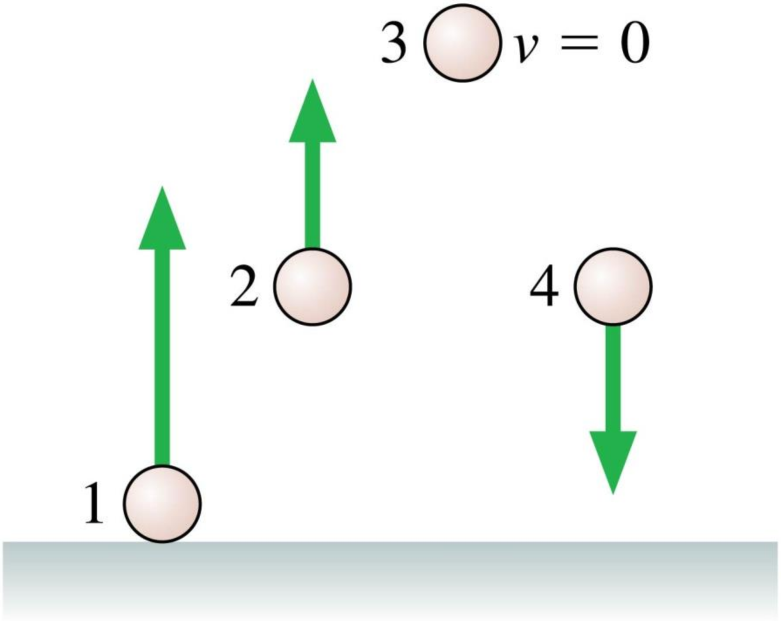


A. 1 > 2 = 4 > 3
B. 1 > 2 > 3 > 4
C. 3 > 2 > 4 > 1
D. 3 > 2 = 4 > 1

QuickCheck 10.13

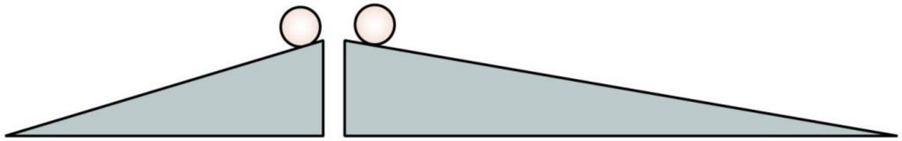
Rank in order, from largest to smallest, the gravitational potential energies of the balls.

A. 1 > 2 = 4 > 3
B. 1 > 2 > 3 > 4
C. 3 > 2 > 4 > 1
✓ D. 3 > 2 = 4 > 1



QuickCheck 10.14

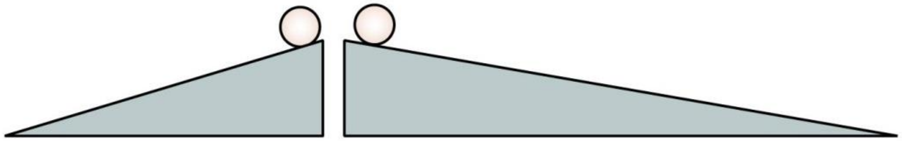
Starting from rest, a marble first rolls down a steeper hill, then down a less steep hill of the same height. For which is it going faster at the bottom?



A. Faster at the bottom of the steeper hill.
B. Faster at the bottom of the less steep hill.
C. Same speed at the bottom of both hills.
D. Can’t say without knowing the mass of the marble.

QuickCheck 10.14

Starting from rest, a marble first rolls down a steeper hill, then down a less steep hill of the same height. For which is it going faster at the bottom?

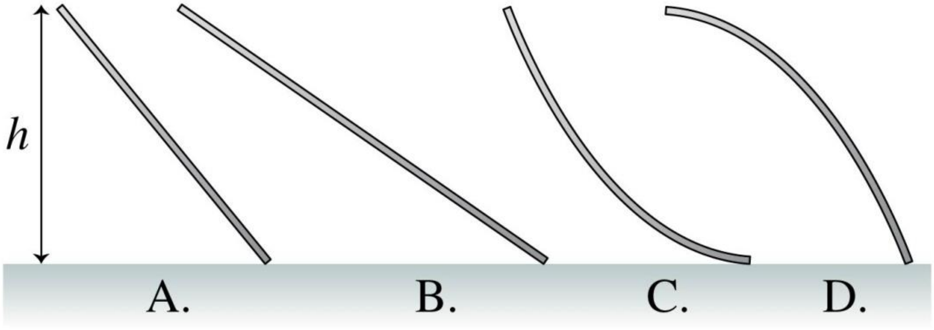


A. Faster at the bottom of the steeper hill.
B. Faster at the bottom of the less steep hill.
✓ C. Same speed at the bottom of both hills.
D. Can’t say without knowing the mass of the marble.

QuickCheck 10.15

A small child slides down the four frictionless slides A–D. Rank in order, from largest to smallest, her speeds at the bottom.

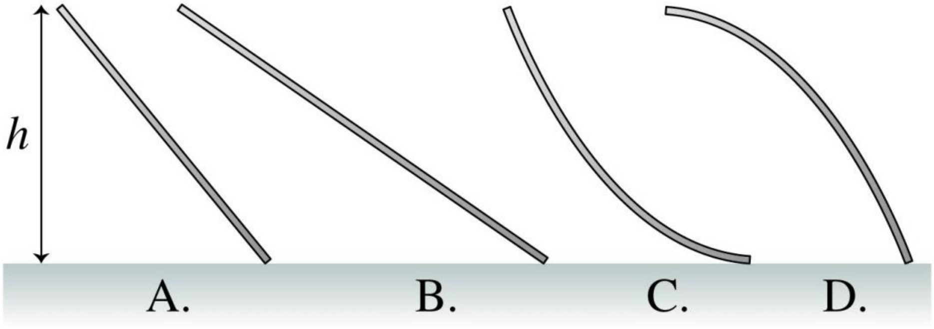
A. $v_D > v_A > v_B > v_C$
B. $v_D > v_A = v_B > v_C$
C. $v_C > v_A > v_B > v_D$
D. $v_A = v_B = v_C = v_D$



QuickCheck 10.15

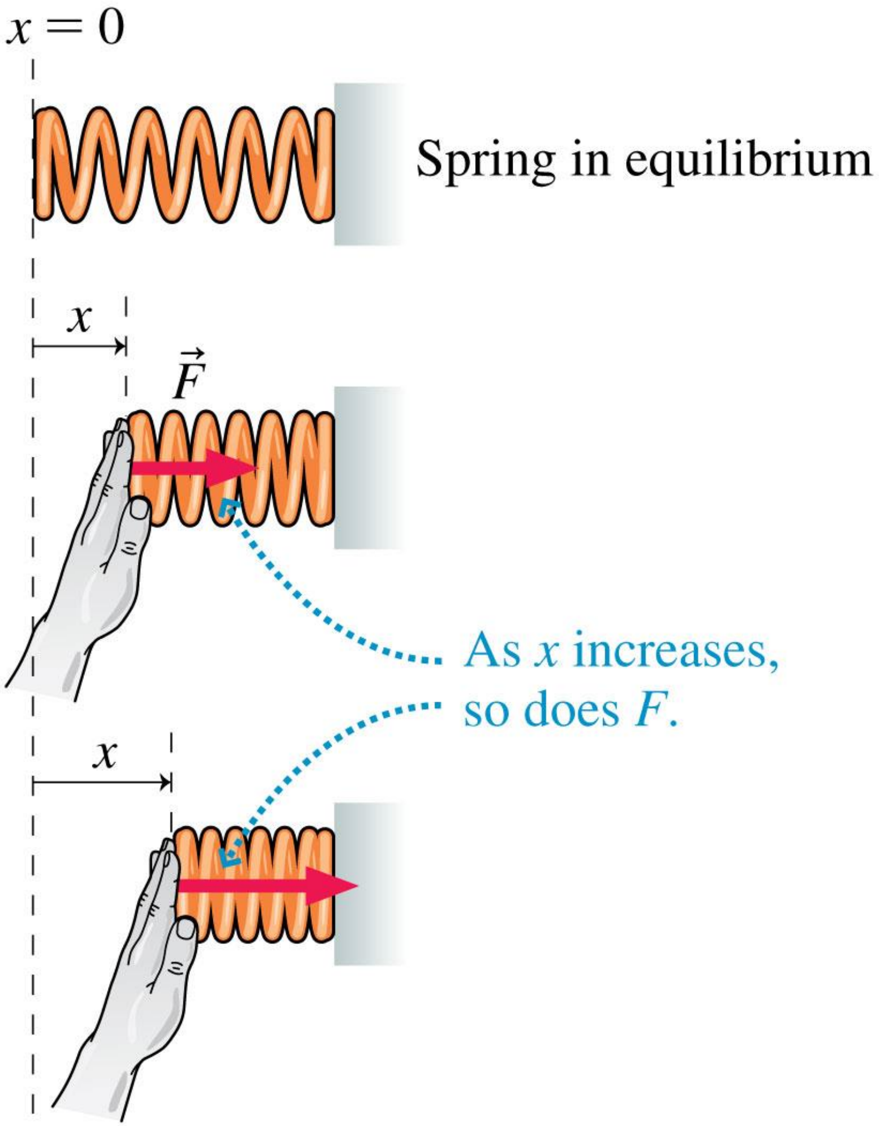
A small child slides down the four frictionless slides A–D. Rank in order, from largest to smallest, her speeds at the bottom.

A. $v_D > v_A > v_B > v_C$
B. $v_D > v_A = v_B > v_C$
C. $v_C > v_A > v_B > v_D$
✓ D. $v_A = v_B = v_C = v_D$



Elastic Potential Energy

- Elastic (or spring) potential energy is stored when a force compresses a spring.
- Hooke’s law describes the force required to compress a spring.



Elastic Potential Energy

The elastic potential energy stored in a spring is determined by the average force required to compress the spring from its equilibrium length.

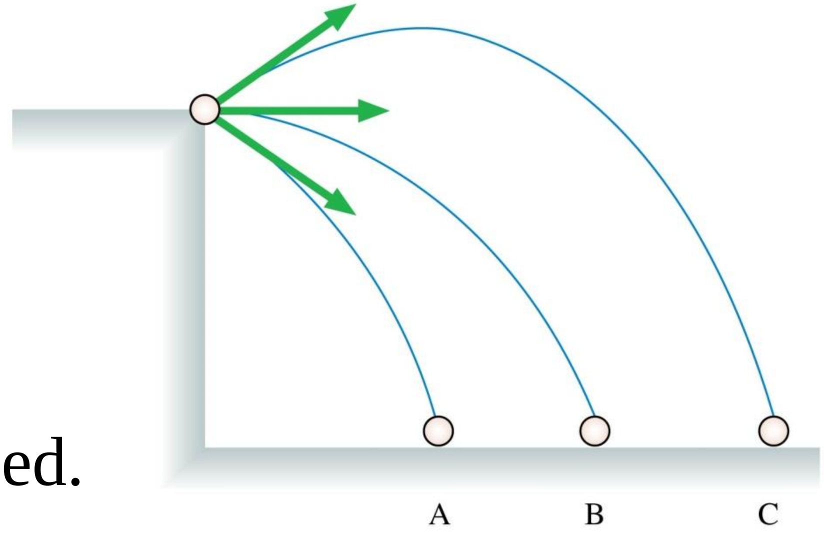
$$U_s = \frac{1}{2}kx^2$$

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

QuickCheck 10.16

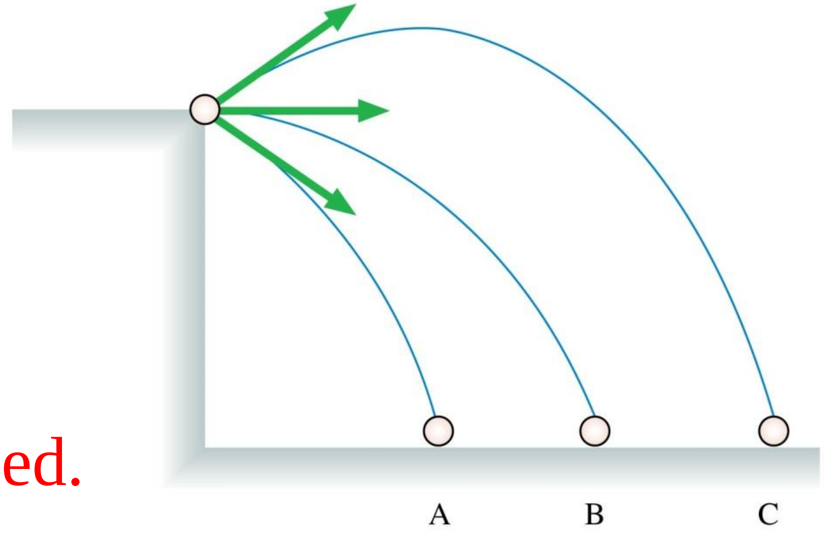
Three balls are thrown from a cliff with the same speed but at different angles. Which ball has the greatest speed just before it hits the ground?

A. Ball A.
B. Ball B.
C. Ball C.
D. All balls have the same speed.



QuickCheck 10.16

Three balls are thrown from a cliff with the same speed but at different angles. Which ball has the greatest speed just before it hits the ground?



A. Ball A.
B. Ball B.
C. Ball C.
✓ D. All balls have the same speed.

QuickCheck 10.17

A hockey puck sliding on smooth ice at 4 m/s comes to a 1-m-high hill. Will it make it to the top of the hill?

A. Yes.
B. No.
C. Can’t answer without knowing the mass of the puck.
D. Can’t say without knowing the angle of the hill.

QuickCheck 10.17

A hockey puck sliding on smooth ice at 4 m/s comes to a 1-m-high hill. Will it make it to the top of the hill?

A. Yes.

✓ B. No.

$$\frac{1}{2}mv^2 = mgy \text{ requires } v^2 = 2gy \approx 20\ \text{m}^2/\text{s}^2$$

C. Can’t answer without knowing the mass of the puck.

D. Can’t say without knowing the angle of the hill.

Example 10.8 Pulling back on a bow

An archer pulls back the string on her bow to a distance of 70 cm from its equilibrium position. To hold the string at this position takes a force of 140 N. How much elastic potential energy is stored in the bow?

PREPARE A bow is an elastic material, so we will model it as obeying Hooke's law, $F_s = -kx$, where x is the distance the string is pulled back. We can use the force required to hold the string, and the distance it is pulled back, to find the bow's spring constant k. Then we can use Equation 10.15 to find the elastic potential energy.

Example 10.8 Pulling back on a bow (cont.)

SOLVE From Hooke’s law, the spring constant is

$$k = \frac{F}{x} = \frac{140\ \text{N}}{0.70\ \text{m}} = 200\ \text{N/m}$$

Then the elastic potential energy of the flexed bow is

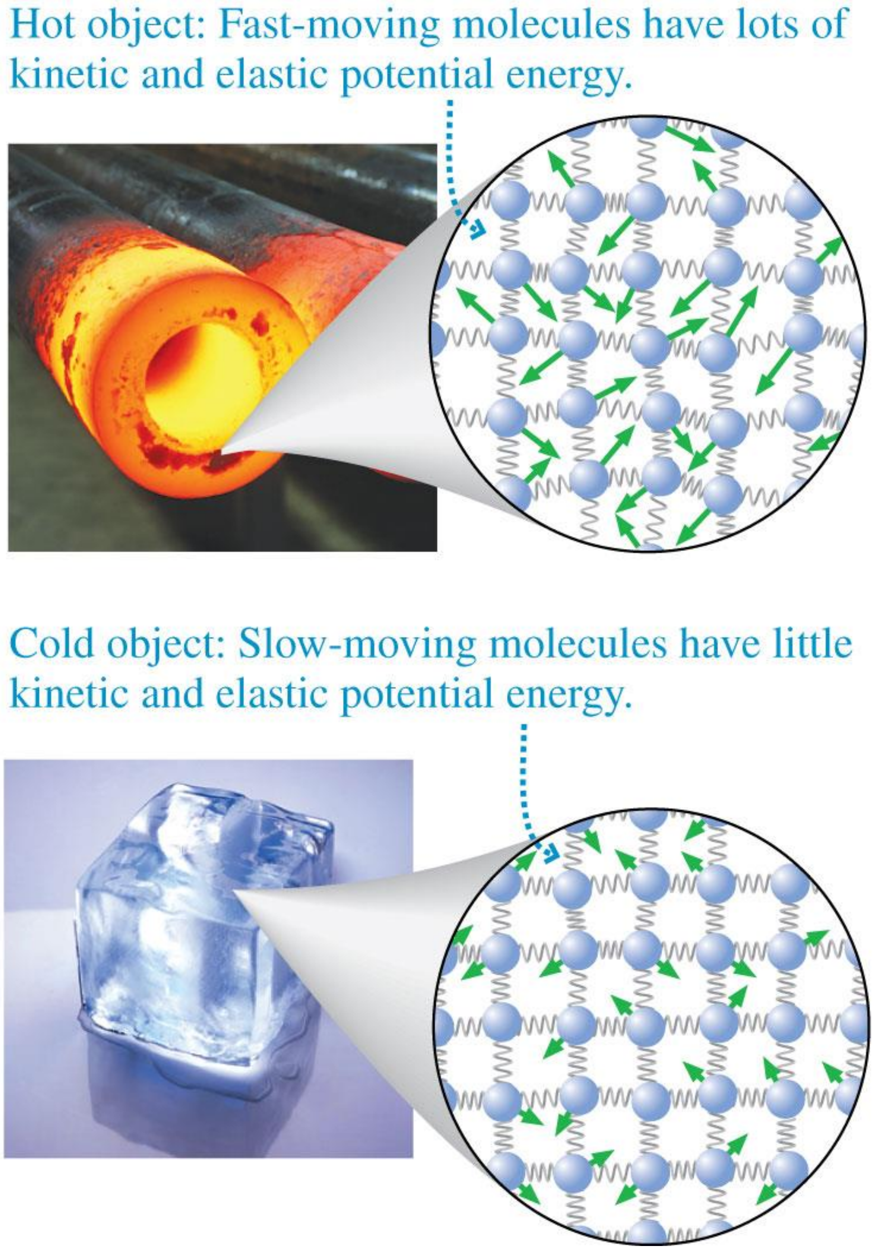
$$U_s = \frac{1}{2}kx^2 = \frac{1}{2}(200\ \text{N/m})(0.70\ \text{m})^2 = 49\ \text{J}$$

ASSESS When the arrow is released, this elastic potential energy will be transformed into the kinetic energy of the arrow. According to Table 10.1, the kinetic energy of a 100 mph fastball is about 150 J, so 49 J of kinetic energy for a fast-moving arrow seems reasonable.

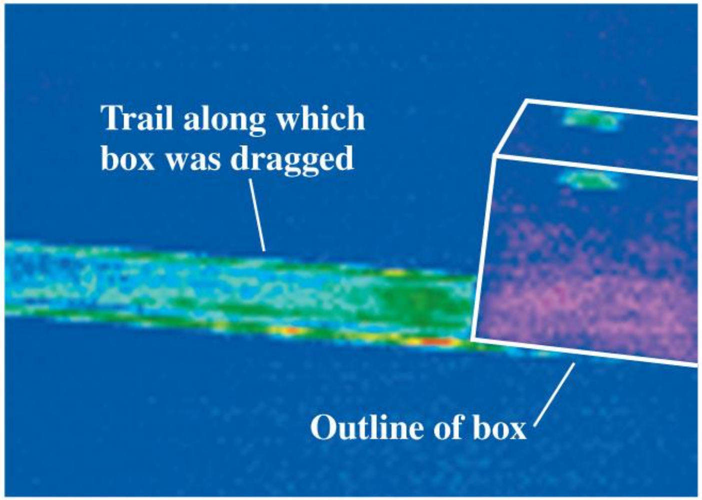
Section 10.5 Thermal Energy

Thermal Energy

Thermal energy is the sum of the kinetic energy of atoms and molecules in a substance and the elastic potential energy stored in the molecular bonds between atoms.



Creating Thermal Energy



Friction on a moving object does work. That work creates thermal energy.

$$\Delta E_{\text{th}} = f_{\text{k}} \Delta x$$

Change in thermal energy for a system consisting of an object and the surface it slides on, as the object undergoes displacement Δx while acted on by friction force f_{k}

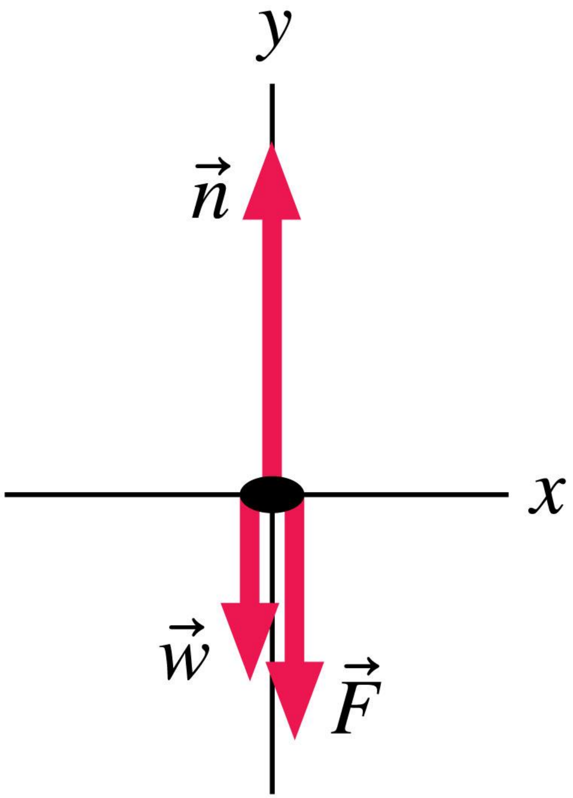
Example 10.9 Creating thermal energy by rubbing

A 0.30 kg block of wood is rubbed back and forth against a wood table 30 times in each direction. The block is moved 8.0 cm during each stroke and pressed against the table with a force of 22 N. How much thermal energy is created in this process?

PREPARE The hand holding the block does work to push the block back and forth. Work transfers energy into the block + table system, where it appears as thermal energy according to Equation 10.16. The force of friction can be found from the model of kinetic friction introduced in Chapter 5, $f_\text{k} = \mu_\text{k} n$; from Table 5.2 the coefficient of kinetic friction for wood sliding on wood is $\mu_\text{k} = 0.20$.

Example 10.9 Creating thermal energy by rubbing (cont.)

To find the normal force *n* acting on the block, we draw the free-body diagram of the figure, which shows only the *vertical* forces acting on the block.



Example 10.9 Creating thermal energy by rubbing (cont.)

SOLVE From Equation 10.16 we have $\Delta E_{\text{th}} = f_{\text{k}}\,\Delta x$, where $f_{\text{k}} = \mu_{\text{k}} n$. The block is not accelerating in the *y*-direction, so from the free-body diagram Newton's second law gives

$$\Sigma\, Fy = n - w - F = ma_y = 0$$

or

$$n = w + F = mg + F = (0.30\ \text{kg})(9.8\ \text{m/s}^2) + 22\ \text{N} = 24.9\ \text{N}$$

The friction force is then $f_{\text{k}} = \mu_{\text{k}} n = (0.20)(24.9\ \text{N}) = 4.98\ \text{N}$. The total displacement of the block is 2 × 30 × 8.0 cm = 4.8 m. Thus the thermal energy created is

$$\Delta E_{\text{th}} = f_{\text{k}}\,\Delta x = (4.98\ \text{N})(4.8\ \text{m}) = 24\ \text{J}$$

ASSESS This modest amount of thermal energy seems reasonable for a person to create by rubbing.

Try It Yourself: Agitating Atoms

Vigorously rub a somewhat soft object such as a blackboard eraser on your desktop for about 10 seconds. If you then pass your fingers over the spot where you rubbed, you’ll feel a distinct warm area. Congratulations: You’ve just set some 100,000,000,000,000,000,000,000 atoms into motion!

Section 10.6 Using the Law of Conservation of Energy

Using the Law of Conservation of Energy

- We can use the law of conservation of energy to develop a before-and-after perspective for energy conservation:

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

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

- This is analogous to the before-and-after approach used with the law of conservation of momentum.
- In an **isolated system**, $W = 0$:

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

Choosing an Isolated System

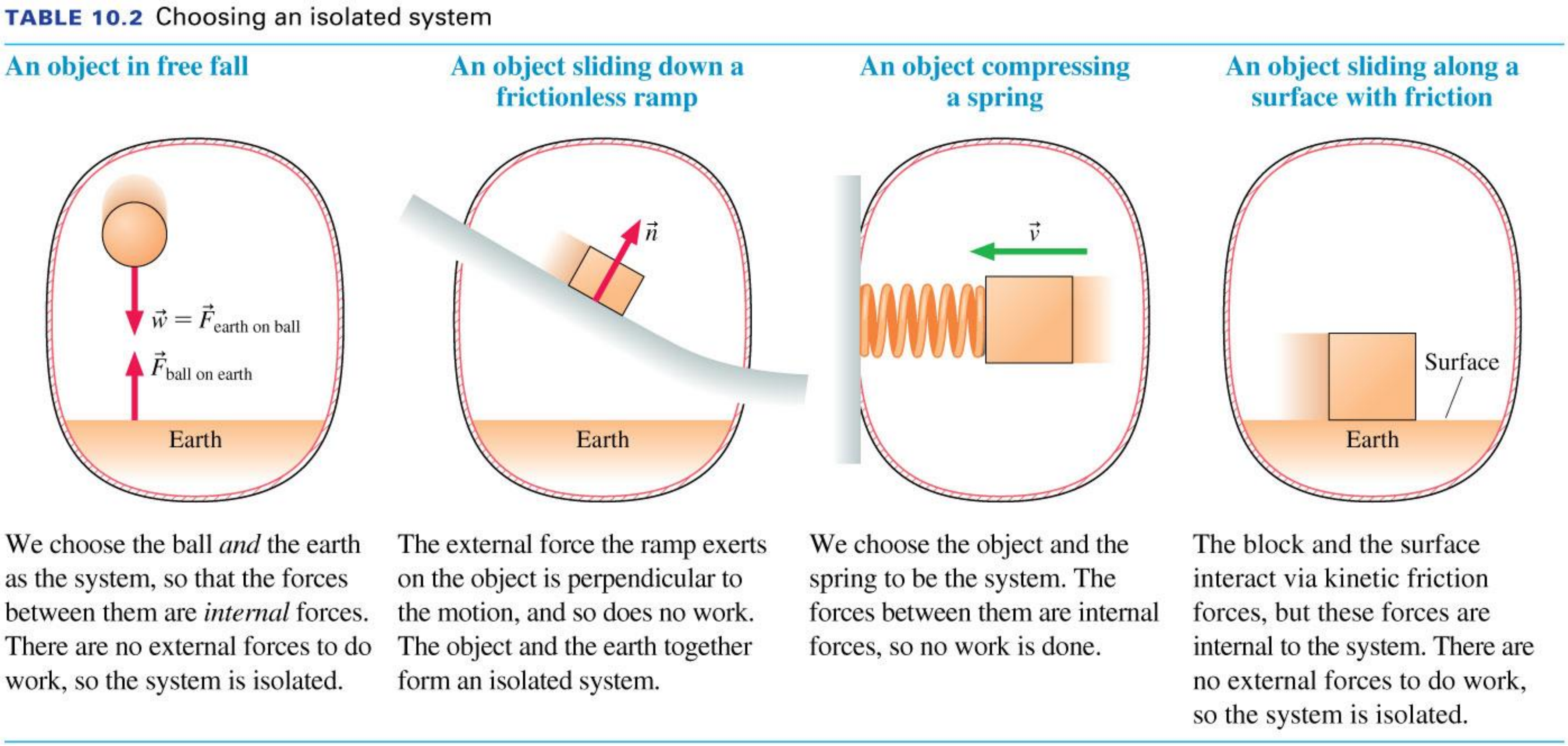


TABLE 10.2 Choosing an isolated system

An object in free fall	An object sliding down a frictionless ramp	An object compressing a spring	An object sliding along a surface with friction
We choose the ball *and* the earth as the system, so that the forces between them are *internal* forces. There are no external forces to do work, so the system is isolated.	The external force the ramp exerts on the object is perpendicular to the motion, and so does no work. The object and the earth together form an isolated system.	We choose the object and the spring to be the system. The forces between them are internal forces, so no work is done.	The block and the surface interact via kinetic friction forces, but these forces are internal to the system. There are no external forces to do work, so the system is isolated.

Text: p. 300

QuickCheck 10.18

A spring-loaded gun shoots a plastic ball with a launch speed of 2.0 m/s. If the spring is compressed twice as far, the ball's launch speed will be

A. 1.0 m/s
B. 2.0 m/s
C. 2.8 m/s
D. 4.0 m/s
E. 16.0 m/s

QuickCheck 10.18

A spring-loaded gun shoots a plastic ball with a launch speed of 2.0 m/s. If the spring is compressed twice as far, the ball's launch speed will be

A. 1.0 m/s
B. 2.0 m/s
C. 2.8 m/s
✓ D. 4.0 m/s
E. 16.0 m/s

Conservation of energy: $\frac{1}{2}mv^2 = \frac{1}{2}k(\Delta x)^2$

Double $\Delta x \Rightarrow$ double v

QuickCheck 10.19

A spring-loaded gun shoots a plastic ball with a launch speed of 2.0 m/s. If the spring is replaced with a new spring having twice the spring constant (but still compressed the same distance), the ball’s launch speed will be

A. 1.0 m/s
B. 2.0 m/s
C. 2.8 m/s
D. 4.0 m/s
E. 16.0 m/s

QuickCheck 10.19

A spring-loaded gun shoots a plastic ball with a launch speed of 2.0 m/s. If the spring is replaced with a new spring having twice the spring constant (but still compressed the same distance), the ball’s launch speed will be

A. 1.0 m/s
B. 2.0 m/s
✓ C. 2.8 m/s
D. 4.0 m/s
E. 16.0 m/s

Conservation of energy: $\frac{1}{2}mv^2 = \frac{1}{2}k(\Delta x)^2$

Double k $\Rightarrow$ increase v by square root of 2

Example Problem

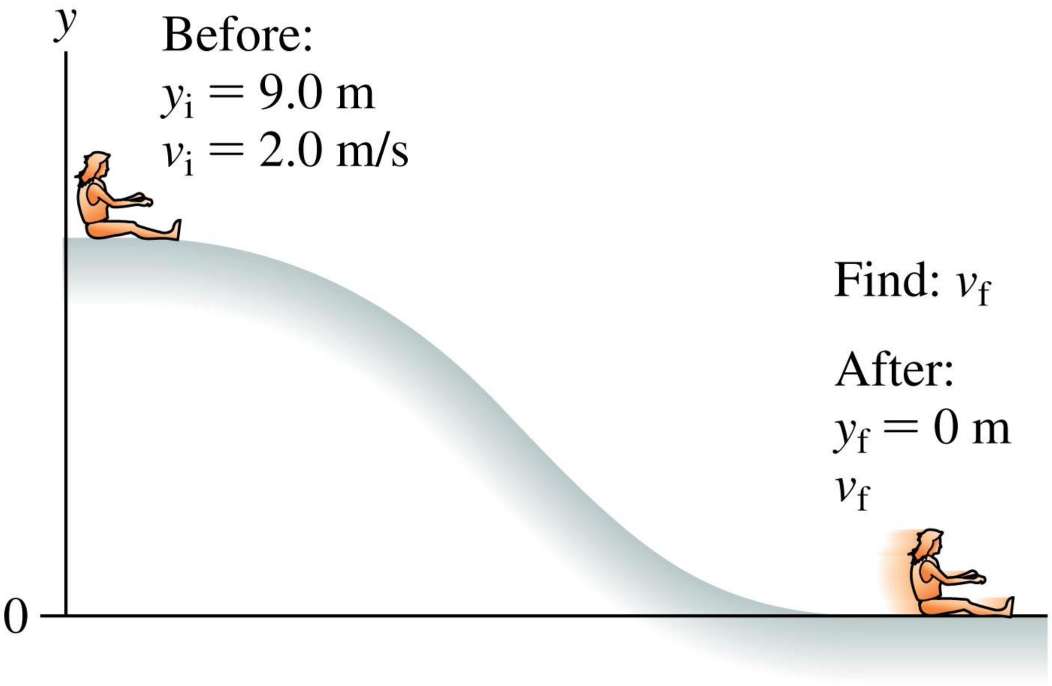
A car sits at rest at the top of a hill. A small push sends it rolling down the hill. After its height has dropped by 5.0 m, it is moving at a good clip. Write down the equation for conservation of energy, noting the choice of system, the initial and final states, and what energy transformation has taken place.

Example Problem

A child slides down a slide at a constant speed of 1.5 m/s. The height of the slide is 3.0 m. Write down the equation for conservation of energy, noting the choice of system, the initial and final states, and what energy transformation has taken place.

Example 10.11 Speed at the bottom of a water slide

While at the county fair, Katie tries the water slide, whose shape is shown in the figure. The starting point is 9.0 m above the ground. She pushes off with an initial speed of 2.0 m/s. If the slide is frictionless, how fast will Katie be traveling at the bottom?



Example 10.11 Speed at the bottom of a water slide (cont.)

PREPARE Table 10.2 showed that the system consisting of Katie and the earth is isolated because the normal force of the slide is perpendicular to Katie’s motion and does no work. If we assume the slide is frictionless, we can use the conservation of mechanical energy equation.

SOLVE Conservation of mechanical energy gives

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

or

$$\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i$$

Example 10.11 Speed at the bottom of a water slide (cont.)

Taking $y_f = 0$ m, we have

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + mgy_i$$

which we can solve to get

$$v_f = \sqrt{v_i^2 + 2gy_i}$$

$$= \sqrt{(2.0\ \text{m/s})^2 + 2(9.8\ \text{m/s}^2)(9.0\ \text{m})} = 13\ \text{m/s}$$

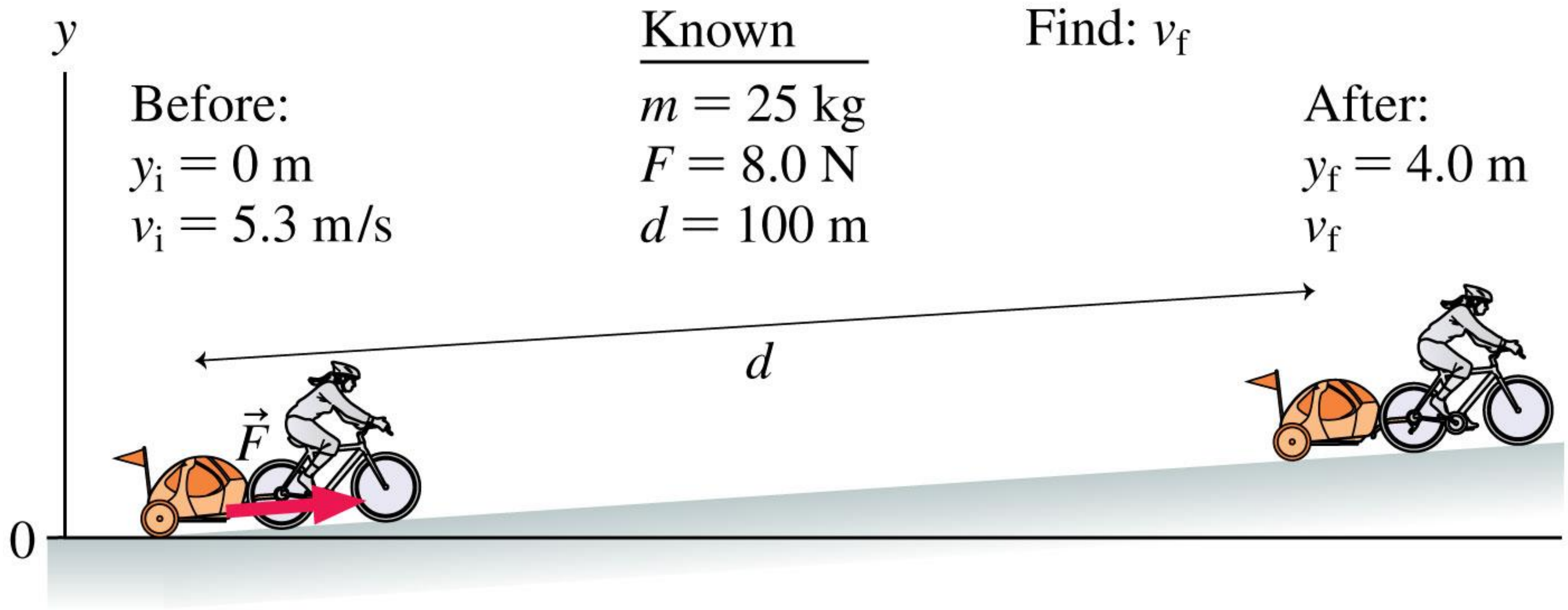
Notice that the shape of the slide does not matter because gravitational potential energy depends only on the *height* above a reference level.

Example 10.13 Pulling a bike trailer

Monica pulls her daughter Jessie in a bike trailer. The trailer and Jessie together have a mass of 25 kg. Monica starts up a 100-m-long slope that's 4.0 m high. On the slope, Monica's bike pulls on the trailer with a constant force of 8.0 N. They start out at the bottom of the slope with a speed of 5.3 m/s. What is their speed at the top of the slope?

Example 10.13 Pulling a bike trailer (cont.)

PREPARE Taking Jessie and the trailer as the system, we see that Monica’s bike is applying a force to the system as it moves through a displacement; that is, Monica’s bike is doing work on the system. Thus we’ll need to use the full version of Equation 10.18, including the work term *W*.



Example 10.13 Pulling a bike trailer (cont.)

SOLVE If we assume there's no friction, so that $\Delta E_{\text{th}} = 0$, then Equation 10.18 is

$$K_{\text{f}} + (U_{\text{g}})_{\text{f}} = K_{\text{i}} + (U_{\text{g}})_{\text{i}} + W$$

or

$$\frac{1}{2}mv_{\text{f}}^2 + mgy_{\text{f}} = \frac{1}{2}mv_{\text{i}}^2 + mgy_{\text{i}} + W$$

Example 10.13 Pulling a bike trailer (cont.)

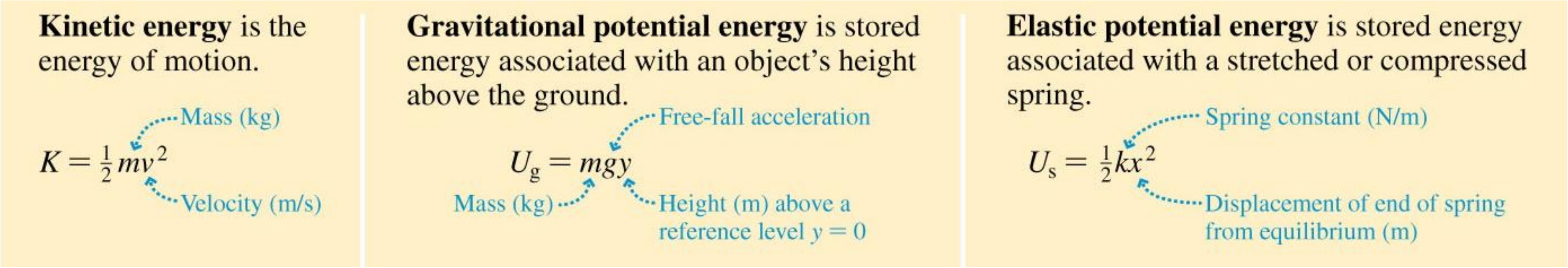
Taking $y_i = 0$ m and writing $W = Fd$, we can solve for the final speed:

$$\begin{aligned} v_f^2 &= v_i^2 - 2gy_f + \frac{2Fd}{m} \\ &= (5.3\text{ m/s})^2 - 2(9.8\text{ m/s}^2)(4.0\text{ m}) + \frac{2(8.0\text{ N})(100\text{ m})}{25\text{ kg}} \\ &= 13.7\text{ m}^2/\text{s}^2 \end{aligned}$$

from which we find that $v_f = 3.7$ m/s. Note that we took the work to be a positive quantity because the force is in the same direction as the displacement.

ASSESS A speed of 3.7 m/s—about 8 mph—seems reasonable for a bicycle's speed. Jessie's final speed is less than her initial speed, indicating that the uphill force of Monica's bike on the trailer is less than the downhill component of gravity.

Energy and Its Conservation



Kinetic energy is the energy of motion.

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

Mass (kg)

Velocity (m/s)

Gravitational potential energy is stored energy associated with an object's height above the ground.

$$U_g = mgy$$

Free-fall acceleration

Mass (kg)

Height (m) above a reference level $y = 0$

Elastic potential energy is stored energy associated with a stretched or compressed spring.

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

Spring constant (N/m)

Displacement of end of spring from equilibrium (m)

Text: p. 304

Energy and Its Conservation

The system consisting of an object and the surface it slides on gains thermal energy if friction is present.

$$\Delta E_{\text{th}} = f_k \Delta x$$

Distance that object slides (m)

Change in thermal energy

Friction force (N)

For an *isolated system*, the **law of conservation of energy** is

$$\underbrace{K_f + (U_g)_f + (U_s)_f + \Delta E_{\text{th}}}_{\text{Final total energy}} = \underbrace{K_i + (U_g)_i + (U_s)_i}_{\text{Initial total energy}}$$

A system's final total energy, including any increase in its thermal energy, is equal to its initial energy.

Text: p. 304

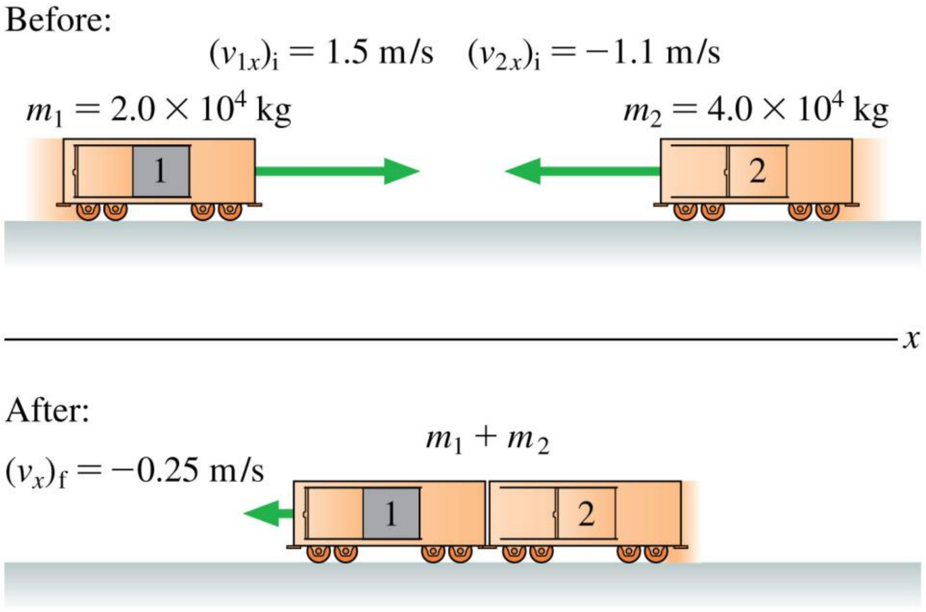
Section 10.7 Energy in Collisions

Energy in Collisions

- A collision in which the colliding objects stick together and then move with a common final velocity is a **perfectly inelastic collision**.
- A collision in which mechanical energy is conserved is called a **perfectly elastic collision**.
- While momentum is conserved in all collisions, mechanical energy is only conserved in a perfectly elastic collision.
- In an inelastic collision, some mechanical energy is converted to thermal energy.

Example 10.15 Energy transformations in a perfectly inelastic collision

The figure shows two train cars that move toward each other, collide, and couple together. In Example 9.8, we used conservation of momentum to find the final velocity shown in the figure from the given initial velocities. How much thermal energy is created in this collision?



Example 10.15 Energy transformations in a perfectly inelastic collision (cont.)

PREPARE We'll choose our system to be the two cars. Because the track is horizontal, there is no change in potential energy. Thus the law of conservation of energy, Equation 10.18a, is $K_f + \Delta E_{th} = K_i$. The total energy before the collision must equal the total energy afterward, but the *mechanical* energies need not be equal.

Example 10.15 Energy transformations in a perfectly inelastic collision (cont.)

SOLVE The initial kinetic energy is

$$\begin{aligned} K_i &= \frac{1}{2} m_1 (v_{1x})_i{}^2 + \frac{1}{2} m_2 (v_{2x})_i{}^2 \\ &= \frac{1}{2}(2.0 \times 10^4 \text{ kg})(1.5 \text{ m/s})^2 + \frac{1}{2}(4.0 \times 10^4 \text{ kg})(-1.1 \text{ m/s})^2 \\ &= 4.7 \times 10^4 \text{ J} \end{aligned}$$

Because the cars stick together and move as a single object with mass $m_1 + m_2$, the final kinetic energy is

$$\begin{aligned} K_f &= \frac{1}{2}(m_1 + m_2)(v_x)_f^2 \\ &= \frac{1}{2}(6.0 \times 10^4 \text{ kg})(-0.25 \text{ m/s})^2 = 1900 \text{ J} \end{aligned}$$

Example 10.15 Energy transformations in a perfectly inelastic collision (cont.)

From the conservation of energy equation on the previous slide, we find that the thermal energy increases by

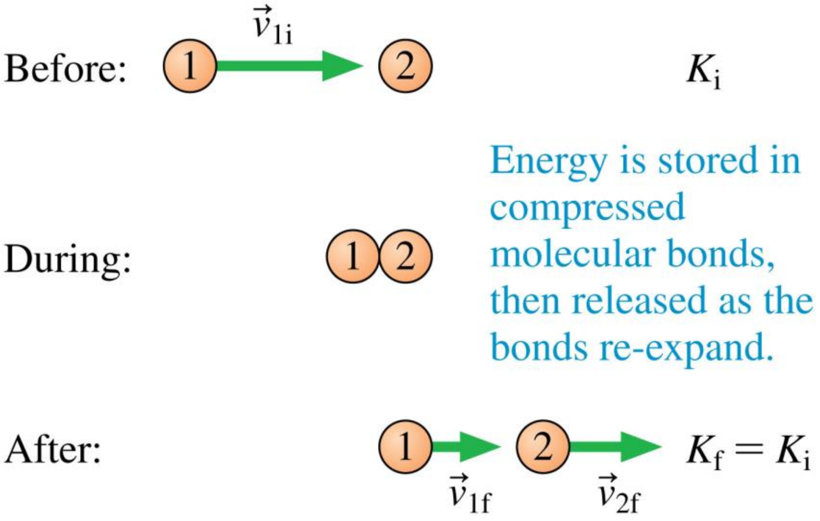
$$\Delta E_{\mathrm{th}} = K_{\mathrm{i}} - K_{\mathrm{f}} = 4.7 \times 10^4\ \mathrm{J} - 1900\ \mathrm{J} = 4.5 \times 10^4\ \mathrm{J}$$

This amount of the initial kinetic energy is transformed into thermal energy during the impact of the collision.

ASSESS About 96% of the initial kinetic energy is transformed into thermal energy. This is typical of many real-world collisions.

Elastic Collisions

Elastic collisions obey conservation of momentum and conservation of mechanical energy.



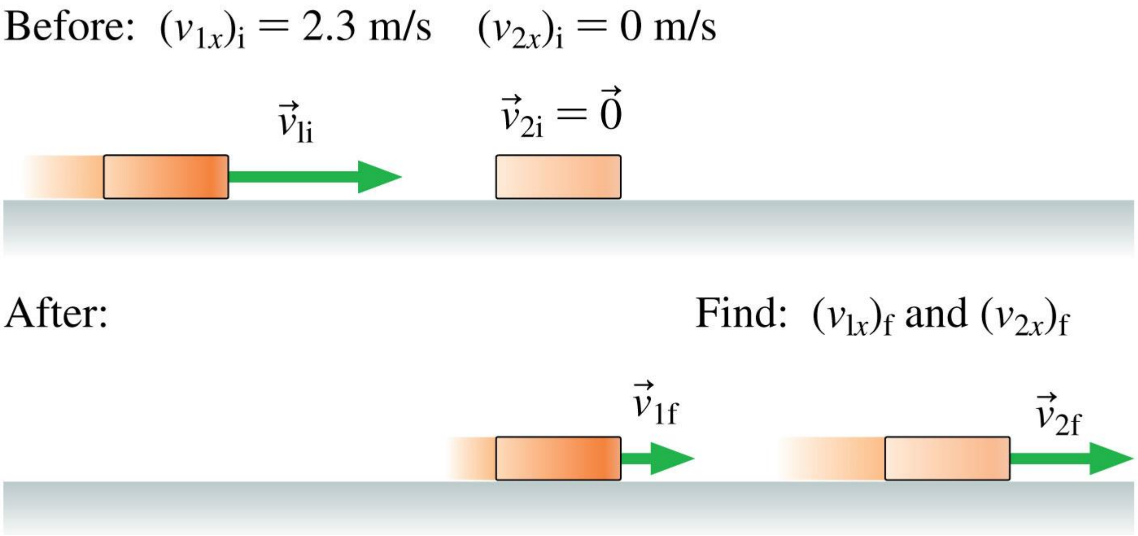
Momentum: $m_1(v_{1x})_i = m_1(v_{1x})_f + m_2(v_{2x})_f$

Energy: $\frac{1}{2}m_1(v_{1x})_i^2 = \frac{1}{2}m_1(v_{1x})_f^2 + \frac{1}{2}m_2(v_{2x})_f^2$

Example 10.16 Velocities in an air hockey collision

On an air hockey table, a moving puck, traveling to the right at 2.3 m/s, makes a head-on collision with an identical puck at rest. What is the final velocity of each puck?

Example 10.16 Velocities in an air hockey collision (cont.)



PREPARE The before-and-after visual overview is shown in the figure. We’ve shown the final velocities in the picture, but we don’t really know yet which way the pucks will move. Because one puck was initially at rest, we can use Equations 10.20 to find the final velocities of the pucks. The pucks are identical, so we have $m_1 = m_2 = m$.

Example 10.16 Velocities in an air hockey collision (cont.)

SOLVE We use Equations 10.20 with $m_1 = m_2 = m$ to get

$$(v_{1x})_{\mathrm{f}} = \frac{m - m}{m + m}(v_{1x})_{\mathrm{i}} = 0\ \mathrm{m/s}$$

$$(v_{2x})_{\mathrm{f}} = \frac{2m}{m + m}(v_{1x})_{\mathrm{i}} = (v_{1x})_{\mathrm{i}} = 2.3\ \mathrm{m/s}$$

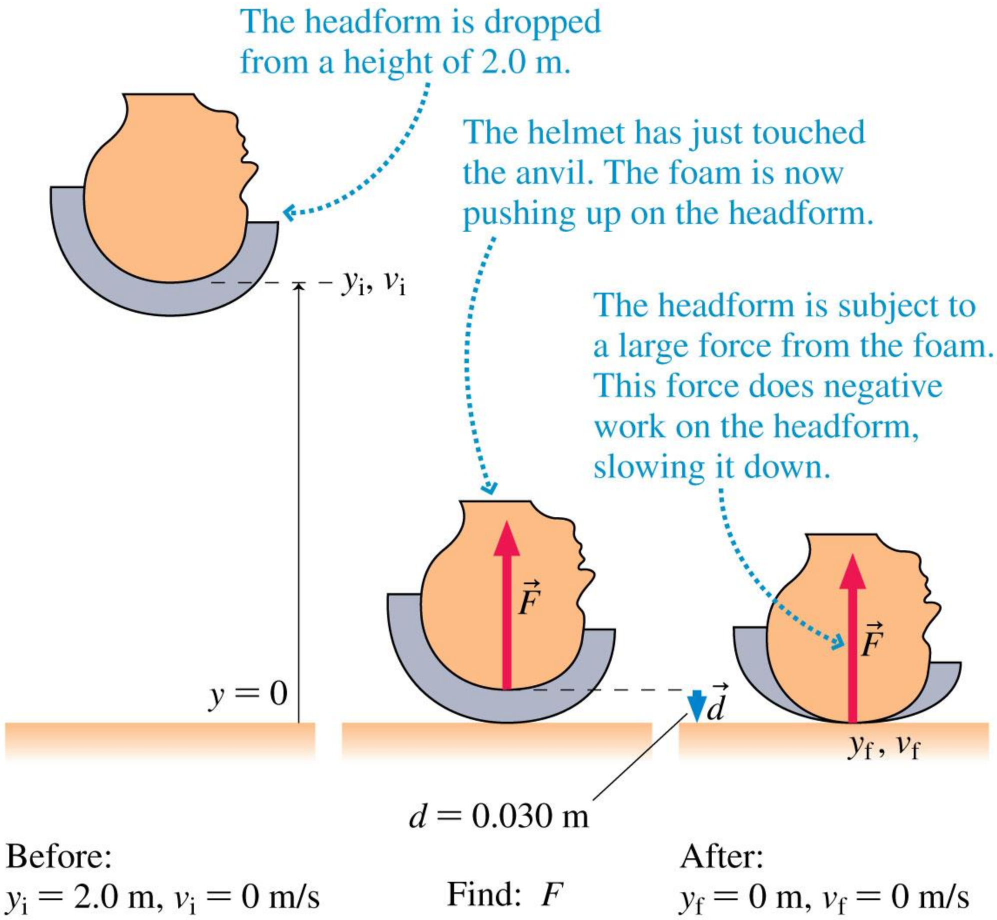
The incoming puck stops dead, and the initially stationary puck goes off with the same velocity that the incoming one had.

Example 10.17 Protecting your head

A bike helmet—basically a shell of hard, crushable foam—is tested by being strapped onto a 5.0 kg headform and dropped from a height of 2.0 m onto a hard anvil. What force is encountered by the headform if the impact crushes the foam by 3.0 cm?

PREPARE We can use the work-energy equation, Equation 10.18, to calculate the force on the headform. We'll choose the headform and the earth to be the system; the foam in the helmet is part of the environment. We make this choice so that the force on the headform due to the foam is an *external* force that does work *W* on the headform.

Example 10.17 Protecting your head (cont.)


The headform is dropped from a height of 2.0 m.

The helmet has just touched the anvil. The foam is now pushing up on the headform.

The headform is subject to a large force from the foam. This force does negative work on the headform, slowing it down.

Before:
$y_i = 2.0$ m, $v_i = 0$ m/s

Find: F

After:
$y_f = 0$ m, $v_f = 0$ m/s

Before-and-after visual overview of the bike helmet test

Example 10.17 Protecting your head (cont.)

SOLVE The headform starts at rest, speeds up as it falls, then returns to rest during the impact. Overall, then, $K_f = K_i$. Furthermore, $\Delta E_{th} = 0$ because there's no friction to increase the thermal energy. Only the gravitational potential energy changes, so the work-energy equation is

$$(U_g)_f - (U_g)_i = W$$

The upward force of the foam on the headform is opposite the downward displacement of the headform. Referring to Tactics Box 10.1, we see that the work done is negative: $W = -Fd$, where we've assumed that the force is constant. Using this result in the work-energy equation and solving for F, we find

$$F = -\frac{(U_g)_f - (U_g)_i}{d} = \frac{(U_g)_i - (U_g)_f}{d}$$

Example 10.17 Protecting your head (cont.)

Taking our reference height to be $y = 0$ m at the anvil, we have $(U_g)_f = 0$. We're left with $(U_g)_i = mgy_i$, so

$$F = \frac{mgy_i}{d} = \frac{(5.0\text{ kg})(9.8\text{ m/s}^2)(2.0\text{ m})}{0.030\text{ m}} = 3300\text{ N}$$

This is the force that acts on the head to bring it to a halt in 3.0 cm. More important from the perspective of possible brain injury is the head's *acceleration:*

$$a = \frac{F}{m} = \frac{3300\text{ N}}{5.0\text{ kg}} = 660\text{ m/s}^2 = 67g$$

ASSESS The accepted threshold for serious brain injury is around 300*g*, so this helmet would protect the rider in all but the most serious accidents. Without the helmet, the rider's head would come to a stop in a much shorter distance and thus be subjected to a much larger acceleration.

Section 10.8 Power

Power

- **Power** is the rate at which energy is transformed or transferred.

$$P = \frac{\Delta E}{\Delta t}$$

Power when an amount of energy ΔE is transformed in a time interval Δt

$$P = \frac{W}{\Delta t}$$

Power when an amount of work W is done in a time interval Δt

- The unit of power is the **watt**:

$$1 \text{ watt} = 1 \text{ W} = 1 \text{ J/s}$$

Output Power of a Force

- A force doing work transfers energy.
- The rate that this force transfers energy is the **output power** of that force:

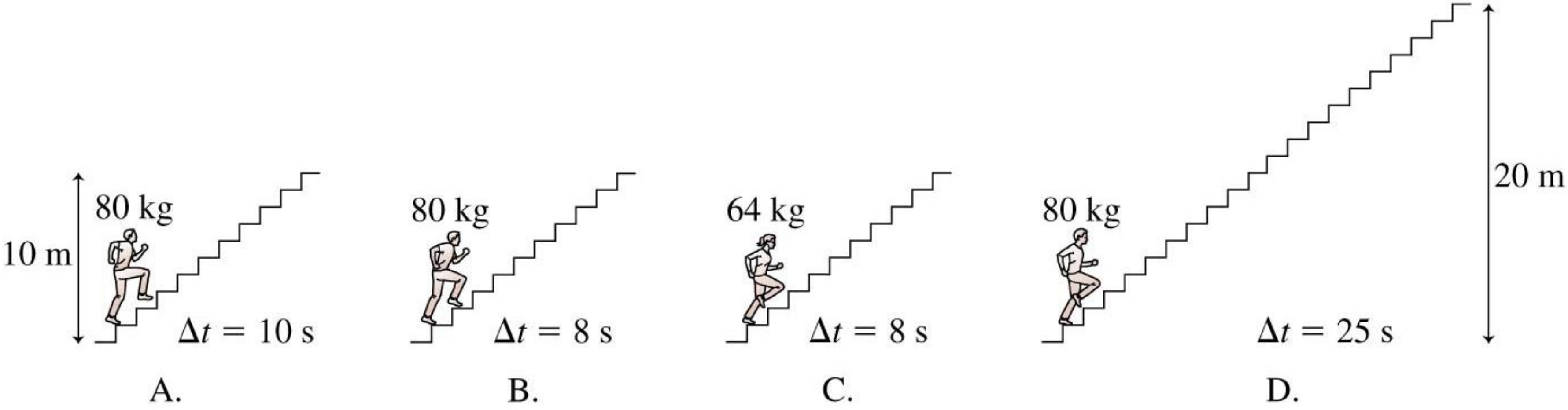
$$P = \frac{W}{\Delta t} = \frac{F\Delta x}{\Delta t} = F\frac{\Delta x}{\Delta t} = Fv$$

$$P = Fv$$

Rate of energy transfer due to a force F acting on an object moving at velocity v

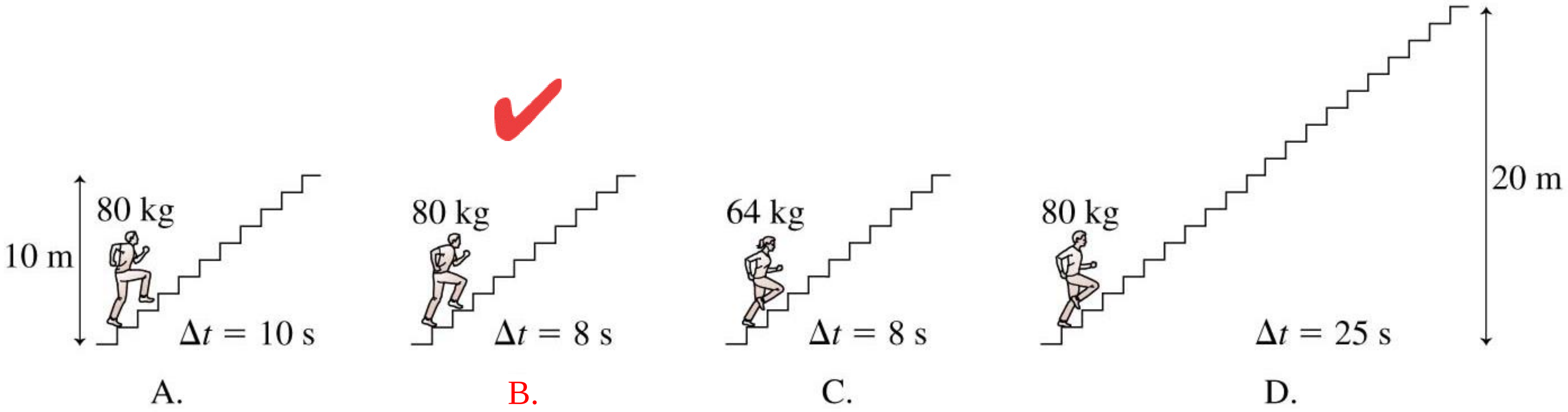
QuickCheck 10.20

Four students run up the stairs in the time shown. Which student has the largest power output?



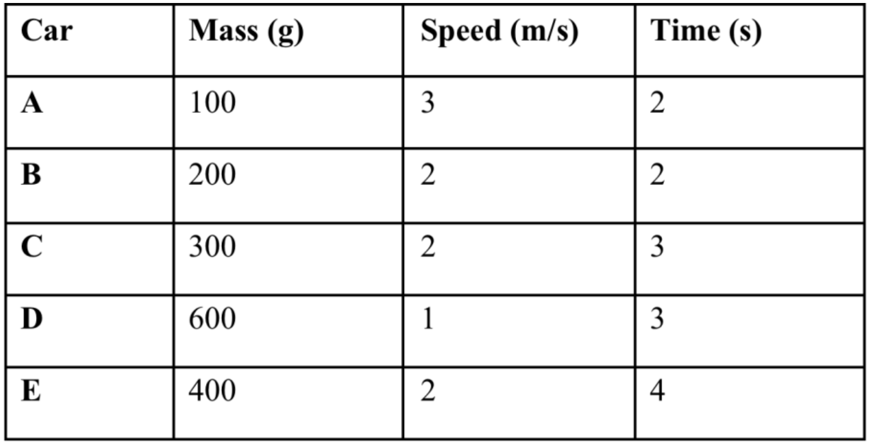
QuickCheck 10.20

Four students run up the stairs in the time shown. Which student has the largest power output?



QuickCheck 10.21

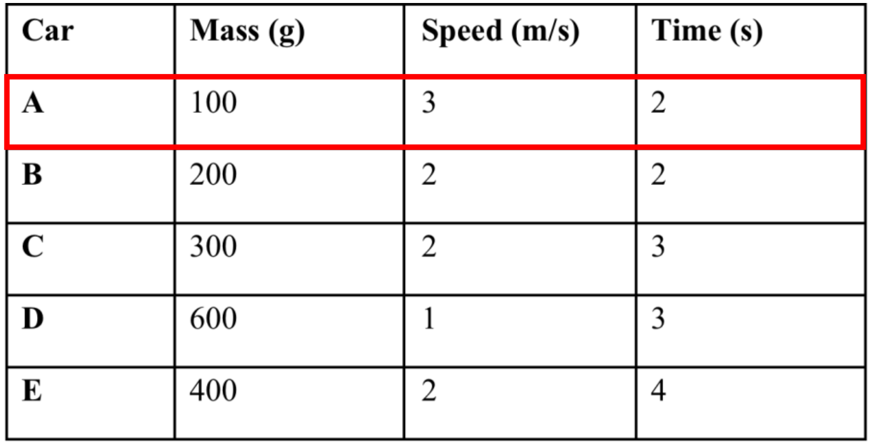
Four toy cars accelerate from rest to their top speed in a certain amount of time. The masses of the cars, the final speeds, and the time to reach this speed are noted in the table. Which car has the greatest power?



Car	**Mass (g)**	**Speed (m/s)**	**Time (s)**
A	100	3	2
B	200	2	2
C	300	2	3
D	600	1	3
E	400	2	4

QuickCheck 10.21

Four toy cars accelerate from rest to their top speed in a certain amount of time. The masses of the cars, the final speeds, and the time to reach this speed are noted in the table. Which car has the greatest power?



Car	Mass (g)	Speed (m/s)	Time (s)
✔ **A**	100	3	2
B	200	2	2
C	300	2	3
D	600	1	3
E	400	2	4

Example 10.18 Power to pass a truck

Your 1500 kg car is behind a truck traveling at 60 mph (27 m/s). To pass the truck, you speed up to 75 mph (34 m/s) in 6.0 s. What engine power is required to do this?

PREPARE Your engine is transforming the chemical energy of its fuel into the kinetic energy of the car. We can calculate the rate of transformation by finding the change ΔK in the kinetic energy and using the known time interval.

Example 10.18 Power to pass a truck (cont.)

SOLVE We have

$$K_i = \frac{1}{2}mv_i^2 = \frac{1}{2}(1500\ \text{kg})(27\ \text{m/s})^2 = 5.47 \times 10^5\ \text{J}$$

$$K_f = \frac{1}{2}mv_f^2 = \frac{1}{2}(1500\ \text{kg})(34\ \text{m/s})^2 = 8.67 \times 10^5\ \text{J}$$

so that

$$\Delta K = K_f - K_i$$

$$= (8.67 \times 10^5\ \text{J}) - (5.47 \times 10^5\ \text{J}) = 3.20 \times 10^5\ \text{J}$$

To transform this amount of energy in 6 s, the power required is

$$P = \frac{\Delta K}{\Delta t} = \frac{3.20 \times 10^5\ \text{J}}{6.0\ \text{s}} = 53{,}000\ \text{W} = 53\ \text{kW}$$

This is about 71 hp. This power is in addition to the power needed to overcome drag and friction and cruise at 60 mph, so the total power required from the engine will be even greater than this.

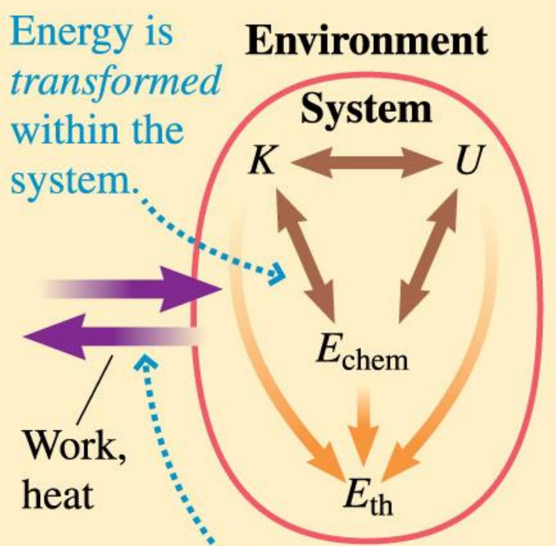
Summary: General Principles

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

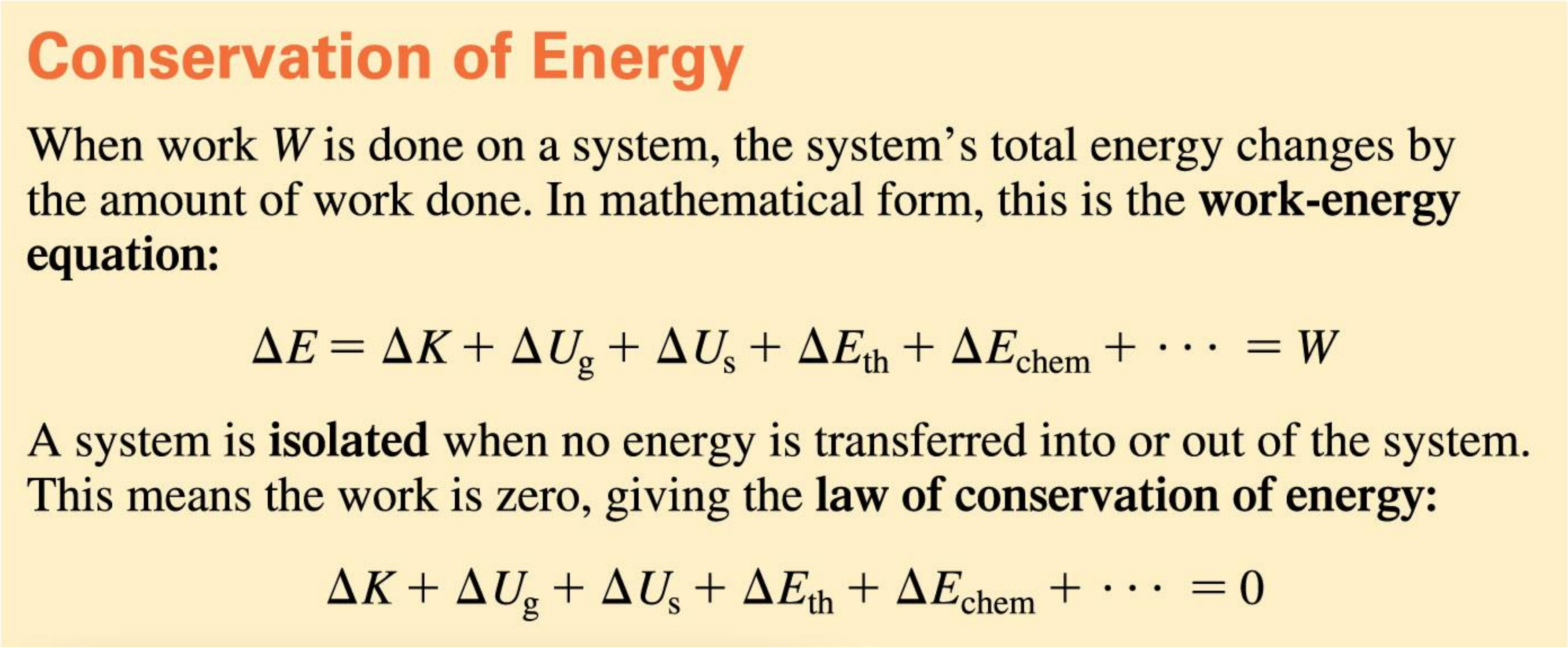


Energy is *transformed* within the system.

Energy is *transferred* to or from the system from or to the environment.

Text: p. 310

Summary: General Principles



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:**

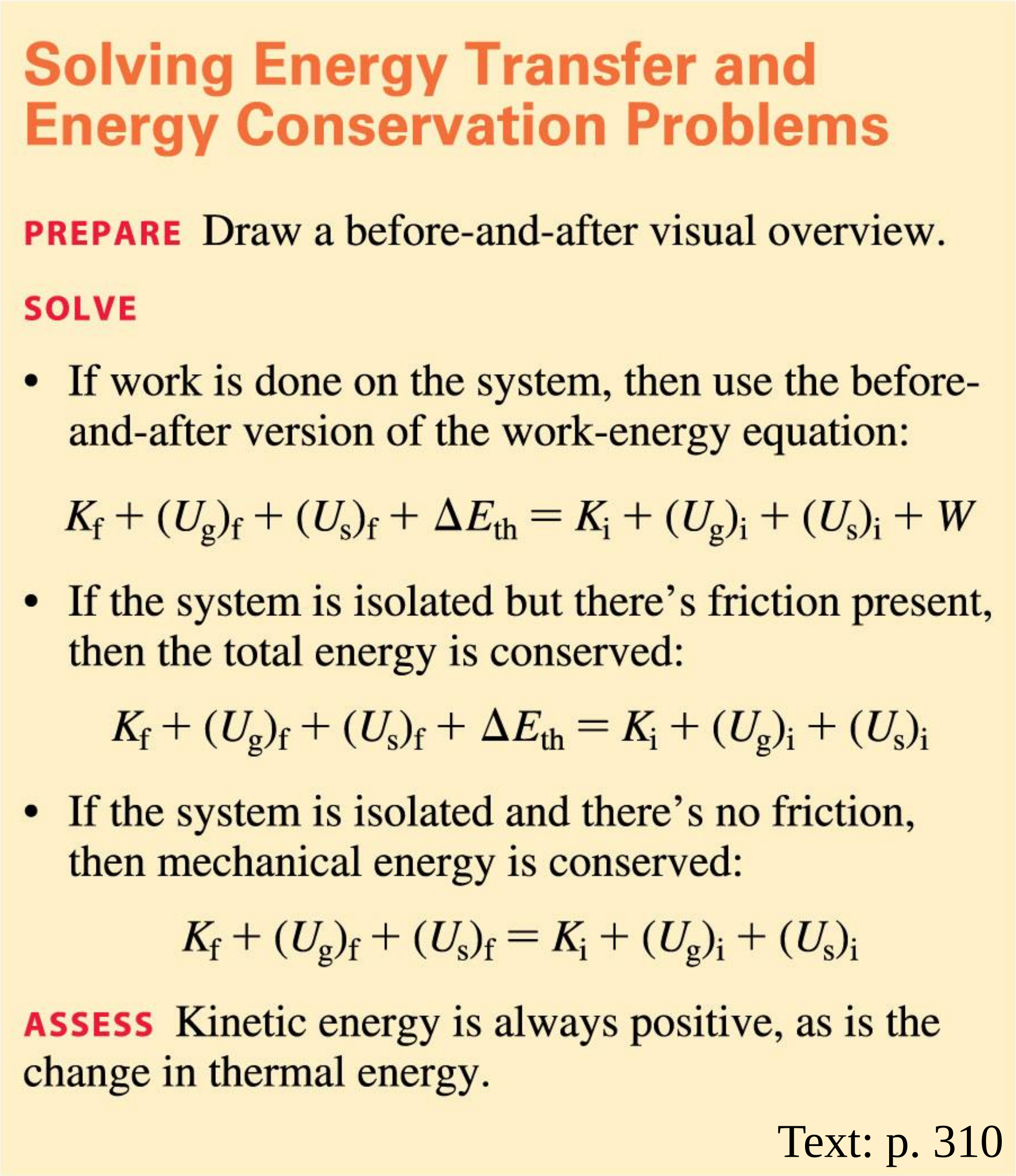
$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \cdots = W$$

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:**

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

Text: p. 310

Summary: General Principles



Solving Energy Transfer and Energy Conservation Problems

PREPARE Draw a before-and-after visual overview.

SOLVE

- If work is done on the system, then use the before-and-after version of the work-energy equation:

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

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

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

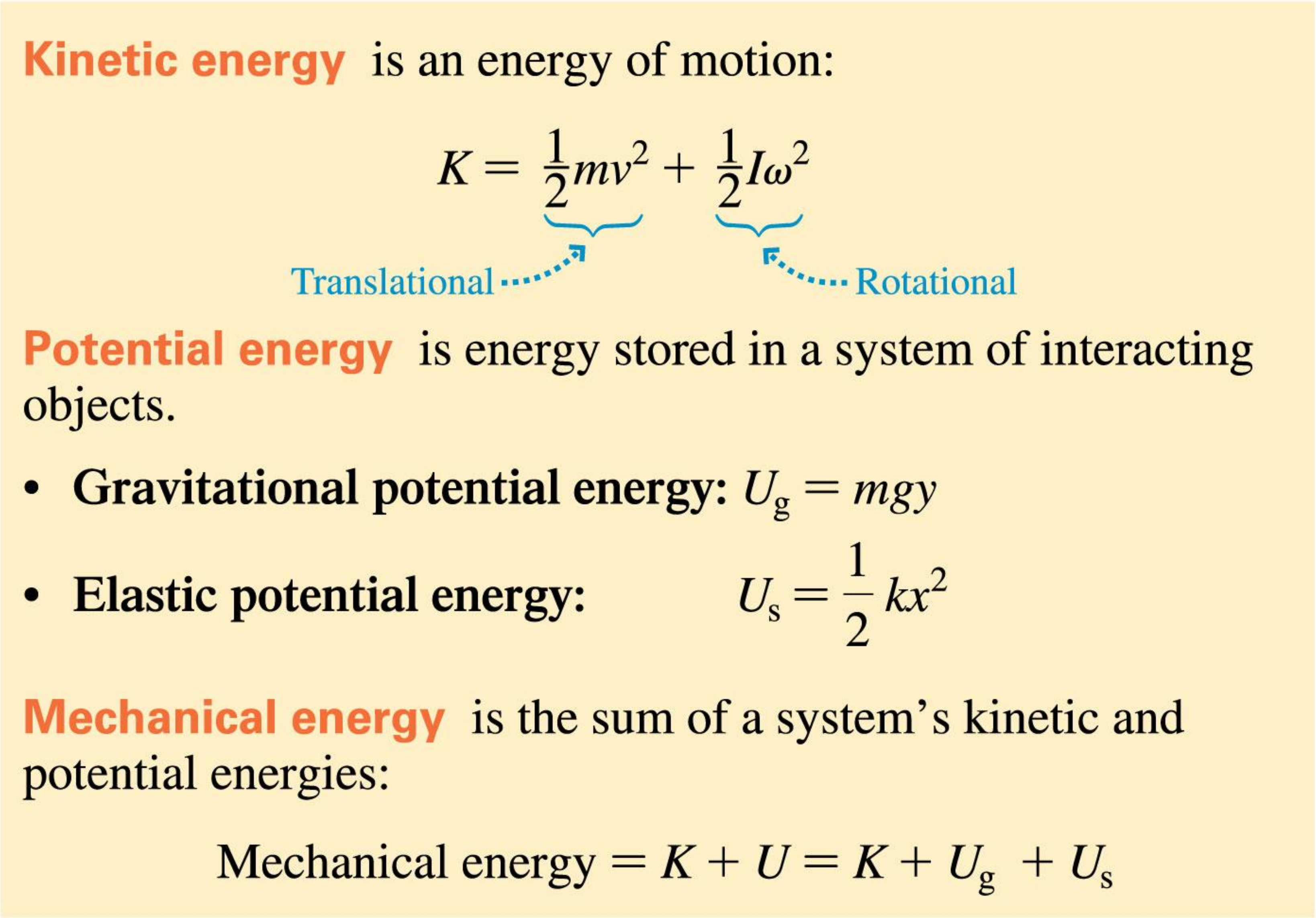
- If the system is isolated and there's no friction, then mechanical energy is conserved:

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

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

Text: p. 310

Summary: Important Concepts



Kinetic energy is an energy of motion:

$$K = \underbrace{\frac{1}{2}mv^2}_{\text{Translational}} + \underbrace{\frac{1}{2}I\omega^2}_{\text{Rotational}}$$

Potential energy is energy stored in a system of interacting objects.

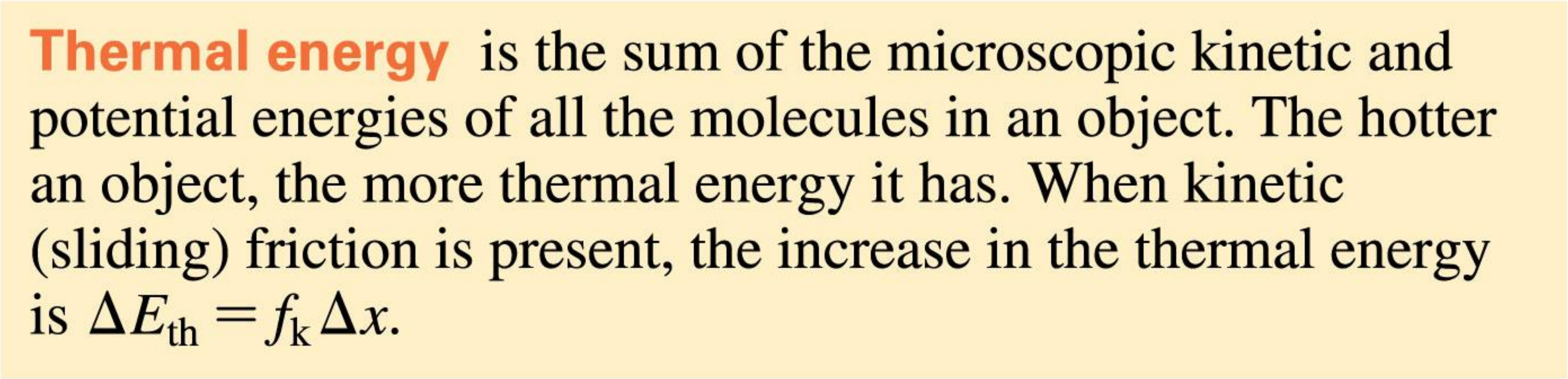
- **Gravitational potential energy:** $U_g = mgy$
- **Elastic potential energy:** $U_s = \frac{1}{2}kx^2$

Mechanical energy is the sum of a system's kinetic and potential energies:

$$\text{Mechanical energy} = K + U = K + U_g + U_s$$

Text: p. 310

Summary: Important Concepts



Thermal energy is the sum of the microscopic kinetic and potential energies of all the molecules in an object. The hotter an object, the more thermal energy it has. When kinetic (sliding) friction is present, the increase in the thermal energy is $\Delta E_{\mathrm{th}} = f_{\mathrm{k}} \Delta x$.

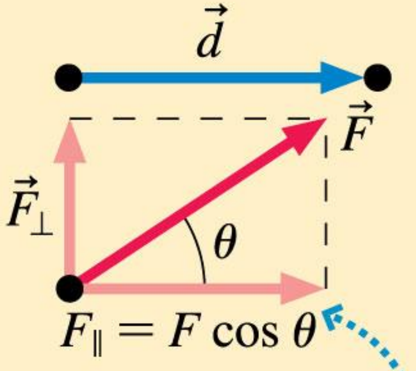
Text: p. 310

Summary: Important Concepts

Work is the process by which energy is transferred to or from a system by the application of mechanical forces.

If a particle moves through a displacement $\vec{d}$ while acted upon by a constant force $\vec{F}$, the force does work

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



Only the component of the force parallel to the displacement does work.

Text: p. 310

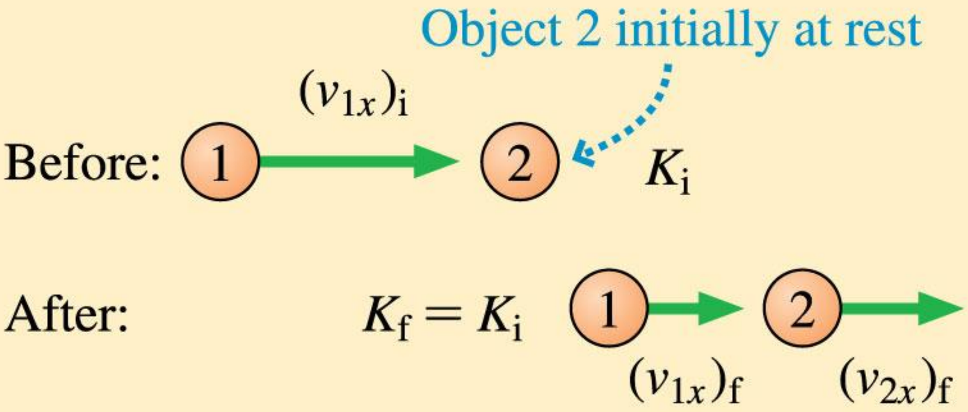
Summary: Applications

Perfectly elastic collisions

Both mechanical energy and momentum are conserved.

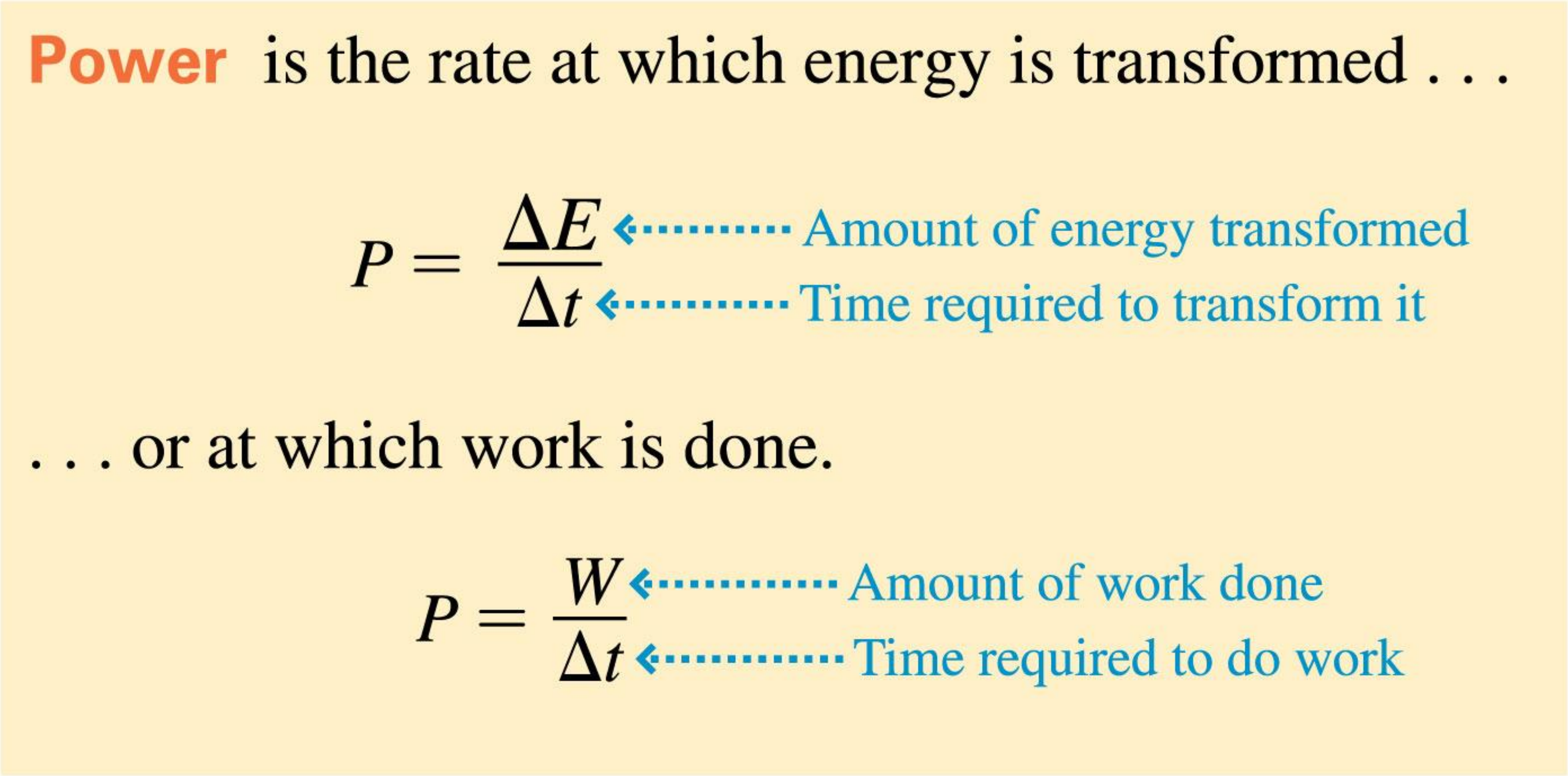
$$(v_{1x})_{\mathrm{f}} = \frac{m_1 - m_2}{m_1 + m_2}(v_{1x})_{\mathrm{i}}$$

$$(v_{2x})_{\mathrm{f}} = \frac{2m_1}{m_1 + m_2}(v_{1x})_{\mathrm{i}}$$



Text: p. 310

Summary: Applications



Power is the rate at which energy is transformed . . .

$$P = \frac{\Delta E}{\Delta t}$$

ΔE ← Amount of energy transformed

Δt ← Time required to transform it

. . . or at which work is done.

$$P = \frac{W}{\Delta t}$$

W ← Amount of work done

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Text: p. 310

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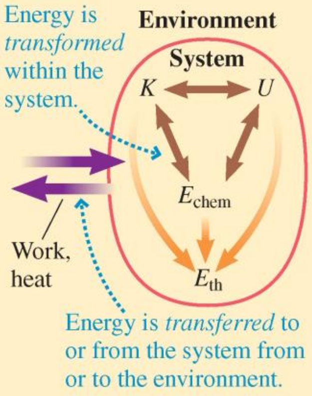

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- If work is done on the system, then use the before-and-after version of the work-energy equation:

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

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

Text: p. 310

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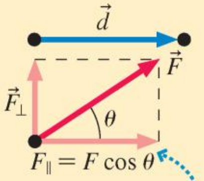


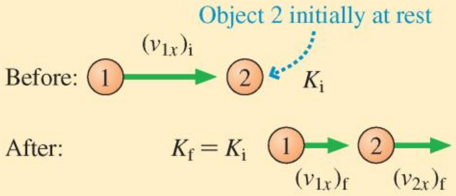
Only the component of the force parallel to the displacement does work.

Text: p. 310

Summary

APPLICATIONS

Perfectly elastic collisions
Both mechanical energy and momentum are conserved.



$$(v_{1x})_f = \frac{m_1 - m_2}{m_1 + m_2}(v_{1x})_i$$

$$(v_{2x})_f = \frac{2m_1}{m_1 + m_2}(v_{1x})_i$$

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. . . or at which work is done.

$$P = \frac{W}{\Delta t}\begin{array}{l}\leftarrow \text{Amount of work done}\\ \leftarrow \text{Time required to do work}\end{array}$$

Text: p. 310