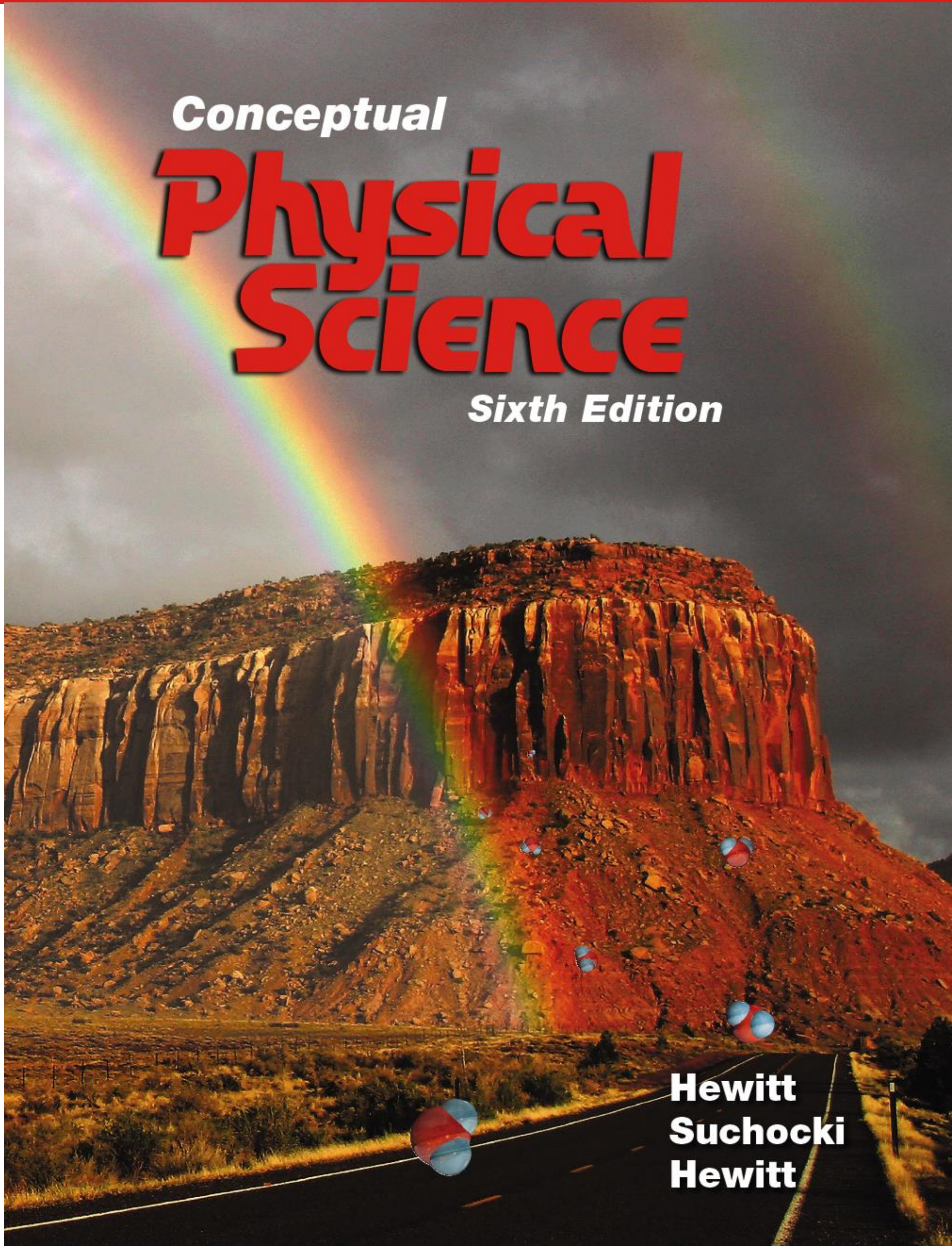
Chapter 4: Momentum and Energy



This lecture will help you understand:

- Momentum
- Conservation of Momentum
- Energy and Work
- Power
- Conservation of Energy

Momentum

- **Momentum**—is *inertia in motion*
  - defined as the product of mass and velocity:

$$\text{momentum} = mv$$

Momentum

- Momentum
  - When direction is unimportant:

momentum = mass × speed

Momentum "P" = mv

Momentum

high mass or high velocity ⇒ high momentum

Both high mass <u>and</u> high velocity ⇒ higher momentum

low mass or low velocity ⇒ low momentum

low mass <u>and</u> low velocity ⇒ lower momentum

Calculating Momentum

Momentum is a property of a moving object that is equal to the mass of the object multiplied by the velocity of the object. Because velocity includes direction, momentum has a direction associated with it. An object's momentum is in the direction of its velocity.

Momentum can be calculated as follows:

$$\text{momentum} = \text{mass} \times \text{velocity}$$

If mass is measured in kilograms and velocity in meters per second, momentum has units of kilogram-meters per second, or kg • m/s.

Momentum and Velocity The greater the velocity of an object is, the greater the object's momentum is. Consider, for example, a 12-kg bicycle. The calculations below show how the bicycle's momentum increases as its velocity increases.

At 2 m/s southward:

$$\text{momentum} = 12\ \text{kg} \times 2\ \text{m/s} = 24\ \text{kg} \cdot \text{m/s southward}$$

At 3 m/s southward:

$$\text{momentum} = 12\ \text{kg} \times 3\ \text{m/s} = 36\ \text{kg} \cdot \text{m/s southward}$$

Momentum and Mass The greater the mass of an object is, the greater the object's momentum is. This time, consider a cart moving at a velocity of 2 m/s westward. Bricks can be added to the cart to change its mass. The calculations below show how the cart's momentum increases as its mass increases.

At 2 kg:

$$\text{momentum} = 2\ \text{kg} \times 2\ \text{m/s} = 4\ \text{kg} \cdot \text{m/s westward}$$

At 5 kg:

$$\text{momentum} = 5\ \text{kg} \times 2\ \text{m/s} = 10\ \text{kg} \cdot \text{m/s westward}$$

Momentum
CHECK YOUR NEIGHBOR

When the speed of an object is doubled, its momentum

A. remains unchanged in accord with the conservation of momentum.
B. doubles.
C. quadruples.
D. decreases.

Momentum
CHECK YOUR ANSWER

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Conservation of Momentum

- In every case, the momentum of a system cannot change unless it is acted on by external forces.
- A system will have the same momentum both before and after any interaction occurs. When the momentum does not change, we say it is **conserved**.

Conservation of Momentum

- Law of conservation of momentum:
  - In the absence of an external force, the momentum of a system remains unchanged.
  - Equation form:

    $(\text{total momentum})_{\text{before}} = (\text{total momentum})_{\text{after}}$

Conservation of Momentum

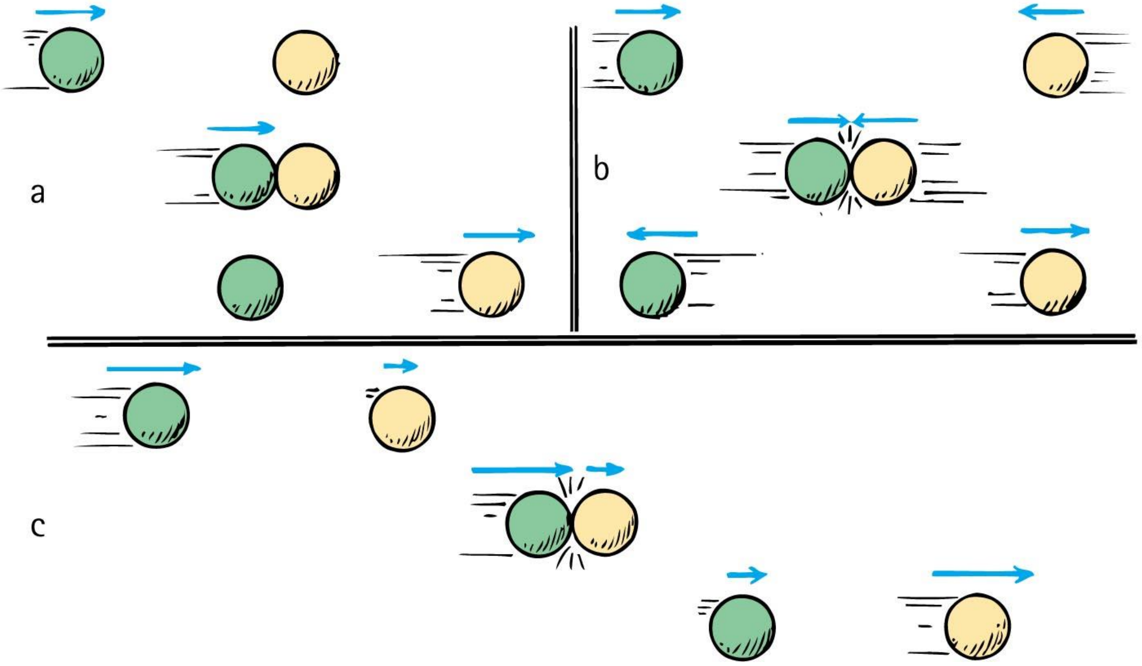
- Collisions
  - When objects collide in the absence of external forces,

    net momentum before collision = net momentum after collision
  - *Examples*:
    - Elastic collisions
    - Inelastic collisions

Conservation of Momentum

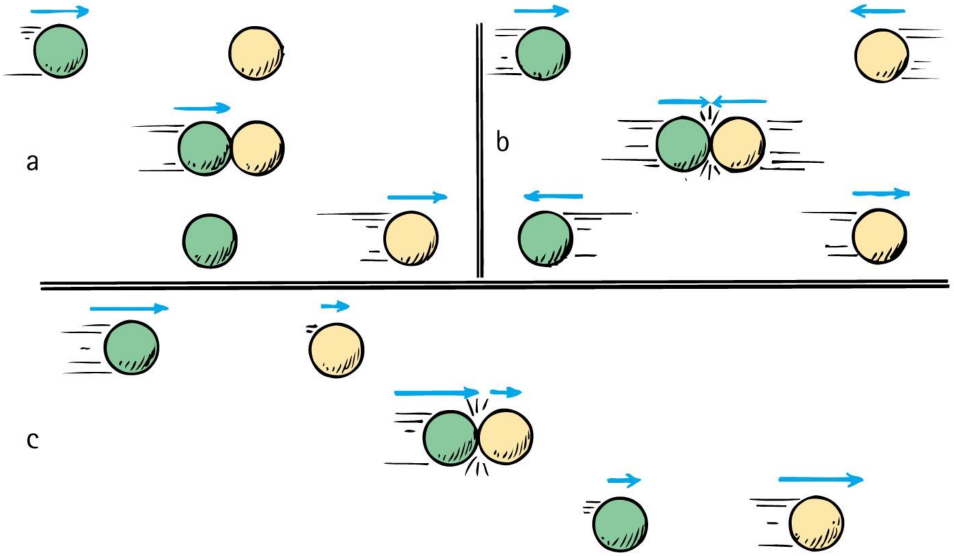
- Elastic collision

is defined as a collision whereupon objects collide without permanent deformation or the generation of heat. (The elastic balls *bounce*!)



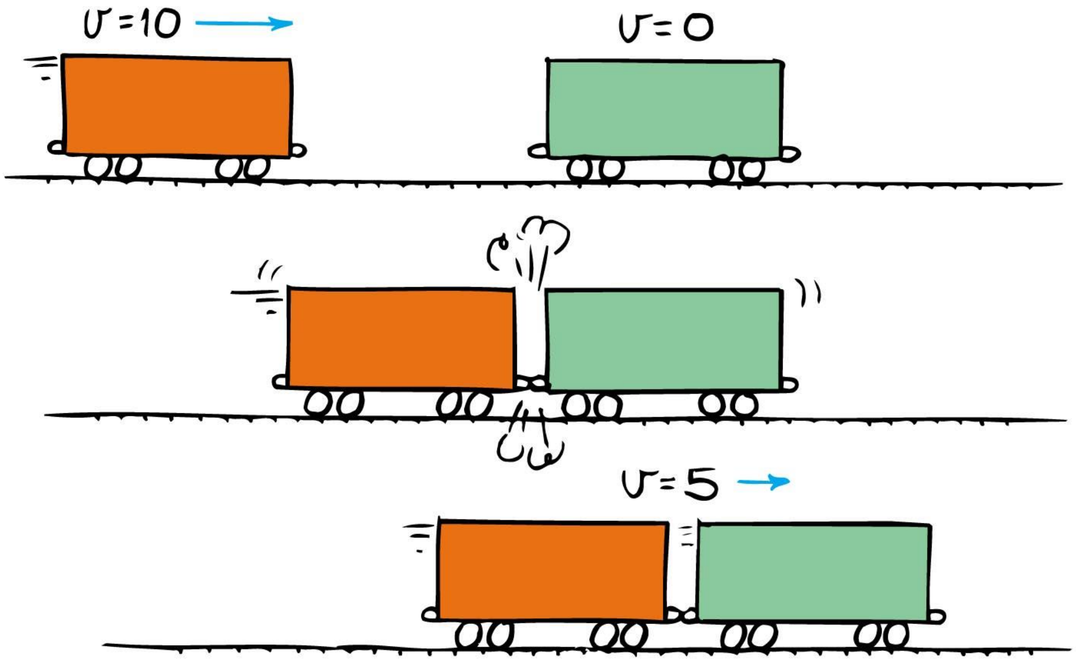
Conservation of Momentum

- In Figure (a)
  - moving green ball hits yellow ball, initially at rest
  - green ball comes to rest, and yellow ball moves away with a velocity equal to the initial velocity of the green ball
- In Figures (a) through (c)
  - momentum is simply transferred from one ball to the other.



Conservation of Momentum

- Inelastic collision
  - is defined as a collision whereupon colliding objects become tangled or coupled together, generating heat. (Inelastic collisions are often *sticky*.)



Work

- Work
  - defined as the product of force exerted on an object and the distance the object moves (in the same direction as the force)
  - is done only when the force succeeds in moving the body it acts upon
  - equation: work = force × distance

Work

- Two things enter where work is done:
  - application of force
  - movement of something by that force
- Work done on the barbell is the average force multiplied by the distance through which the barbell is lifted.

Work

- The quantity of work done is equal to the amount of force × the distance moved in the direction in which the force acts.
- Work falls into two categories:
  - work done against another force
  - work done to change the speed of an object

Energy

- Energy
  - defined as that which produces changes in matter
- Effects of energy observed only when
  - it is being transferred from one place to another

or

  - it is being transformed from one form to another
- Both work and energy are measured in *joules*.

Power

- Power
  - measure of how fast work is done
  - equation:

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

  - units in joule per second or watt
    (One watt = 1 joule of work per second)

Power
CHECK YOUR NEIGHBOR

A job can be done slowly or quickly. Both may require the same amount of work, but different amounts of

A. energy.

B. momentum.

C. power.

D. impulse.

Power
CHECK YOUR ANSWER

A job can be done slowly or quickly. Both may require the same amount of work, but different amounts of

A. energy.

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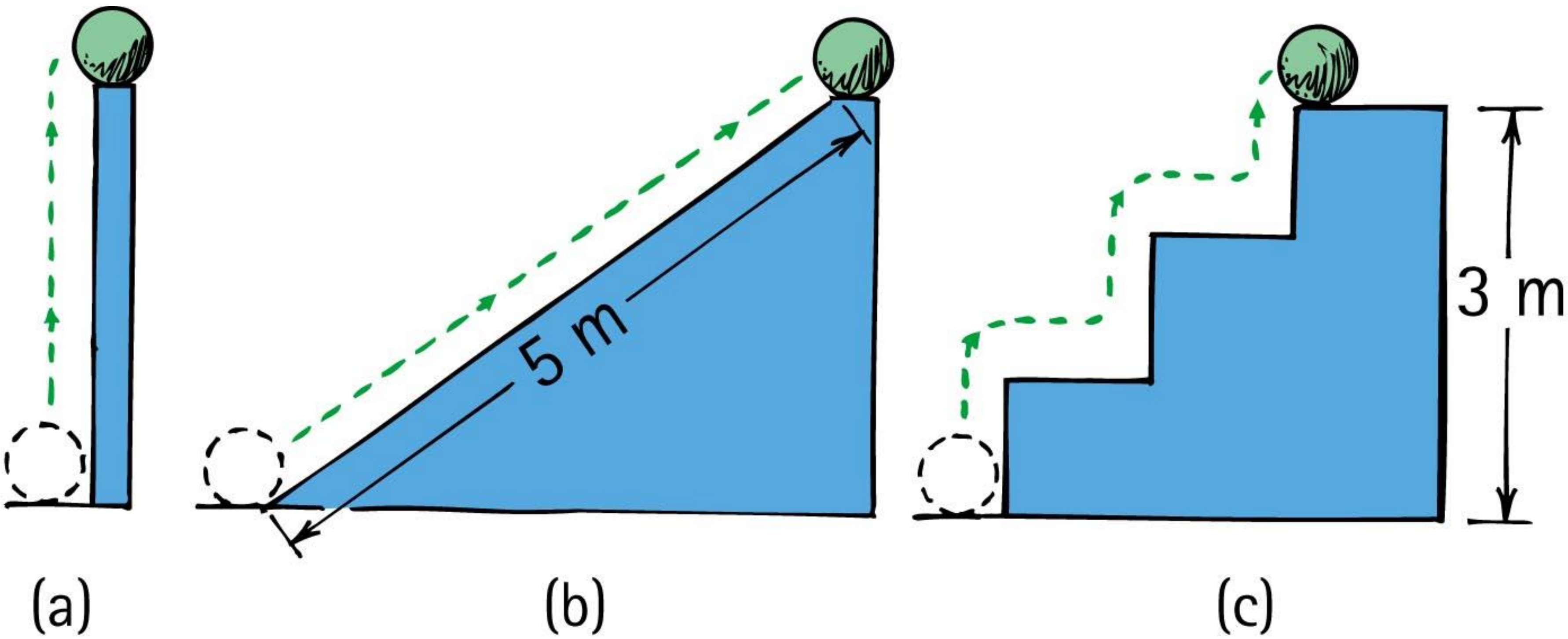
Explanation:

Power is the rate at which work is done.

Potential Energy

Example:
potential energy of 10-N ball is the same in all 3 cases because work done in elevating it is the same



Potential Energy

- Potential energy
  - is defined as stored energy due to position, shape, or state. In its stored state, energy has the potential for doing work.
  - *Examples*:
    - Drawn bow
    - Stretched rubber band
    - Raised ram of a pile driver

Gravitational Potential Energy

- The amount of gravitational potential energy possessed by an elevated object is equal to the *work done against gravity in raising it.*
- Work done equals force required to move it upward × the vertical distance moved

$$W = F \times d$$

- The upward force when moved at constant velocity is the weight, *mg*, of the object. So the work done in lifting it through height *h* is the product *mgh*.

$$W = mg \times h$$

Gravitational Potential Energy

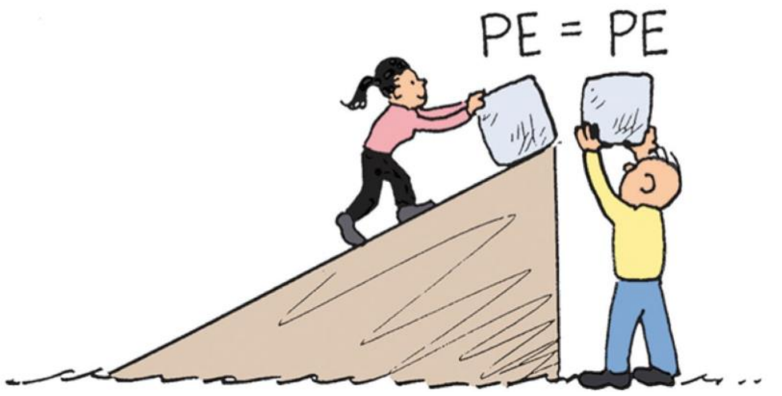
- Equation for gravitational potential energy:

$$PE = \text{weight} \times \text{height}$$

or

$$PE = mgh$$

- Gravitational potential energy examples:
  - Water in an elevated reservoir
  - The elevated ram of a pile driver



Kinetic Energy

- Kinetic energy
  - is defined as the energy of a moving body
  - Equation for kinetic energy:

$$\text{Kinetic energy} = {}^{1}/_{2}\ \text{mass} \times \text{speed}^2$$

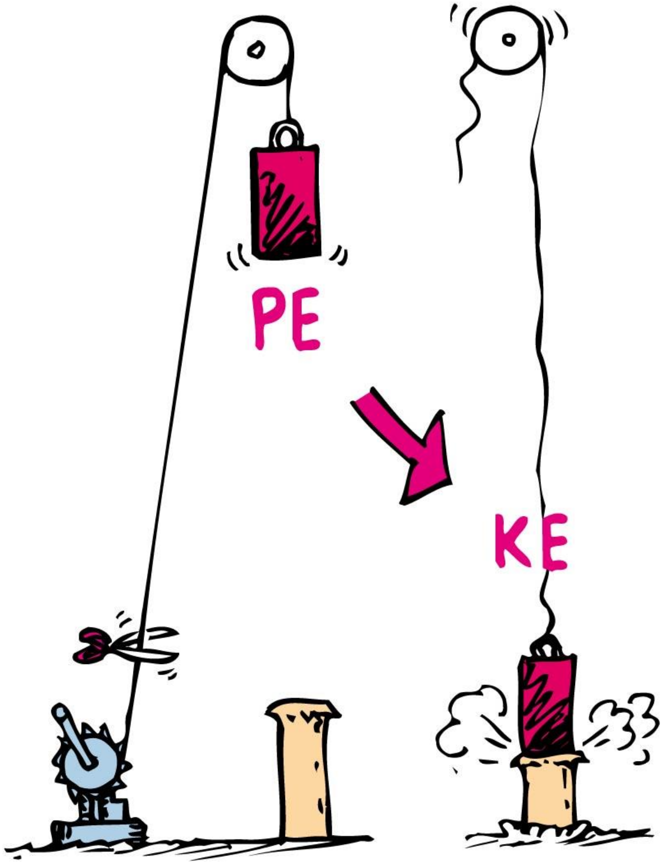
or

$$KE = {}^{1}/_{2}\ mv^2$$

- small changes in speed ⇒ large changes in KE

Conservation of Energy

Example:
energy transforms without net loss or net gain in the operation of a pile driver



Conservation of Energy

- Conservation defined in
  - everyday language as " to save"
  - physics as to "remain unchanged"
- Law of conservation of energy
  - **Energy can not be created or destroyed; it may be transformed from one form into another, but the total amount of the energy never change**

Conversions Among Energy Forms

Each of the forms of energy can be converted into the others. An energy conversion takes place almost every time something happens.

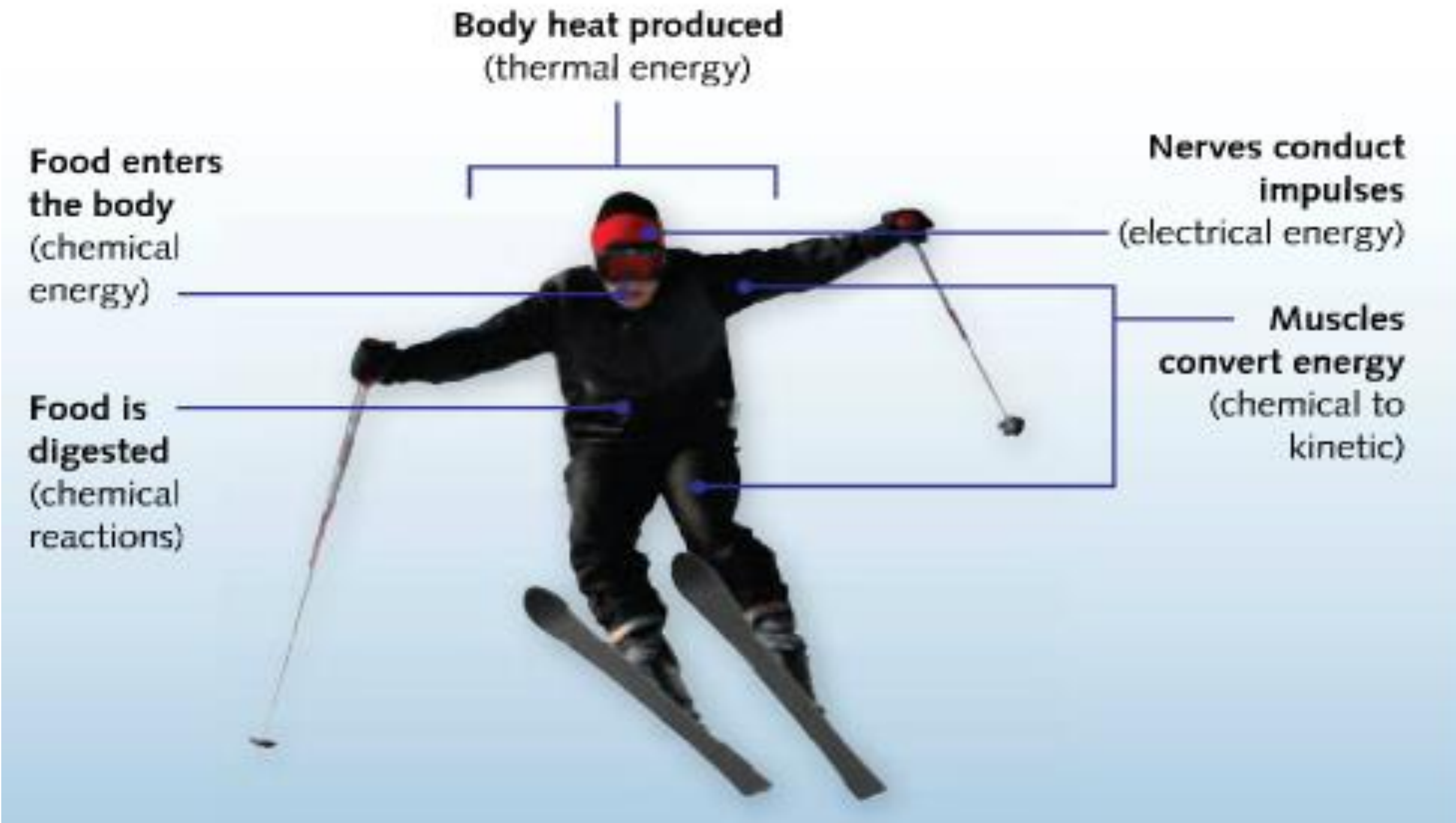


Figure 16.9 Many energy transformations occur within the human body.

No energy conversion is 100 percent efficient. Some thermal energy is generated every time that energy changes form. Power stations convert about 35 percent of their fuel into electrical energy. A typical car engine converts only about 15 percent of the chemical potential energy in gasoline into the car's kinetic energy. The human body loses more than 95 percent of its food energy as waste heat!

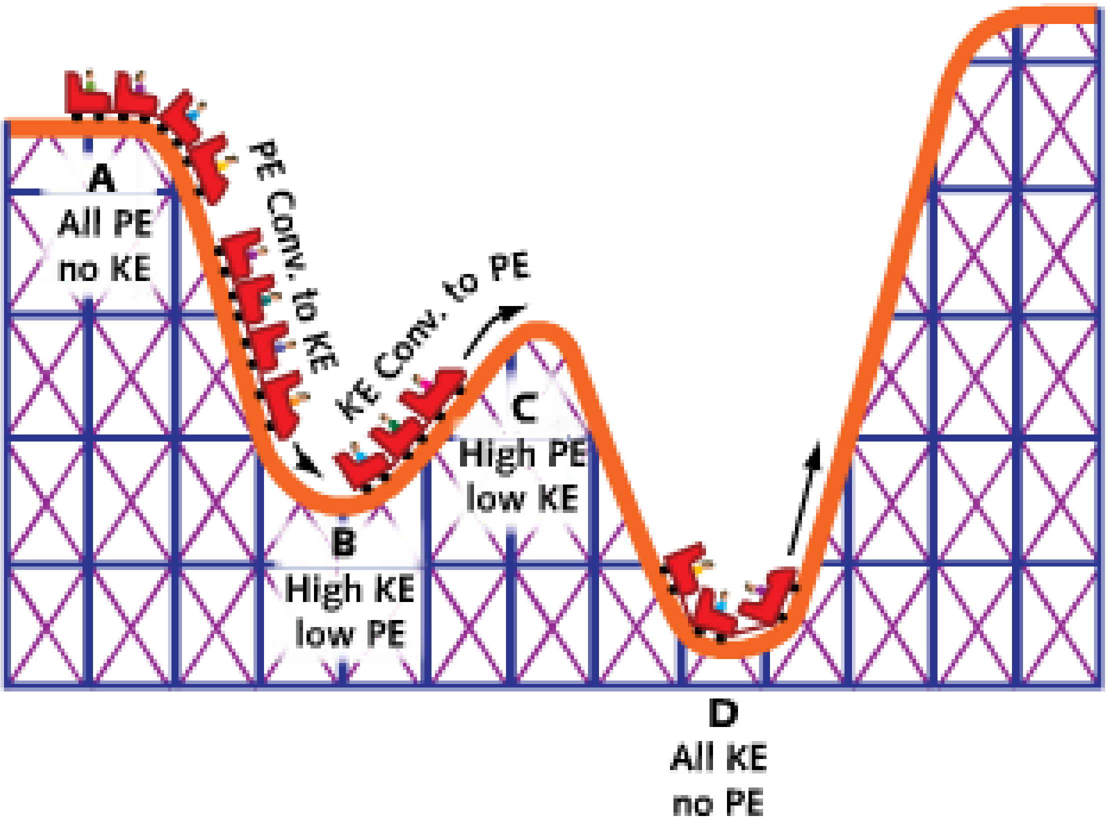


Figure 16.8 Energy is converted between potential and kinetic forms as a roller coaster travels down its track. Ignoring friction, the total mechanical energy remains the same throughout the ride.

Conservation of Energy

It can take some detective work to follow the path of the energy as it changes forms. For example, it takes a lot of energy to run a race. After the race, the runner's body has less energy than it had before. The energy used to power muscles has been converted into heat. However, the total amount of energy in the universe is just the same after the race as it was before. No energy is ever truly destroyed.

Conservation of Energy
A situation to ponder…

- Consider the system of a bow and arrow. In drawing the bow, we do work on the system and give it potential energy.
- When the bowstring is released, most of the potential energy is transferred to the arrow as kinetic energy and some as heat to the bow.

A situation to ponder…
CHECK YOUR NEIGHBOR

Suppose the potential energy of a drawn bow is 50 joules, and the kinetic energy of the shot arrow is 40 joules. Then

A. energy is not conserved.
B. 10 joules go to warming the bow.
C. 10 joules go to warming the target.
D. 10 joules is mysteriously missing.

A situation to ponder…
CHECK YOUR ANSWER

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Explanation:

The total energy of the drawn bow, which includes the poised arrow, is 50 joules. The arrow gets 40 joules and the remaining 10 joules warms the bow—still in the initial system.