Section 1: Work, Power, and Machines

Preview

Key Ideas

- How is work calculated?
- What is the relationship between work and power?
- How do machines make work easier?

Bellringer

1. Which of the following is an example of work: bowling or reading?

2. a. A man pushes against a brick wall, which doesn’t move. Is this an example of work?

   b. A student carries her books to class. Is this an example of work?

   c. A woman raises and lowers dumbbells at the gym. Is this an example of work?

   d. A book falls off a table and lands on the floor. Is this an example of work?

What Is Work?

- How is work calculated?
- Work is calculated by multiplying the force by the distance over which the force is applied.
  - work = force x distance, or *W* = *Fd*
  - The force must be applied in the direction of the object's motion.

What Is Work?, *continued*

- **work:** the transfer of energy to an object by the application of a force that causes the object to move in the direction of the force

- Work is zero when an object is not moving.

- Work is measured in joules (J):

  $1\ \text{N} \cdot \text{m} = 1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2$

Math Skills

Work

Imagine a father playing with his daughter by lifting her repeatedly in the air. How much work does he do with each lift if he lifts her 2.0 m and exerts an average force of 190 N?

1. List the given and unknown values.

Given: *force*, F = 190 N

distance, d = 2.0 m

Unknown: *work*, W = ? J

Math Skills, *continued*

2. Write the equation for work.

$$work = force \times distance$$

$$W = f \times d$$

3. Insert the known values into the equation, and solve.

$$W = 190 \text{ N} \times 2.0 \text{ m} = 380 \text{ N} \cdot \text{m}$$

$$\boxed{W = 380 \text{ J}}$$

Power

- What is the relationship between work and power?

- Power is the rate at which work is done, or how much work is done in a given amount of time.

$$\text{power} = \frac{\text{work}}{\text{time}}, \text{ or } P = \frac{W}{t}$$

Power, *continued*

- **power:** a quantity that measures the rate at which work is done or energy is transformed

- Power is measured in watts (W):

  $1\ W = 1\ J/s$

Math Skills

Power

Lifting an elevator 18 m takes 100 kJ. If doing so takes 20 s, what is the average power of the elevator during the process?

1. List the given and unknown values.

Given: *work, W* = 100 kJ = 1×10^5 J

time, t = 20 s

Distance is not needed.

Unknown: *power, P* = ? W

Math Skills, *continued*

2. **Write the equation for power.**

$$power = \frac{work}{time}$$

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

3. **Insert the known values into the equation, and solve.**

$$P = \frac{1 \times 10^5 \text{ J}}{20 \text{ s}} = 5 \times 10^3 \text{ J/s}$$

$$\boxed{P = 5 \times 10^3 \text{ W} = 5 \text{ kW}}$$

Machines and Mechanical Advantage

- How do machines make work easier?

- Machines help do work by changing the size of an input force, the direction of the force, or both.

Machines and Mechanical Advantage, *continued*

- Mechanical advantage is an important ratio.
- **mechanical advantage:** a quantity that expresses how much a machine multiplies force or distance

$$mechanical\ advantage = \frac{output\ force}{input\ force} = \frac{input\ distance}{output\ distance}$$

Math Skills

Mechanical Advantage

Calculate the mechanical advantage of a ramp that is 5.0 m long and 1.5 m high.

1. List the given and unknown values.

Given: *input distance* = 5.0 m
output distance = 1.5 m

Unknown: *mechanical advantage* = ?

Math Skills, *continued*

2. Write the equation for mechanical advantage.

We need only the distance part of the full equation:

$$mechanical\ advantage = \frac{input\ distance}{output\ distance}$$

3. Insert the known values into the equation, and solve.

$$\text{mechanical advantage} = \frac{5.0\ \text{m}}{1.5\ \text{m}} = \boxed{3.3}$$

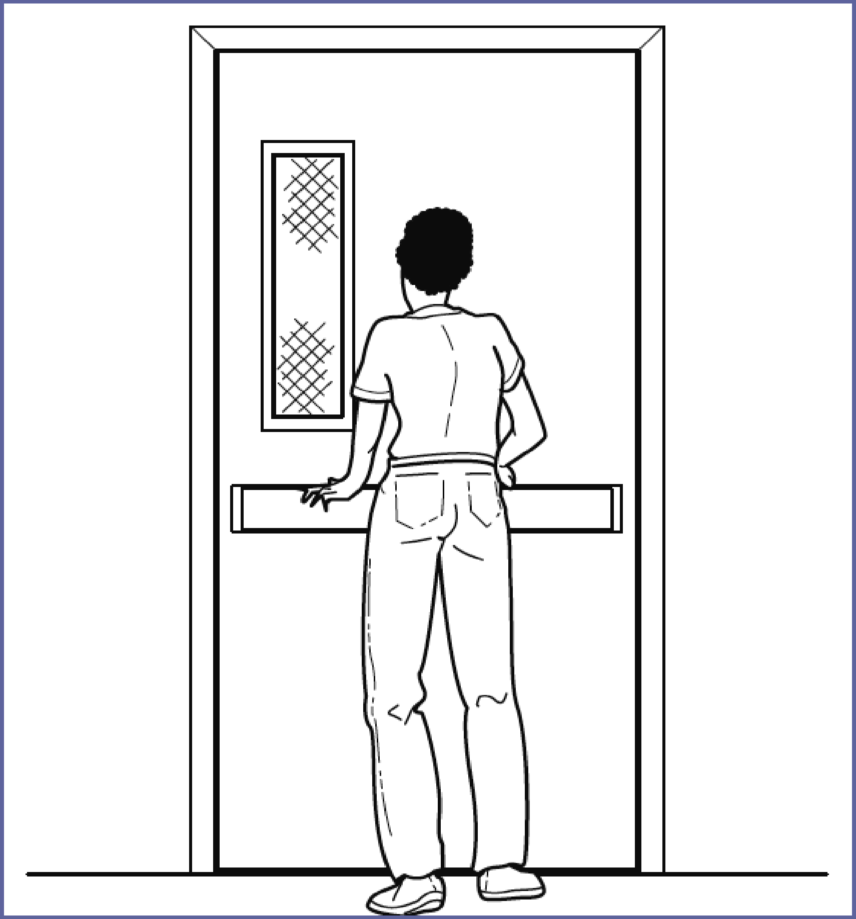
Section 2: Simple Machines

Preview

Key Ideas

- What are the six types of simple machines?
- What are the two principal parts of all levers?
- How does using an inclined plane change the force required to do work?
- What simple machines make up a pair of scissors?

Bellringer



You may not think of a door as a simple machine, but it is one. The door functions like a lever. Like other levers, when you exert a force on it (an input force), that force is exerted along the entire door (the output force).

Bellringer, *continued*

1. For all levers, there is one point along the lever that remains still while the rest of the lever moves. This point is called the fulcrum. Where is the fulcrum of a door?
2. You can push at any point along the width of a door and it will open. Which position requires the least force: pushing the door near the hinges, in the middle, or near the side farthest from the hinges? (Hint: Which of these feels easiest to do?)
3. If you are trying to prop the door open with a small, light doorstop, where would you place the doorstop: near the hinges, in the middle, or near the side farthest from the hinges?

What Are Simple Machines?

- What are the six types of simple machines?

- The six types of simple machines are the simple lever, the pulley, the wheel and axle, the simple inclined plane, the wedge, and the screw.

What Are Simple Machines?, *continued*

- Simple machines are divided into two families: the *lever family* and the *inclined plane family.*

Lever family:
- simple lever
- pulley
- wheel and axle

Inclined plane family:
- simple inclined plane
- wedge
- screw

The Lever Family

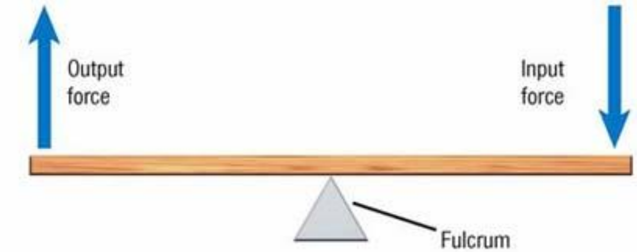
- What are the two principal parts of all levers?
- All levers have a rigid arm that turns around a point called the fulcrum.

- Levers are divided into three classes.

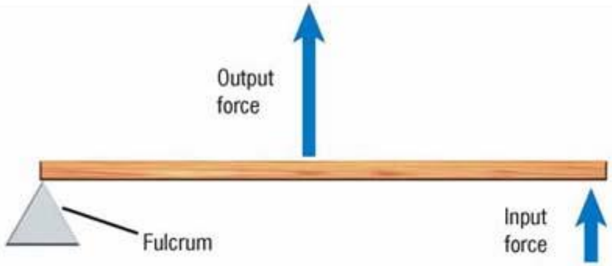
The Lever Family, *continued*

The Three Classes of Levers

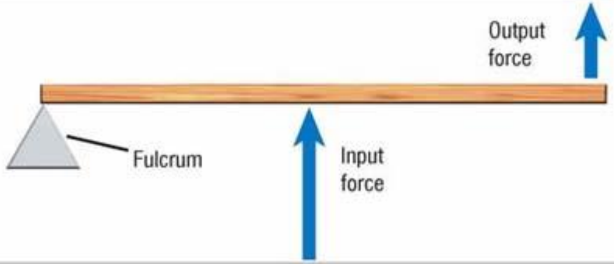
A **first-class lever** has a fulcrum located between the points of application of the input and output forces.



In a **second-class lever,** the fulcrum is at one end of the arm, and the input force is applied to the other end. The wheel of a wheelbarrow is a fulcrum.



Third-class levers multiply distance rather than force. As a result, they have a mechanical advantage of less than one. The human body contains many third-class levers.



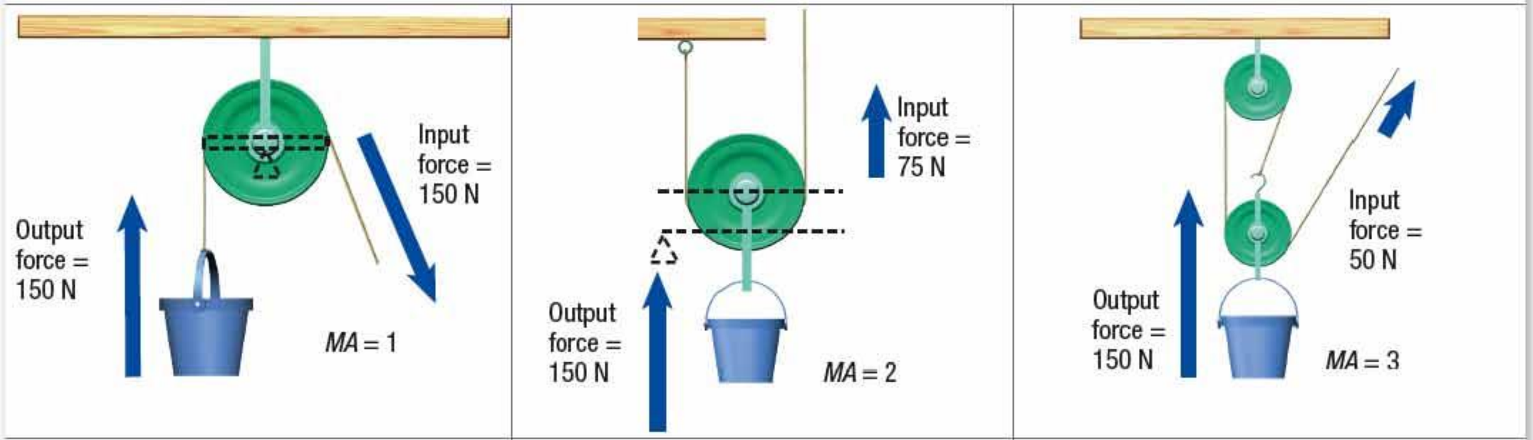
The Lever Family, *continued*

- Pulleys are modified levers.
  - The point in the middle of a pulley is like the fulcrum of a lever.
  - The rest of the pulley behaves like the rigid arm of a first-class lever.

- A wheel and axle is a lever or pulley connected to a shaft.
  - Screwdrivers and cranks are common wheel-and-axel machines.

The Mechanical Advantage of Pulleys

The Mechanical Advantage of Pulleys

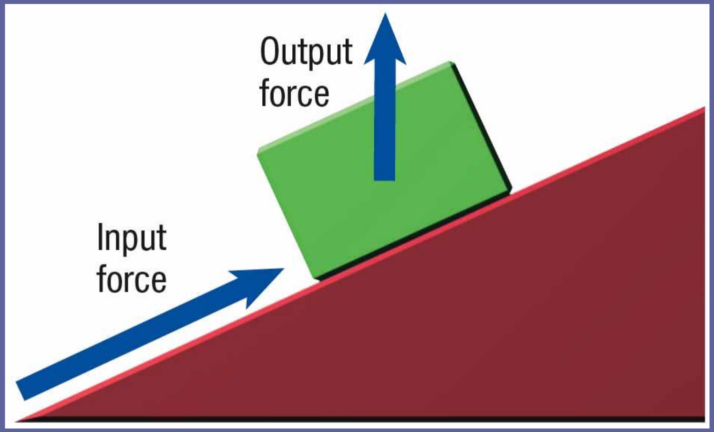


When a 150 N weight is lifted by using a single, fixed pulley, the weight must be fully supported by the rope on each side of the pulley. This kind of pulley has a mechanical advantage of one.	When a moving pulley is used, the load is shared by two sections of rope pulling upward. The input force supports only half of the weight. This pulley system has a mechanical advantage of two.	In this arrangement of multiple pulleys, all of the sections of rope are pulling up against the downward force of the weight. This arrangement gives an even higher mechanical advantage.

The Inclined Plane Family

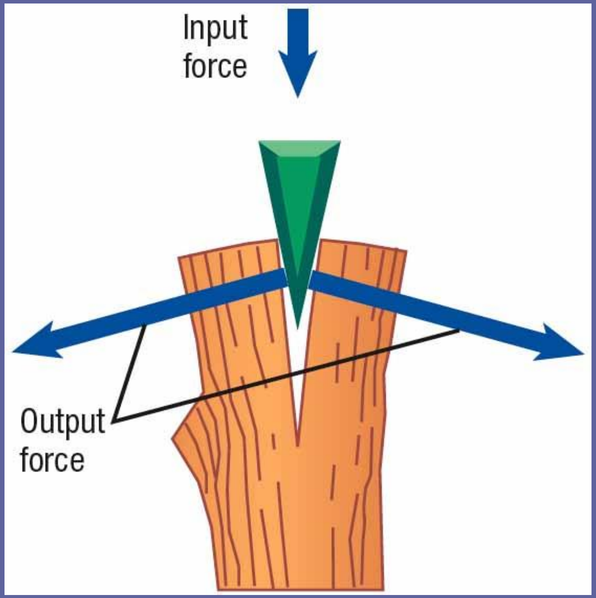
- How does using an inclined plane change the force required to do work?

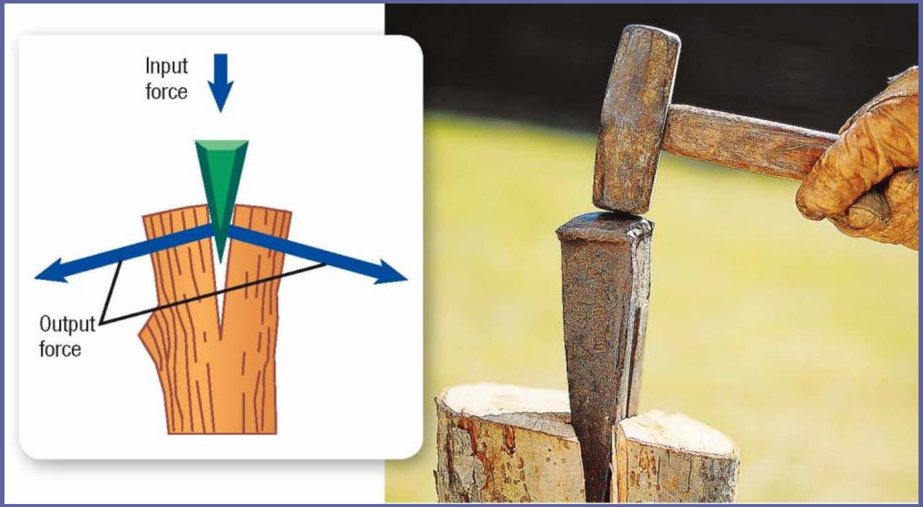
- Pushing an object up an inclined plane requires less input force than lifting the same object does.



The Inclined Plane Family

- A wedge is a modified inclined plane.
- A screw is an inclined plane wrapped around a cylinder.





Compound Machines

- What simple machines make up a pair of scissors?
- A pair of scissors uses two first-class levers joined at a common fulcrum; each lever arm has a wedge that cuts into the paper.

- **compound machine:** a machine made of more than one simple machine

Section 3: What is Energy?

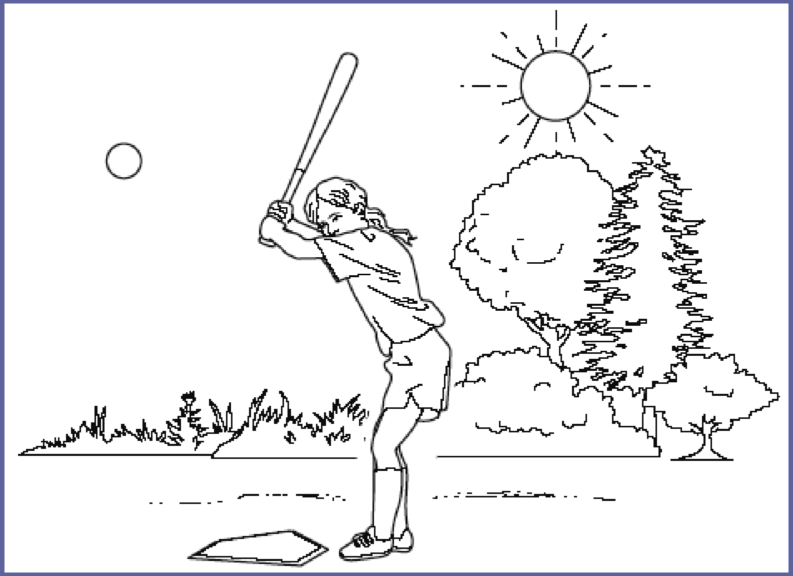
Preview

Key Ideas

- What is the relationship between energy and work?
- Why is potential energy called energy of position?
- What factors does kinetic energy depend on?
- What is nonmechanical energy?

Bellringer

You should already have learned that energy is always conserved. Instead of being created or destroyed, energy just changes from one form to another. For example, sunlight is the ultimate source of energy on Earth. Look at the illustration below, and identify the types of energy involved.



Bellringer, *continued*

1. How does sunlight provide the energy the girl needs to swing the bat? (**Hint:** What do you need to have energy?)
2. When the girl hits the ball, she exerts a force on it. Does she do work on the ball in the scientific sense of the term? Explain your answer.
3. After the girl hits the ball, the ball moves very fast and has energy. When the ball hits the fielder's glove, it stops moving. Given that energy can never be destroyed but merely changes form, what happens to the energy the ball once had? (**Hint:** If you are the fielder, what do you hear and feel as you catch the ball?)

Energy and Work

- What is the relationship between energy and work?

- Whenever work is done, energy is transformed or is transferred from one system to another system.

- **energy**: the capacity to do work

- Energy is measured in joules (J).

Potential Energy

- Why is potential energy called energy of position?

- Potential energy (*PE*) is sometimes called energy of position because it results from the relative positions of objects in a system.

- **potential energy:** the energy that an object has because of the position, shape, or condition of the object

Potential Energy, *continued*

- Any object that is stretched or compressed to increase or decrease the distance between its parts has *elastic potential energy.*
  - Examples: stretched bungee cords, compressed springs
- Any system of two or more objects separated by a vertical distance has *gravitational potential energy.*
  - Example: a roller coaster at the top of a hill

Potential Energy, *continued*

- Gravitational potential energy depends on both mass and height.

- *grav. PE = mass × free-fall acceleration × height,* or $PE = mgh$

- The height can be relative.

Math Skills

Gravitational Potential Energy

A 65 kg rock climber ascends a cliff. What is the climber's gravitational potential energy at a point 35 m above the base of the cliff?

1. List the given and unknown values.

Given: *mass,* m = 65 kg

height, h = 35 m

free-fall acceleration, g = 9.8 m/s^2

Unknown: *gravitational potential energy,* PE = ? J

Math Skills, *continued*

2. Write the equation for gravitational potential energy.

$$PE = mgh$$

3. Insert the known values into the equation, and solve.

$$PE = (65\ \text{kg})(9.8\ \text{m/s}^2)(35\ \text{m})$$

$$PE = 2.2 \times 10^4\ \text{kg}\cdot\text{m}^2/\text{s}^2$$

$$\boxed{PE = 2.2 \times 10^4\ \text{J}}$$

Kinetic Energy

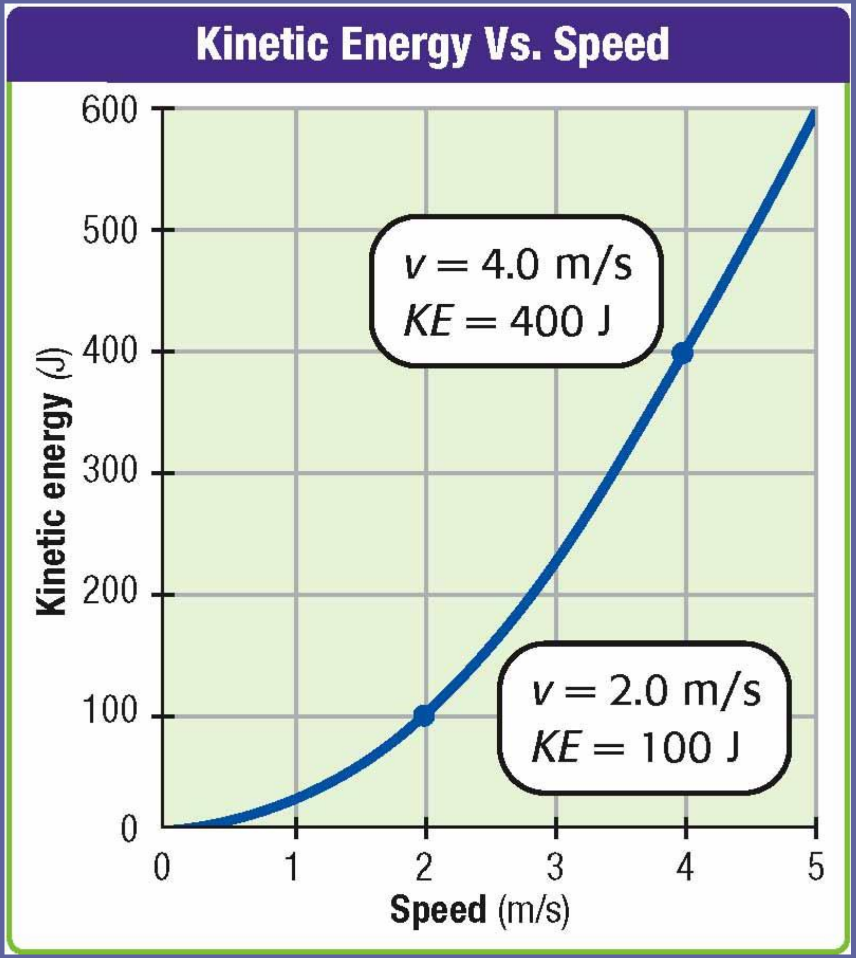
〉 What factors does kinetic energy depend on?

〉 Kinetic energy depends on both the mass and the speed of an object.

- **kinetic energy:** the energy of an object due to the object's motion
- *KE = ½ × mass × speed squared,* or *KE= ½mv²* ($KE = \frac{1}{2}mv^2$)

Kinetic Energy, *continued*

- Kinetic energy depends on speed more than mass.
- Atoms and molecules have kinetic energy.



Math Skills

Kinetic Energy

What is the kinetic energy of a 44 kg cheetah running at 31 m/s?

1. List the given and unknown values.

Given: *mass, m* = 44 kg

speed, v = 31 m/s

Unknown: *kinetic energy, KE* = ? J

Math Skills, *continued*

2. Write the equation for kinetic energy.

$$kinetic\ energy = \frac{1}{2} \times mass \times speed\ squared$$

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

3. Insert the known values into the equation, and solve.

$$KE = \frac{1}{2}(44\ \text{kg})(31\ \text{m/s})^2 = 2.1 \times 10^4\ \text{kg} \bullet \text{m}^2/\text{s}^2$$

$$\boxed{KE = 2.1 \times 10^4\ \text{J}}$$

Other Forms of Energy

- What is nonmechanical energy?

- Energy that lies at the level of the atom is sometimes called *nonmechanical energy*.

- **mechanical energy:** the amount of work an object can do because of the object's kinetic and potential energies
- In most cases, nonmechanical forms of energy are just special forms of either kinetic or potential energy.

Other Forms of Energy, *continued*

- Chemical reactions involve potential energy.
  - The amount of *chemical energy* associated with a substance depends in part on the relative positions of the atoms it contains.
- Living things get energy from the sun.
  - Plants use *photosynthesis* to turn the energy in sunlight into chemical energy.
- The sun gets energy from nuclear reactions.
  - The sun is fueled by *nuclear fusion* reactions in its core.

Other Forms of Energy, *continued*

- Energy can be stored in fields.
  - Electrical energy results from the location of charged particles in an *electric field.*
  - When electrons move from an area of higher *electric potential* to an area of lower electric potential, they gain energy.

Other Forms of Energy, *continued*

- Light can carry energy across empty space.
  - Light energy travels from the sun to Earth across empty space in the form of *electromagnetic waves*.
  - Electromagnetic waves are made of *electric and magnetic fields,* so light energy is another example of energy stored in a field.

Section 4: Conservation of Energy

Preview

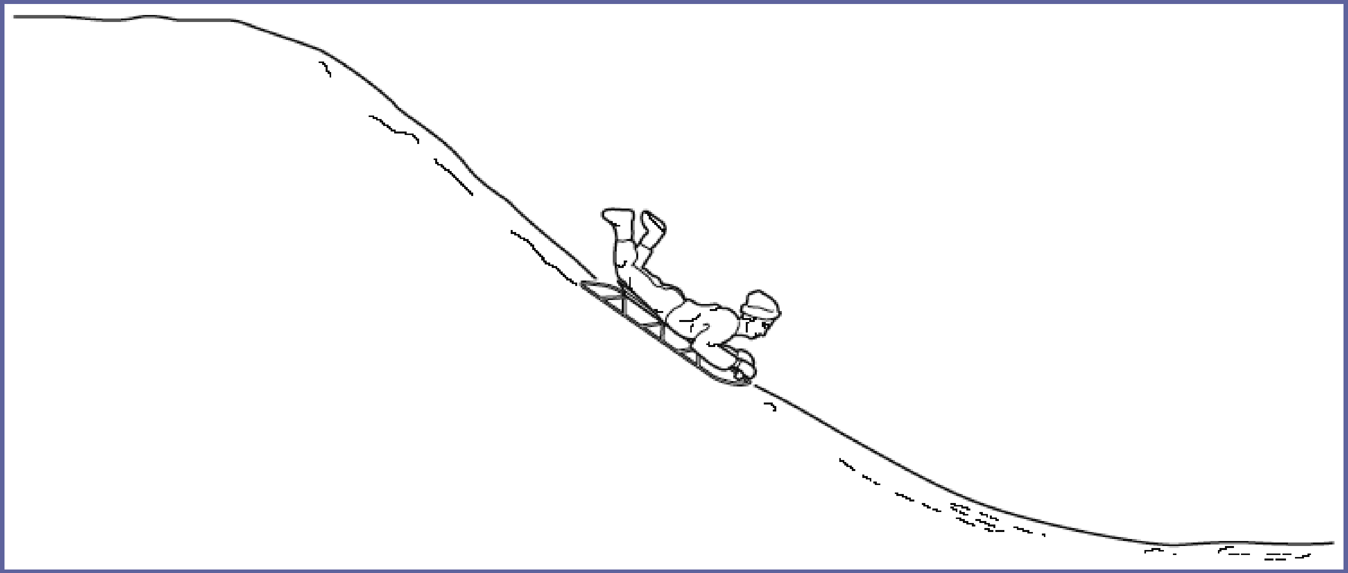
- Key Ideas
- Bellringer
- Energy Transformations
- Graphing Skills
- The Law of Conservation of Energy
- Efficiency of Machines
- Math Skills

Key Ideas

- How does energy change?
- What is the law of conservation of energy?
- How much of the work done by a machine is actually useful work?

Bellringer

You give yourself and your sled gravitational potential energy when you pull your sled to the top of a snowy hill. You board your sled and slide to the bottom of the hill, speeding up as you go.



Bellringer, *continued*

1. When does the sled have the most potential energy? When does it have the least potential energy?
2. Where does the sled have the most kinetic energy and the least kinetic energy?
3. What happens to the relative amounts of potential and kinetic energy as the sled slides down the hill? What happens to the total energy?
4. After the sled reaches the bottom of the hill, it coasts across level ground and eventually stops. What happened to the energy the sled had?

Energy Transformations

- How does energy change?

- Energy readily changes from one form to another.

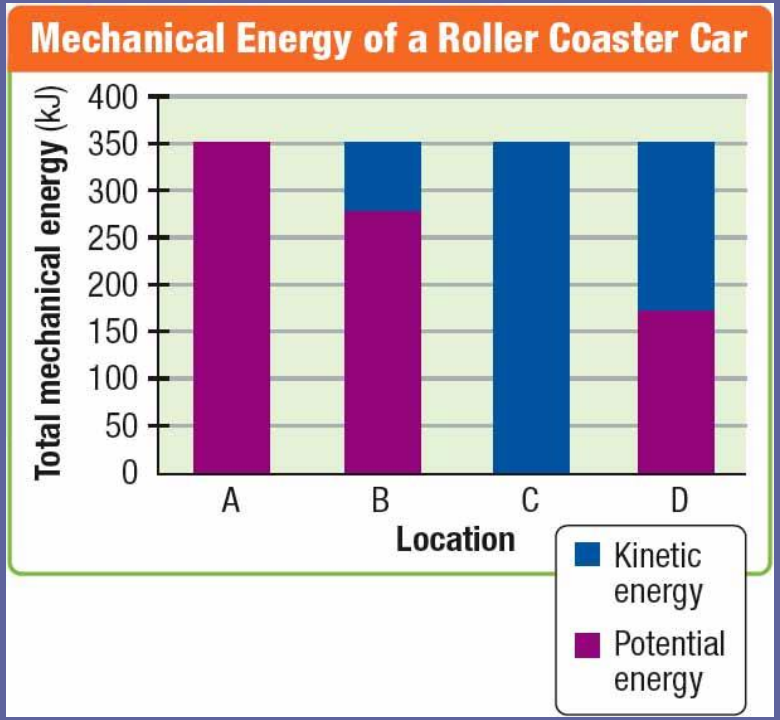
Energy Transformations, *continued*

- Potential energy can become kinetic energy.
  - Example: As a roller coaster car goes down a hill, *PE* changes to *KE*.
- Kinetic energy can become potential energy.
  - Example: The *KE* of a roller coaster car at the bottom of a hill can do work to carry it up another hill.
- Mechanical energy can change to other forms of energy.

Graphing Skills

Graphing Mechanical Energy

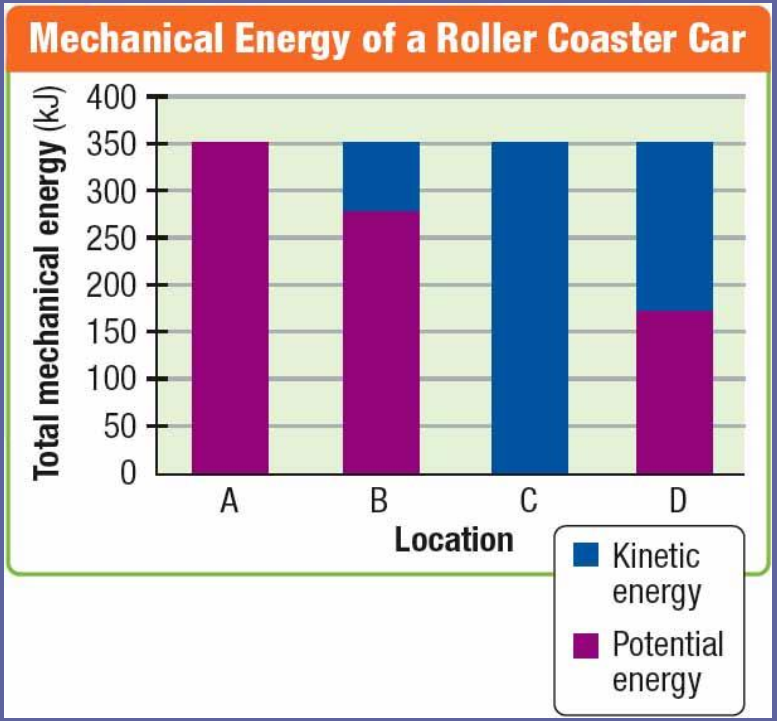
The bar graph shown here presents data about a roller coaster car. What variables are plotted? Identify the dependent and independent variables. What does the legend tell you about this graph?



Graphing Skills, *continued*

1. **Study the axes and legend to determine the variables.**

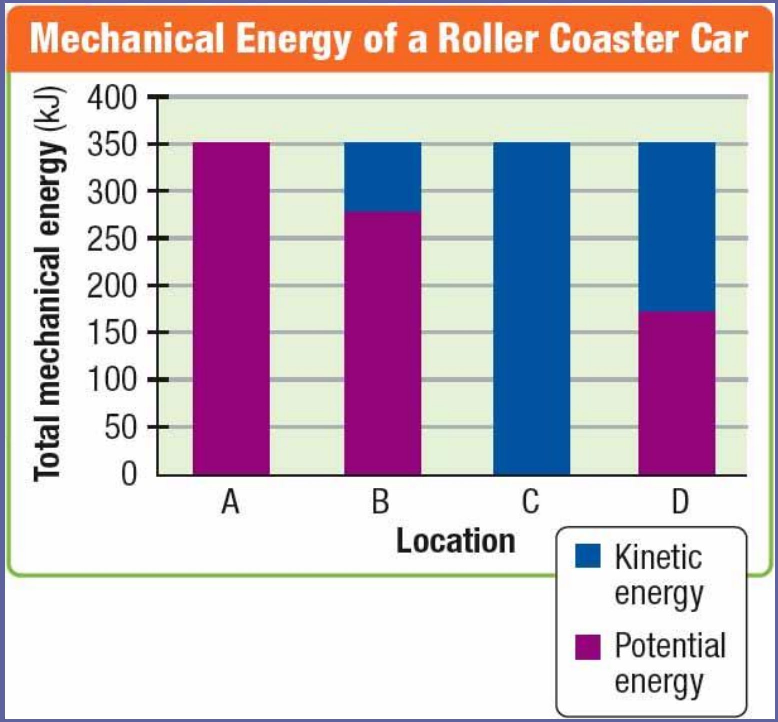
Location is the variable on the *x*-axis. Two variables are plotted on the *y*-axis: kinetic and potential energy



Graphing Skills, *continued*

2. Consider the relationship between the variables.

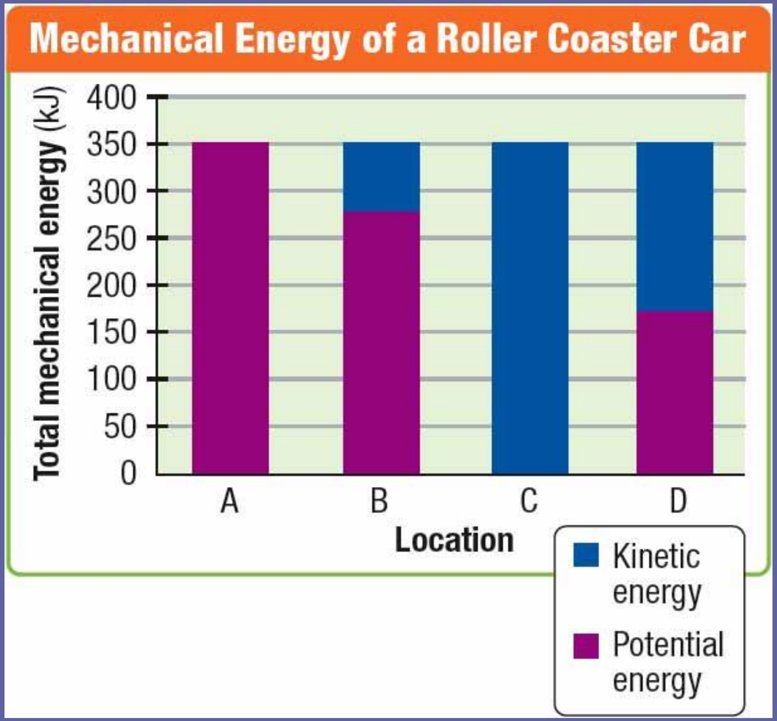
The independent variable is location, because the car's kinetic energy and potential energy change with location.



Graphing Skills, *continued*

3. Examine the legend and how it relates to the graph.

The legend indicates that the car's mechanical energy consists of both kinetic energy and potential energy.



The Law of Conservation of Energy

- What is the law of conservation of energy?

- Energy cannot be created or destroyed. In other words, the total amount of energy in the universe never changes, although energy may change from one form to another.

The Law of Conservation of Energy, *continued*

- Energy does not appear or disappear.
  - Whenever the total energy in a system increases, it must be due to energy that enters the system from an external source.
- Thermodynamics describes energy conservation.
  - For any system, the net change in energy equals the energy transferred as work and as heat.
  - This form of the law of energy conservation is called the *first law of thermodynamics.*

The Law of Conservation of Energy, *continued*

- Systems may be open, closed, or isolated.
  - *open system:* energy and matter are exchanged with the surroundings
  - *closed system:* energy but not matter is exchanged
  - *isolated system:* neither energy nor matter is exchanged
- Most real-world systems are open.

Efficiency of Machines

- How much of the work done by a machine is actually useful work?

- Only a portion of the work done by any machine is *useful work*— that is, work that the machine is designed or intended to do.

Efficiency of Machines, *continued*

- Not all of the work done by a machine is useful work.
  - because of friction, work output < work input
- Efficiency is the ratio of useful work out to work in.
  - **efficiency:** a quantity, usually expressed as a percentage, that measures the ratio of useful work output to work input

$$efficiency = \frac{useful\ work\ output}{work\ input}$$

Math Skills

Efficiency

A sailor uses a rope and an old, squeaky pulley to raise a sail that weighs 140 N. He finds that he must do 180 J of work on the rope to raise the sail by 1 m. (He does 140 J of work on the sail.) What is the efficiency of the pulley? Express your answer as a percentage.

1. List the given and unknown values.

Given: *work input* = 180 J

useful work output = 140 J

Unknown: *efficiency* = ? %

Math Skills, *continued*

2. Write the equation for efficiency.

$$efficiency = \frac{useful\ work\ output}{work\ input}$$

3. Insert the known values into the equation, and solve.

$$efficiency = \frac{140\ \text{J}}{180\ \text{J}} = 0.78$$

To express this as a percentage, multiply by 100 and add the percent sign, "%."

$$\boxed{efficiency = 0.78 \times 100\% = 78\%}$$