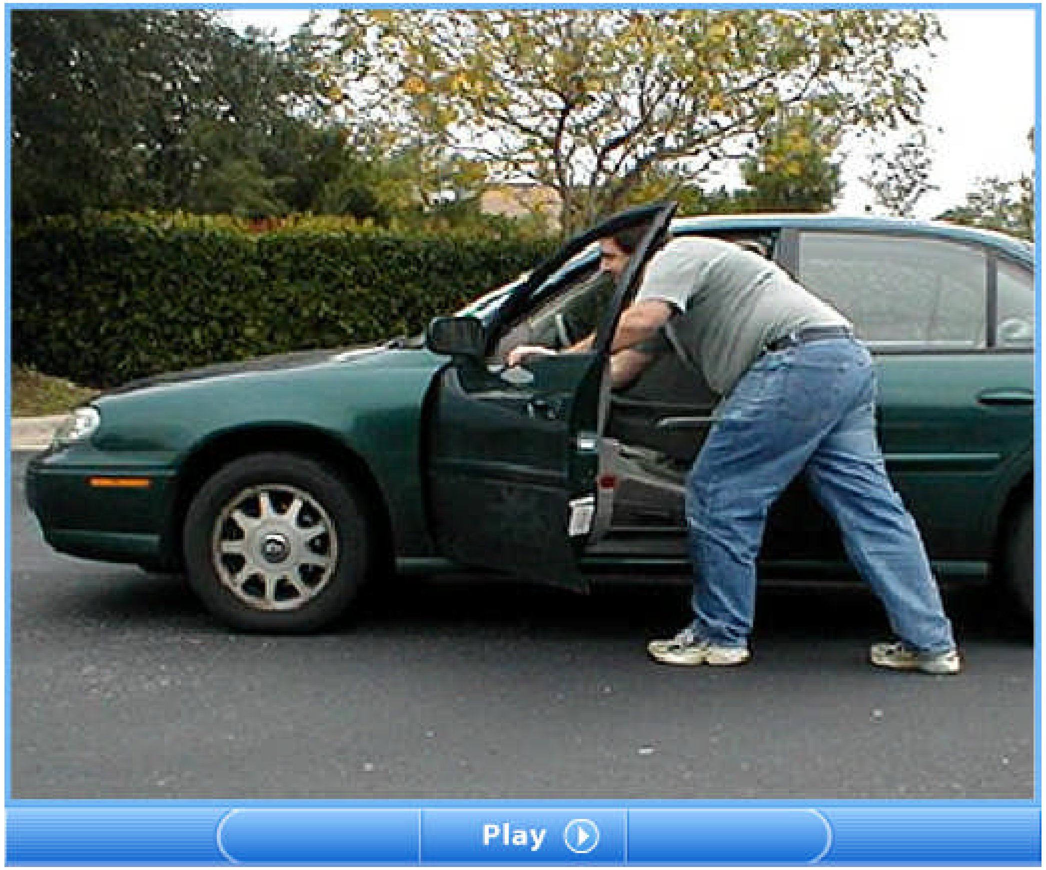
Work and Energy

- **Skills**
  - Experiment Design
  - SI Units and SI unit conversions
  - Using graphs
  - Scientific Notation and use in calculations
  - Significant Digits
  - Using and manipulating equations
  - Newton’s Laws
  - Law of Conservation of Energy

Objectives

- **Define** work and power.
- **Calculate** the work done on an object and the rate at which work is done.
- **Use** the concept of mechanical advantage to explain how machines make doing work easier.
- **Calculate** the mechanical advantage of various machines.

Work



What is Work?

- **Work** is the transfer of energy to a body by the application of a force that causes the body to move in the direction of the force.

- Work is done only when a force causes an object to move in the direction of the force. This is different from the everyday meaning of *work*.

- Work Equation

$$\text{work} = \text{force} \times \text{distance}$$

$$\boxed{W = Fd}$$

What is Work?, ***continued***

- Work is measured in joules.
  - Because work is calculated as force times distance, it is measured in units of newtons times meters, N•m.
  - These units are also called *joules* (J). In terms of SI base units, a joule is equivalent to 1 kg•m^2/s^2.

- Definition of joules

$$1\,J = 1\,N\,m = 1\,kg\,m^2/s^2$$

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, assuming 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* × *distance*

$W = f \times d$

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

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

$W = 380\ \text{J}$

Power

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

- Power Equation

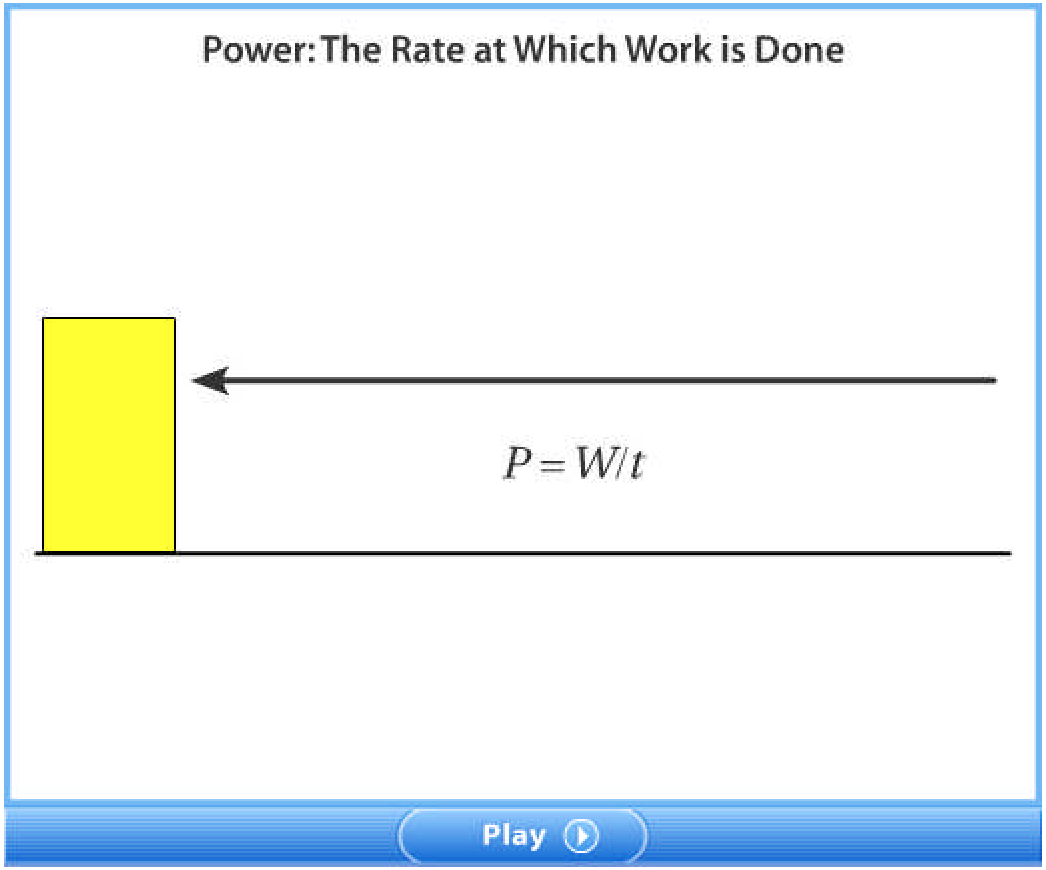
$$power = \frac{work}{time}$$

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

- Power is measured in watts.

$$watt\,(W) = \frac{J}{s} = \frac{kg\,m^2}{s^3}$$

Power



Math Skills

Power It takes 100 kJ of work to lift an elevator 18 m. If this is done in 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, d = 18 m

Unknown: *power, P* = ? watts

Math Skills, *continued*

2. Write the equation for power.

$$power = \frac{work}{time} \qquad P = \frac{W}{t}$$

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

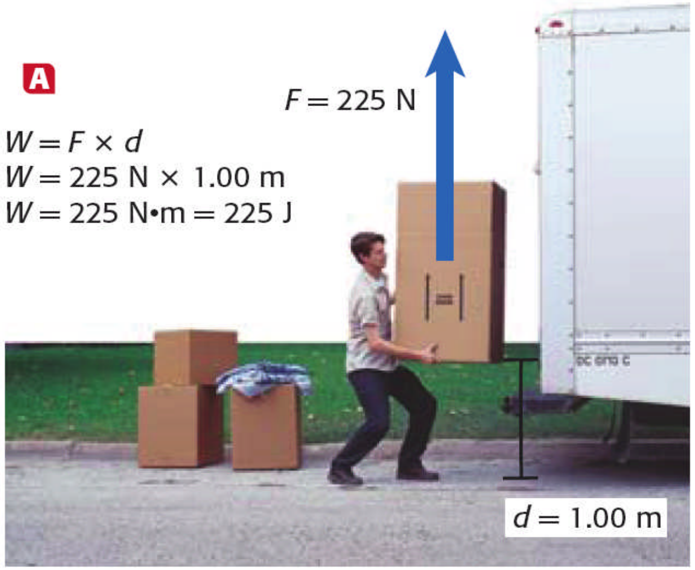
$$P = \frac{10^5 J}{20 s} = 5x10^3 watts$$

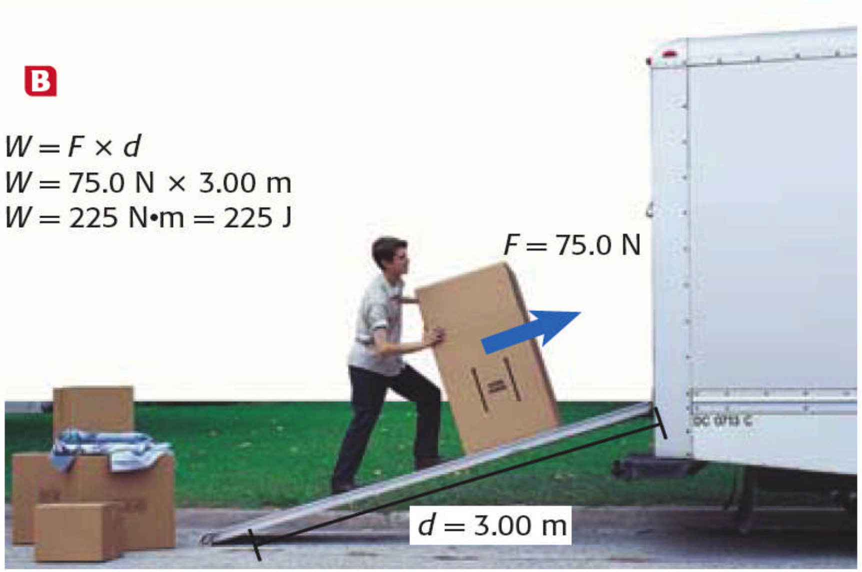
Machines and Mechanical Advantage

- Machines multiply and redirect forces.
  - They can change either the size or the direction of the input force.

- Different forces can do the same amount of work.
  - A machine allows the same amount of work to be done by either decreasing the distance while increasing the force or by decreasing the force while increasing the distance.

Force and Work





Machines and Mechanical Advantage, ***continued***

- **Mechanical advantage** tells how much a machine multiplies force or increases distance.

- Mechanical Advantage Equation

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

$$MA = \frac{F_{out}}{F_{in}} = \frac{d_{in}}{d_{out}}$$

Math Skills

Mechanical Advantage Calculate the mechanical advantage of a ramp that is 8.0 m long and 2.0 m high.

1. List the given and unknown values.

Given: *input distance* = 8.0 m

output distance = 2.0 m

Unknown: *mechanical advantage* = ?

Math Skills, ***continued***

2. Write the equation for mechanical advantage.

$$MA = \frac{d_{in}}{d_{out}}$$

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

$$MA = \frac{8.0\,m}{2.0\,m} = 4$$

Practice p.379; Practice p.381; Practice p.384; Math Skills p.384

Objectives

- **Name** and describe the six types of simple machines.

- **Discuss** the mechanical advantage of different types of simple machines.

- **Recognize** simple machines within compound machines.

The Lever Family

- The most basic machines are called **simple machines.**

- The six types of simple machines are divided into two families.

The lever family:

- simple lever
- pulley
- wheel and axle

The inclined plane family:

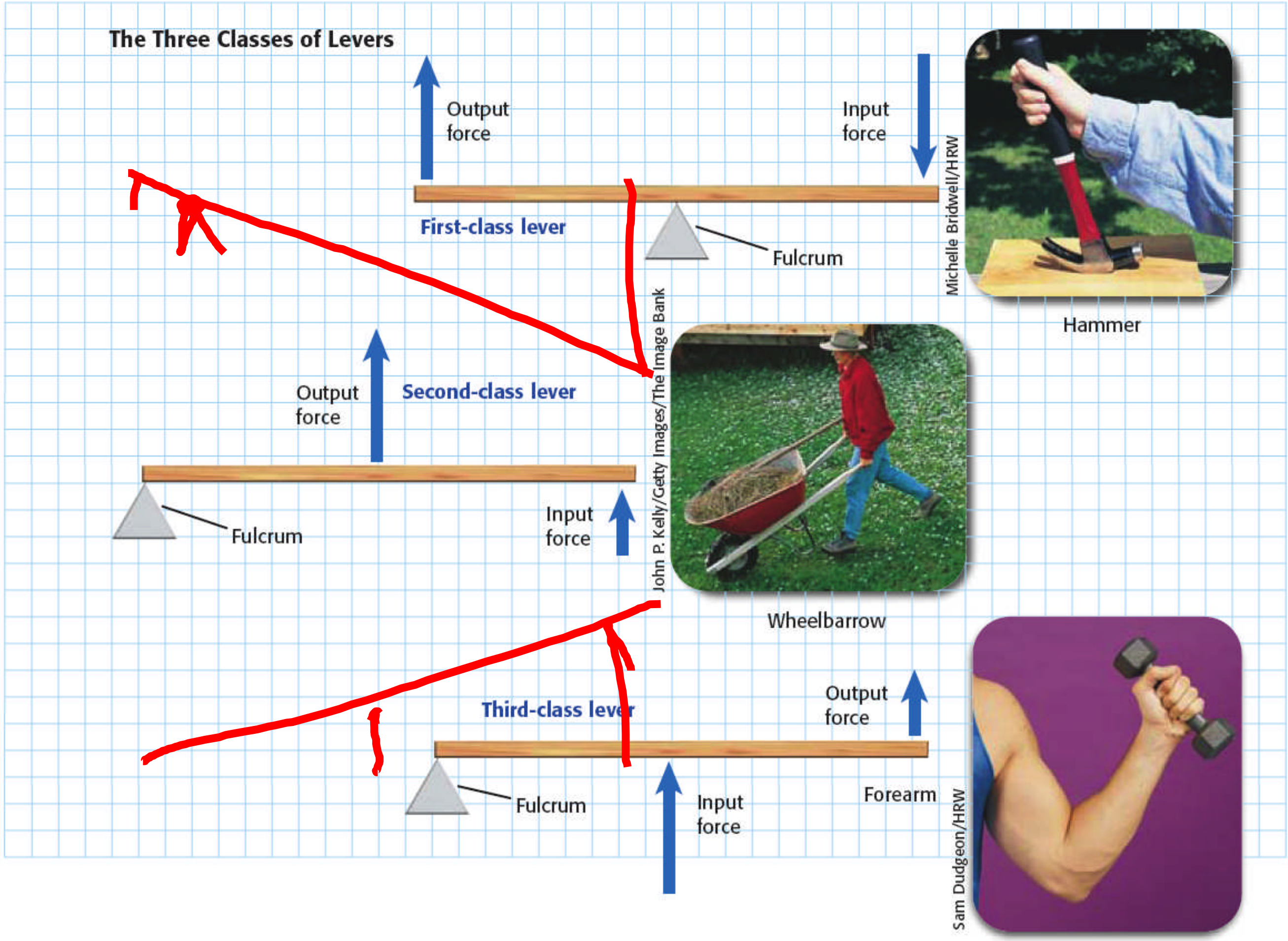
- simple inclined plane
- wedge
- screw

The Lever Family, ***continued***

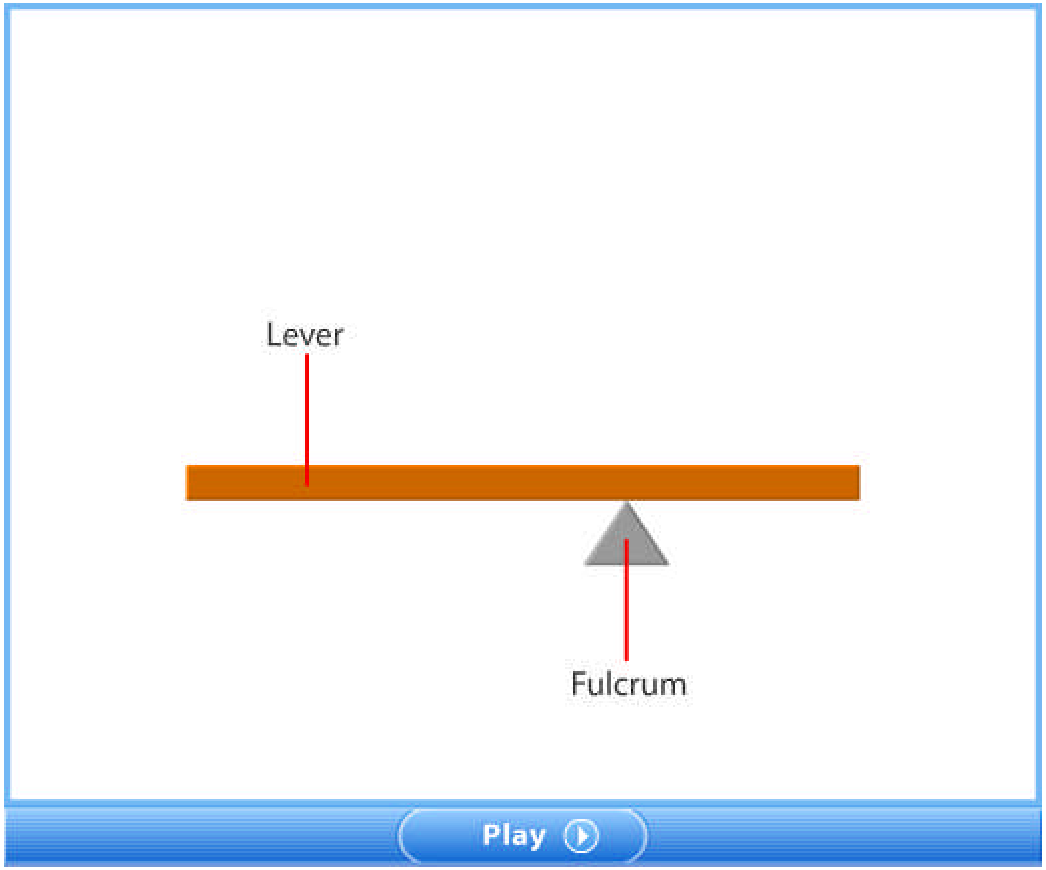
- Levers have a rigid arm and a fulcrum.

- Levers are divided into three classes.
  - First-class levers -- fulcrum located between the input and output forces.
  - Second-class lever-- output force located between the input and the fulcrum.
  - Third-class lever --the input force located between the fulcrum and the output.

Levers


The Three Classes of Levers
Output force
Input force
First-class lever
Fulcrum
Michelle Bridwell/HRW
Hammer
Output force
Second-class lever
Fulcrum
Input force
John P. Kelly/Getty Images/The Image Bank
Wheelbarrow
Third-class lever
Output force
Fulcrum
Input force
Forearm
Sam Dudgeon/HRW

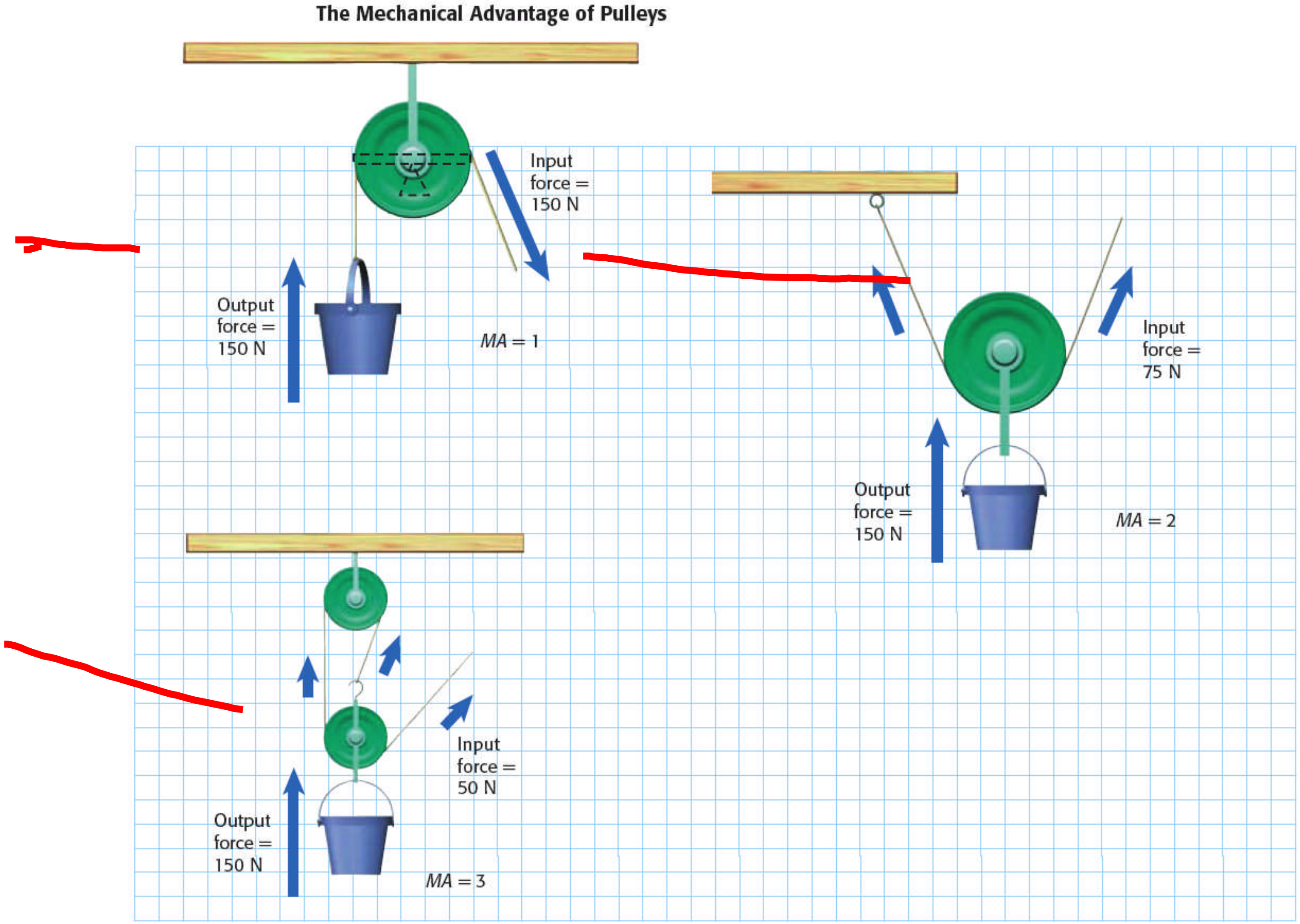
Lever



The Lever Family, ***continued***

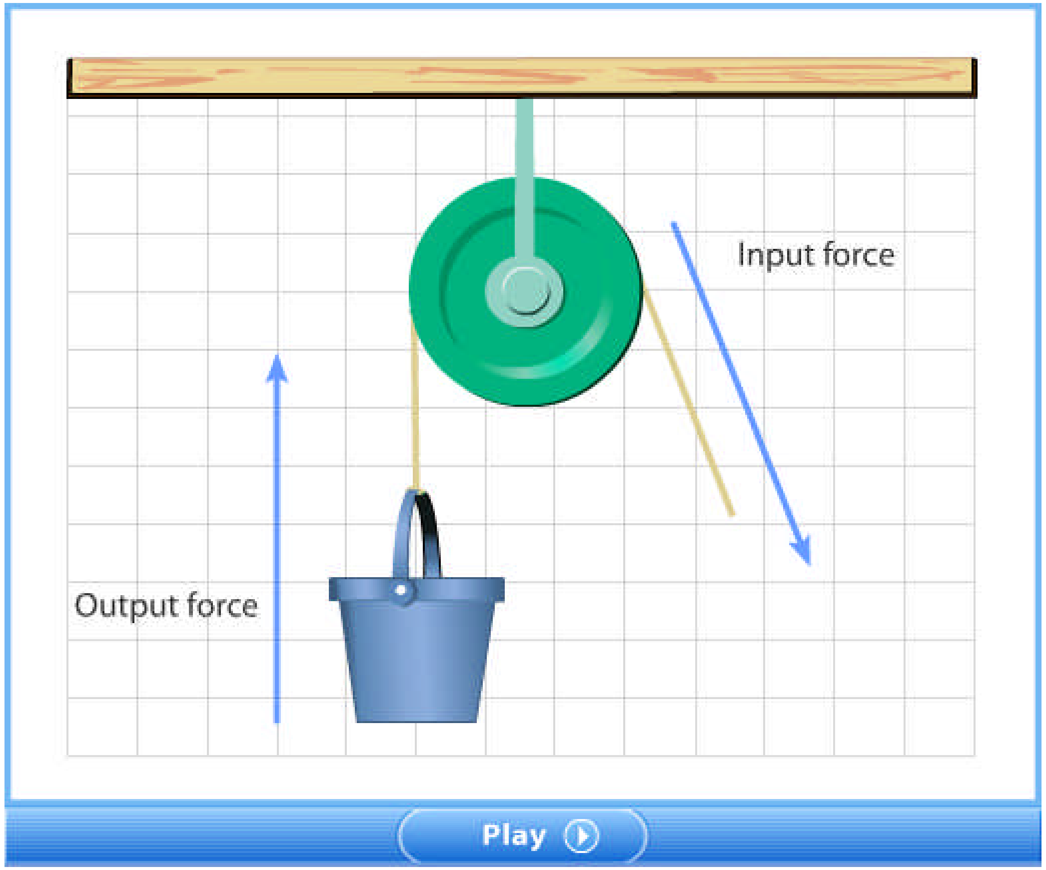
- Pulleys are modified levers.
  - The point in the middle of a pulley is like the fulcrum of a lever.
  - A single, fixed pulley has a mechanical advantage of 1.
  - Multiple pulleys are sometimes put together in a single unit called a *block and tackle.*
- A wheel and axle is a lever or pulley connected to a shaft.
  - The steering wheel of a car, screwdrivers, and cranks are common wheel-and-axel machines.

Pulleys



The Mechanical Advantage of Pulleys
Input
force =
150 N
Output
force =
150 N
MA = 1
Input
force =
75 N
Output
force =
150 N
MA = 2
Input
force =
50 N
Output
force =
150 N
MA = 3

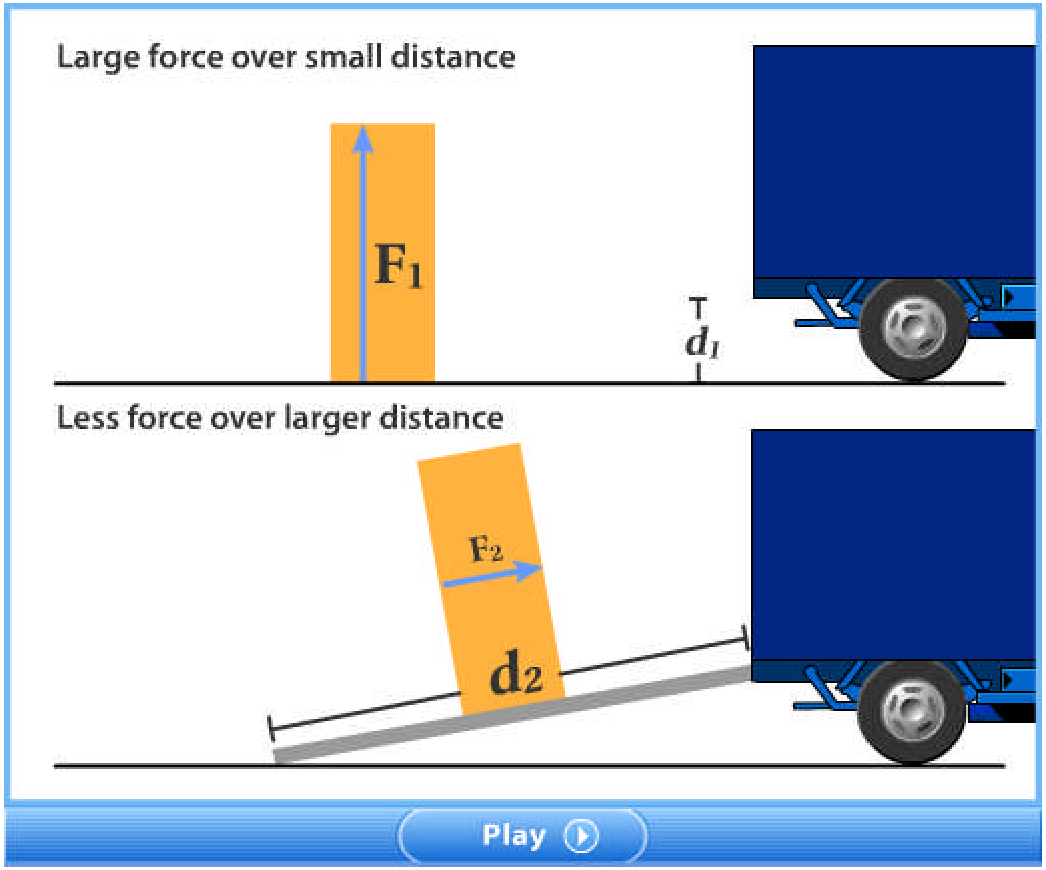
Pulley



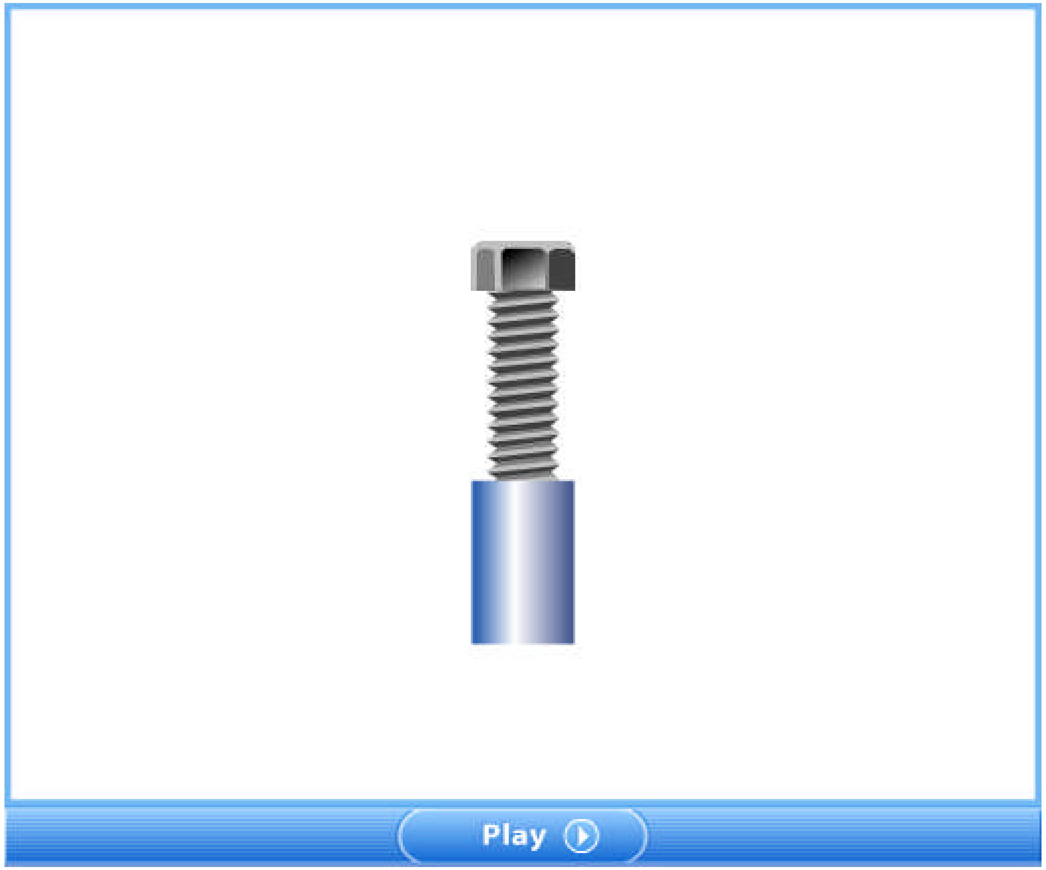
The Inclined Plane Family

- Inclined planes multiply and redirect force.
  - An inclined plane turns a small input force into a large output force by spreading the work out over a large distance.
- A wedge is a modified inclined plane.
- A screw is an inclined plane wrapped around a cylinder.

Inclined Plane



Screws



Compound Machines

- A machine made of more than one simple machine is called a **compound machine.**

- Examples of compound machines are:
  - scissors, which use two first class levers joined at a common fulcrum
  - a car jack, which uses a lever in combination with a large screw

Objectives

- **Explain** the relationship between energy and work.
- **Define** potential energy and kinetic energy.
- **Calculate** kinetic energy and gravitational potential energy.
- **Distinguish** between mechanical and non-mechanical energy.

Energy and Work

- Energy is the ability to do work or cause change.
  - When you do work on an object, you transfer energy to that object.
  - Whenever work is done, energy is transformed or transferred to another system.

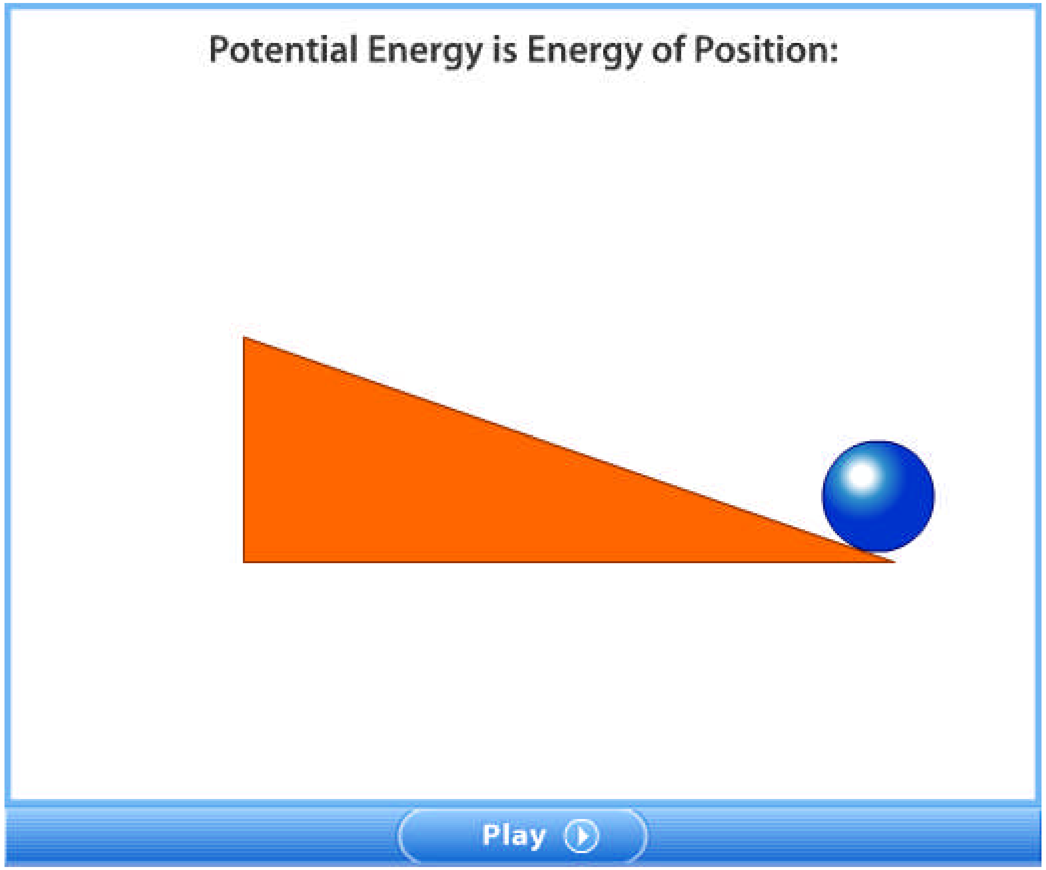
- Energy is measured in joules.
  - Because energy is a measure of the ability to do work, energy and work are expressed in the same units.

Potential Energy

- The energy that an object has because of the position, shape, or condition of the object is called **potential energy.**

- Potential energy is stored energy.
  - *Elastic potential energy* is the energy stored in elastic material (spring or a rubber band).
  - *Gravitational potential energy* is the energy stored in the gravitational field between objects.
  - *Chemical potential energy* is the energy stored in the bonds between elements.

Potential Energy, ***continued***



Potential Energy, ***continued***

- Gravitational potential energy depends on both mass and height.

- Gravitational Potential Energy Equation

$$\textit{gravitational PE} = \textit{mass} \times g \times \textit{height}$$

$$\boxed{PE = mgh}$$

- The height can be relative.
  - The height used in the above equation is usually measured from the ground.
  - However, it can be a relative height between two points, such as between two branches in a tree.

Math Skills

Gravitational Potential Energy A 100 kg rock climber ascends a cliff. What is the climber's gravitational potential energy at a point 50 m above the base of the cliff?

1. List the given and unknown values.

Given: *mass, m* = 100 kg

height, h = 50 m

free-fall acceleration, g = 10 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.

$PE = (100\ kg)(10\ m/s^2)(50\ m)$

$PE = 5 \times 10^4\ kg \cdot m^2/s^2$

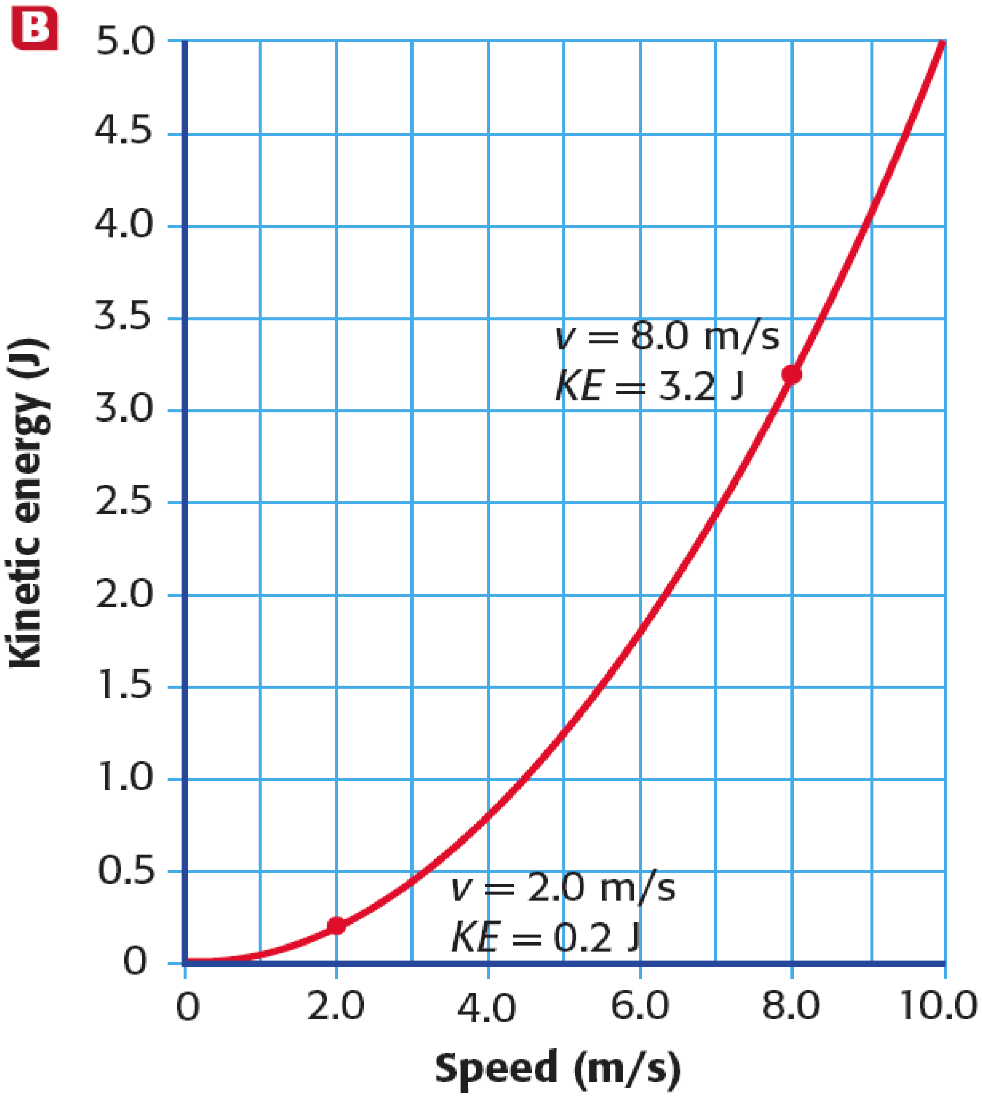
$PE = 5 \times 10^4\ J$

Kinetic Energy

- The energy of a moving object due to the object's motion is called **kinetic energy.**
- Kinetic energy depends on mass and speed.
- Kinetic Energy Equation

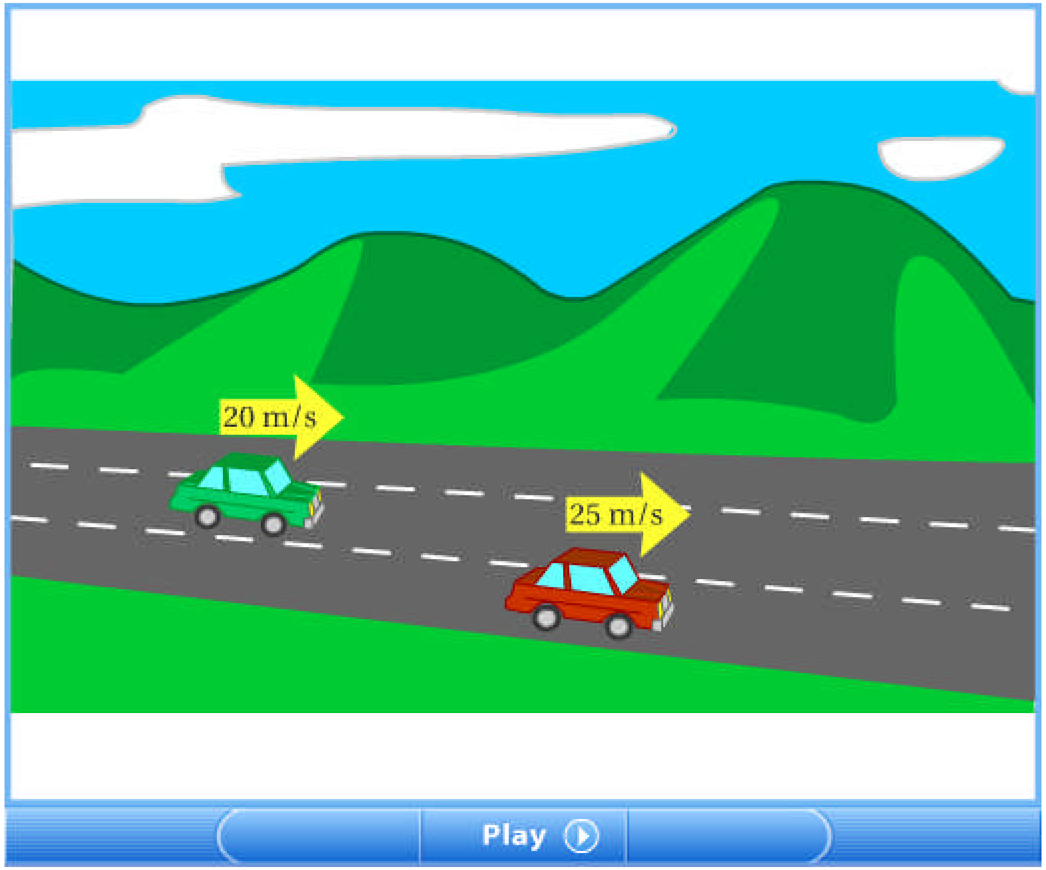
$$KE = \frac{1}{2} m v^2$$

Kinetic Energy Graph



m = 0.1 kg

Kinetic Energy



Math Skills

Kinetic Energy What is the kinetic energy of a 50 kg cheetah running at 20 m/s?

1. List the given and unknown values.

Given: *mass, m* = 50 kg

speed, v = 20 m/s

Unknown: *kinetic energy, KE* = ? J

Math Skills, ***continued***

2. Write the equation for kinetic energy.

$$KE = \frac{1}{2} m v^2$$

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

$$KE = \frac{1}{2}(50\,kg)(20\,m/s)^2$$

$$KE = 10^4\,\frac{kg\,m^2}{s^2}$$

$$KE = 10^4\ J$$

Other Forms of Energy

- The sum of the object's or a system's kinetic *and* potential energies is called **mechanical energy.**

- In addition to mechanical energy, most systems contain *non-mechanical energy.*

Other Forms of Energy, ***continued***

- Atoms and molecules have kinetic energy.
  - The kinetic energy of particles is related to heat and temperature.

- 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 and their bond strengths.

- Living things get energy from the sun.
  - Plants use *photosynthesis* to turn the energy in sunlight into chemical energy.

Other Forms of Energy, ***continued***

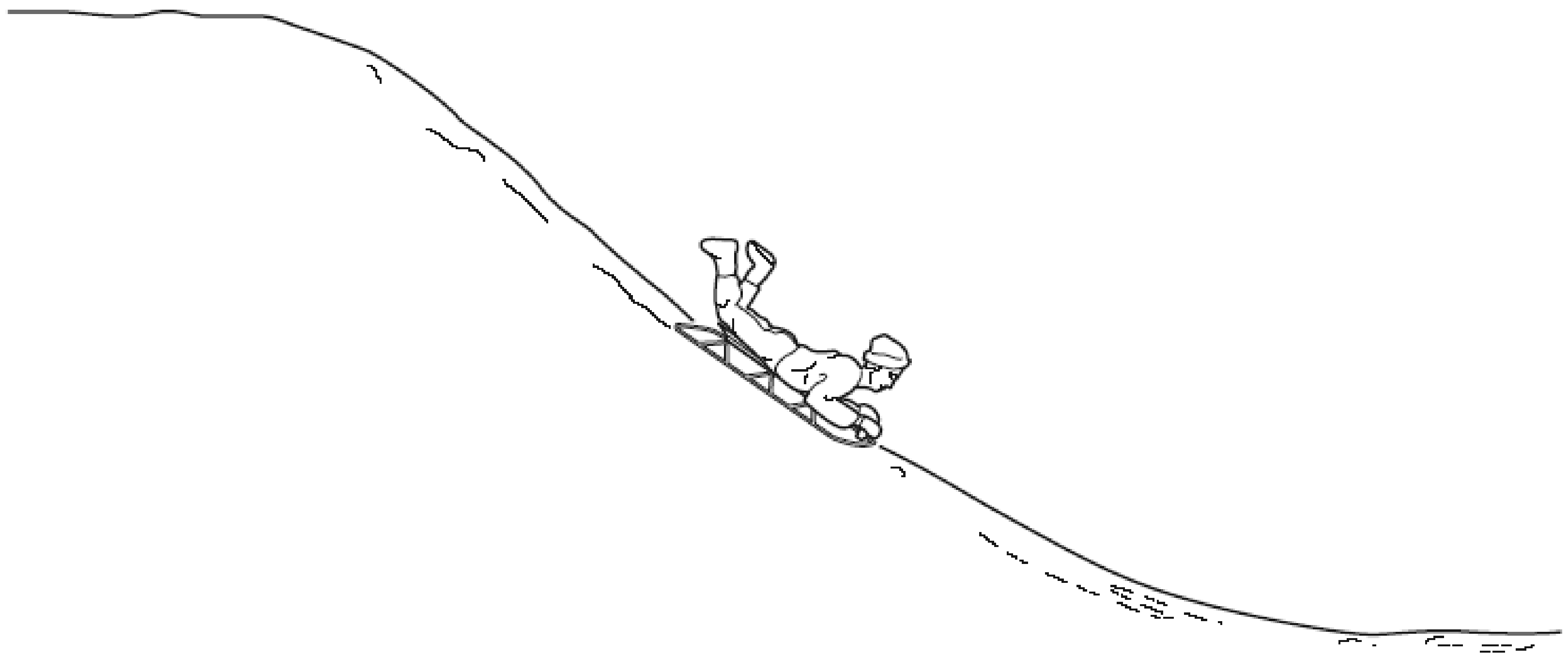
- The sun gets energy from nuclear reactions.
  - The sun is fueled by nuclear fusion reactions in its core.
- Electricity is a form of energy.
  - Electrical energy is derived from the flow of charged particles, as in a bolt of lightning or in a wire.
- Light can carry energy across empty space.
  - Light energy travels from the sun to Earth across empty space in the form of *electromagnetic waves.*

Practice p.393; Practice p.395; Math Skills p.399

Objectives

- **Identify** and describe transformations of energy.
- **Explain** the law of conservation of energy.
- **Discuss** where energy goes when it seems to disappear.
- **Analyze** the efficiency of machines.

Energy Transformations



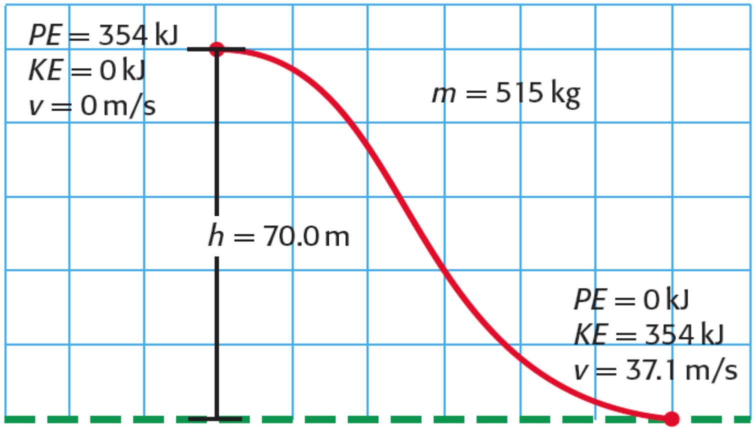
Energy Transformations, ***continued***

- Energy readily changes from one form to another.

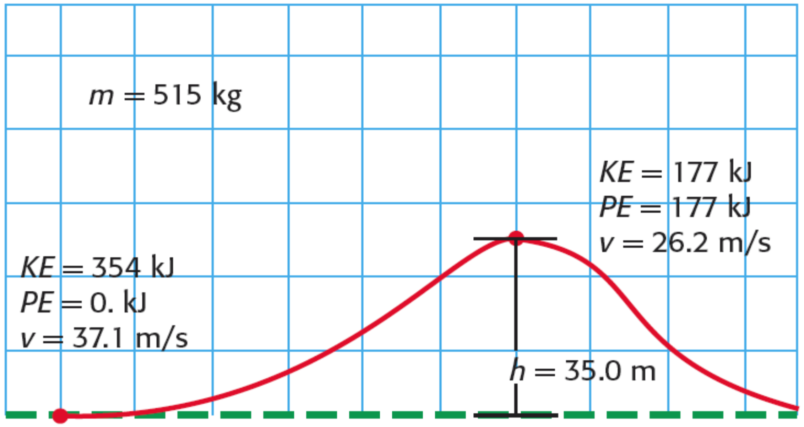
- Potential energy can become kinetic energy.
  - As a car goes down a hill on a roller coaster, potential energy changes to kinetic energy.

- Kinetic energy can become potential energy.
  - The kinetic energy a car has at the bottom of a hill can do work to carry the car up another hill.

Energy Graphs



A As a car goes down a hill on a roller coaster, potential energy changes to kinetic energy.



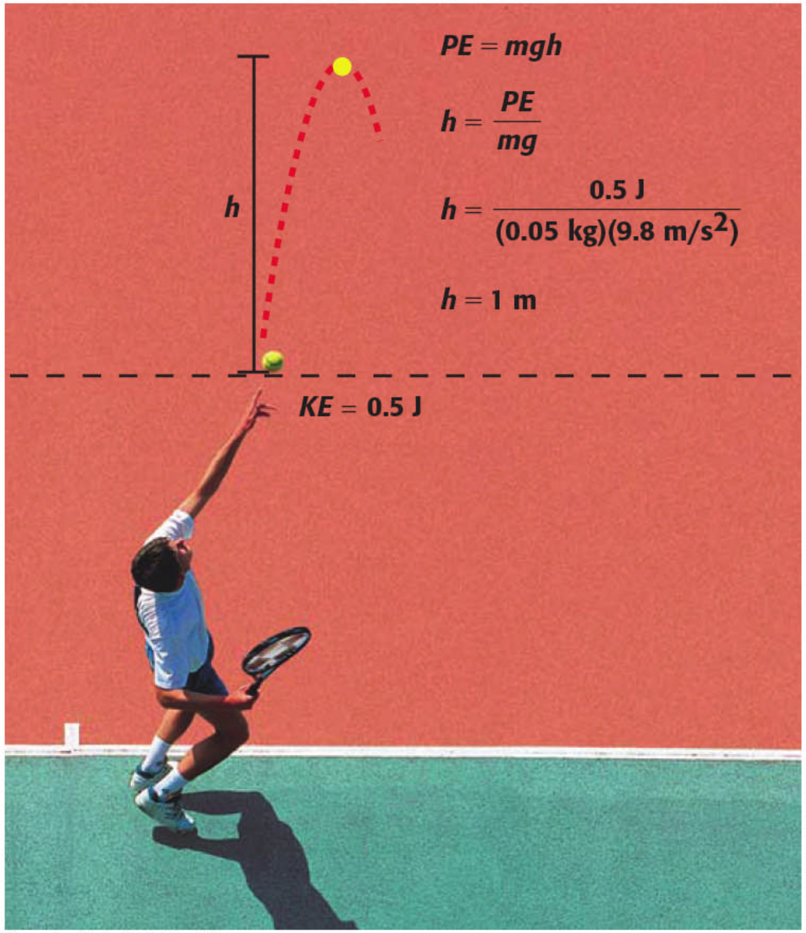
B At the top of this small hill, half the kinetic energy has become potential energy. The rest of the kinetic energy carries the car over the crest of the hill at high speed.

Energy Transformations, ***continued***

- Energy transformations explain the flight of a ball.

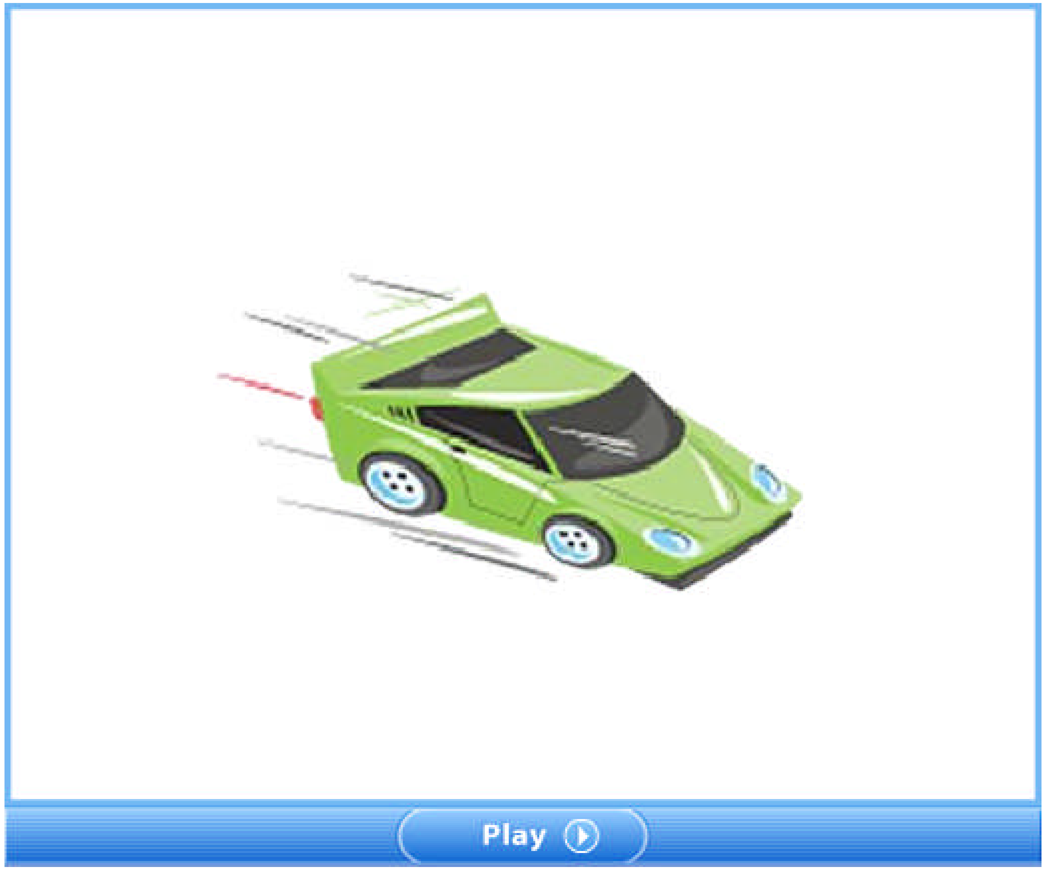
- Mechanical energy can change to other forms of energy.
  - Mechanical energy can change to non-mechanical energy as a result of friction, air resistance, or other means.

Kinetic and Potential Energy Graph



Henry Groskinsky/Peter Arnold, Inc.

Energy Conversion in Automobile Engines



The Law of Conservation of Energy

- The law of conservation of energy states that energy cannot be created or destroyed.

- Energy doesn’t appear out of nowhere.
  - Whenever the total energy in a system increases, it must be due to energy that enters the system from an external source.

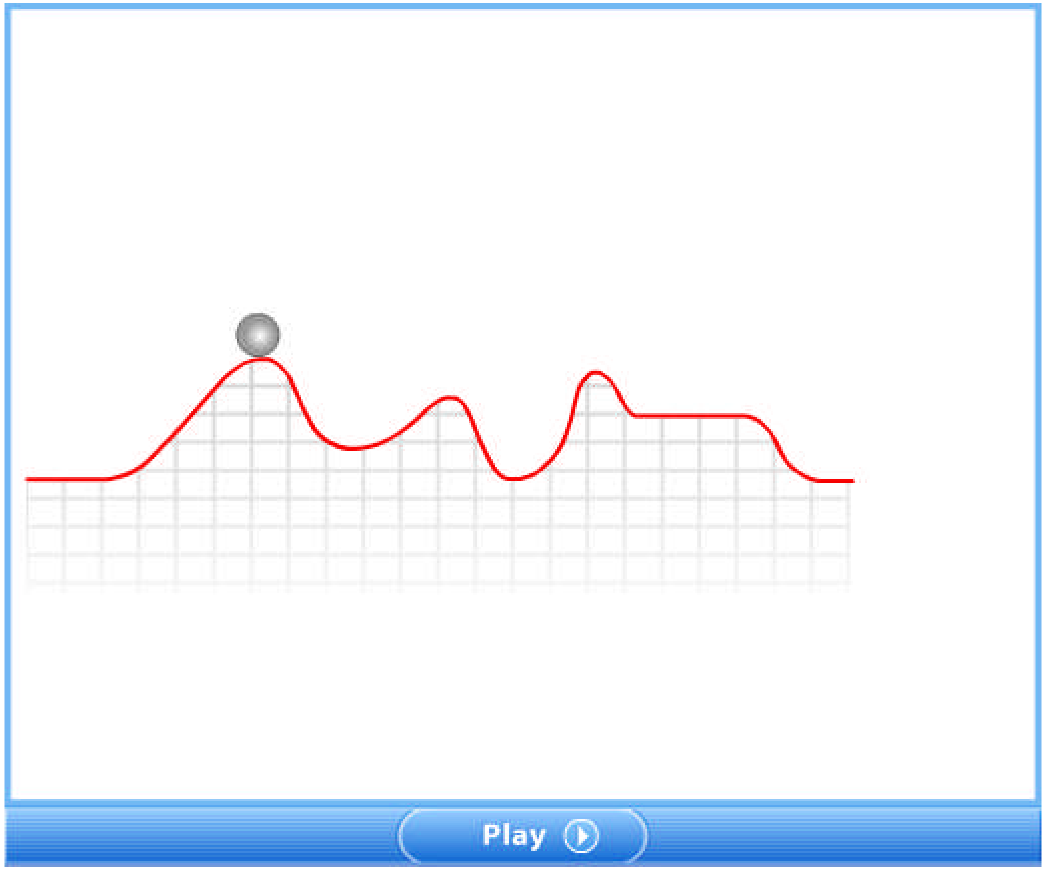
- Energy doesn’t disappear, but it can be changed to another form.

The Law of Conservation of Energy, ***continued***

- Scientist study energy systems.
  - Boundaries define a system.

- Systems may be open or closed.
  - When the flow of energy into and out of a system is small enough that it can be ignored, the system is called a *closed system.*
  - Most systems are *open systems,* which exchange energy with the space that surrounds them.

Conservation of Mechanical Energy



Efficiency of Machines

- Not all of the work done by a machine is useful work.
  - A machine cannot do more work than the work required to operate the machine.
  - Because of friction, the work output of a machine is always somewhat less than the work input.

- **Efficiency** is the ratio of useful work out to work in.
  - Efficiency is often expressed as a percentage.
  - The efficiency of a machine is a measure of how much useful work it can do.

Efficiency of Machines, ***continued***

- Efficiency Equation

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

$$\eta = \frac{W_o}{W_i}$$

- Perpetual motion machines are impossible.
  - Energy is always lost to friction or air resistance , $\eta < 1$

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 in order to raise the sail by 1 m (doing 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.

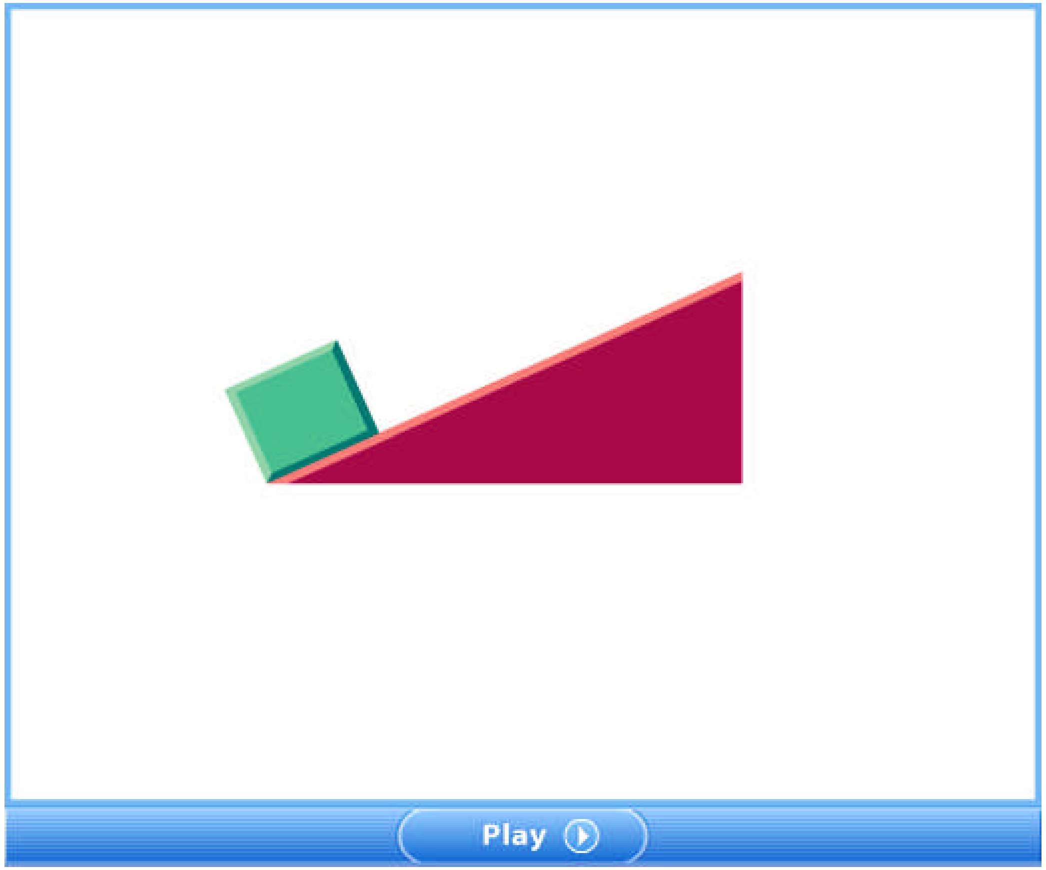
$$\eta = \frac{W_o}{W_i}$$

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

$$\eta = \frac{140\,J}{180\,J} = 0.78$$

$$\eta = 78\%$$

Mechanical Efficiency



Practice p.407; Math Skills p.408

- TERMS — TOOLS (equations)
  - length (x, l, h) (m)
  - mass (m) (kg)
  - time (t) (s)
  - velocity (v) (m/s)
  - acceleration (a) (m/s^2)
  - force (F) ($N=kg\ m/s^2$)
    - weight
  - momentum (p) (kg m/s)
  - work (W) ($J=kg\ m^2/s^2$)
  - energy (E) (J)
    - potential energy
    - kinetic energy
  - power (P) ($watt=kg\ m^2/s^3$)

$$v_A = \frac{\Delta x}{t} \qquad d = vt$$

$$a_A = \frac{\Delta v}{t} \qquad a_c = \frac{v^2}{r}$$

$$\Delta x = v_0 t + \frac{1}{2} a t^2$$

$$v = v_0 + at$$

$$v^2 = v_0^{\ 2} + 2a\Delta x \qquad \Sigma F = ma$$

$$F_g = G\frac{m_1 m_2}{d^2}$$

$$g = G\frac{m_e}{r_e^2} = 10\frac{m}{s^2}$$

$$w = mg$$

$$p = mv$$

$$W = Fd$$

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

$$MA = \frac{F_{out}}{F_{in}} = \frac{d_{in}}{d_{out}} \qquad \eta = \frac{W_o}{W_i}$$

$$PE = m\,g\,h$$

$$KE = \frac{1}{2} m v^2$$

Chapter Review p.410; 1-8, 14-15