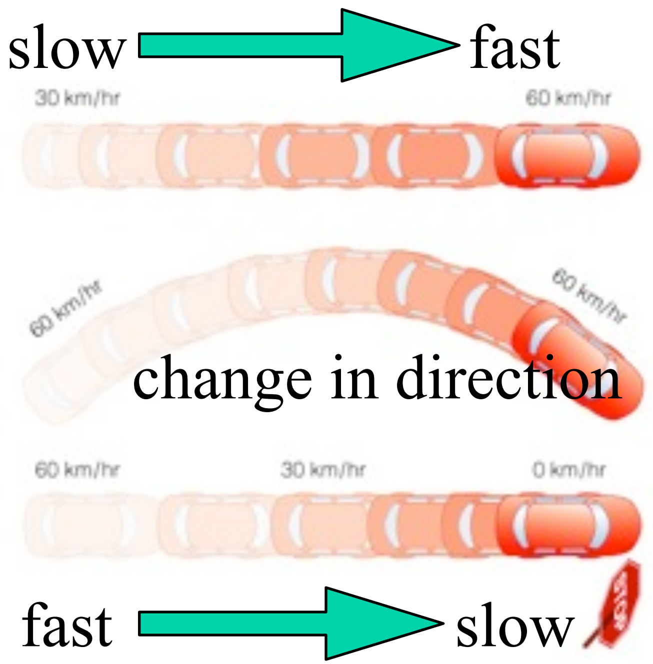
Today

- Laws of Motion
- Conservation Laws
- Gravity

Laws of Motion



Motion notions:

- **Speed**: Rate at which object moves

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \left(\text{units of } \frac{\text{m}}{\text{s}}\right)$$

example: speed of 10 m/s

- **Velocity**: Speed and <u>direction</u>

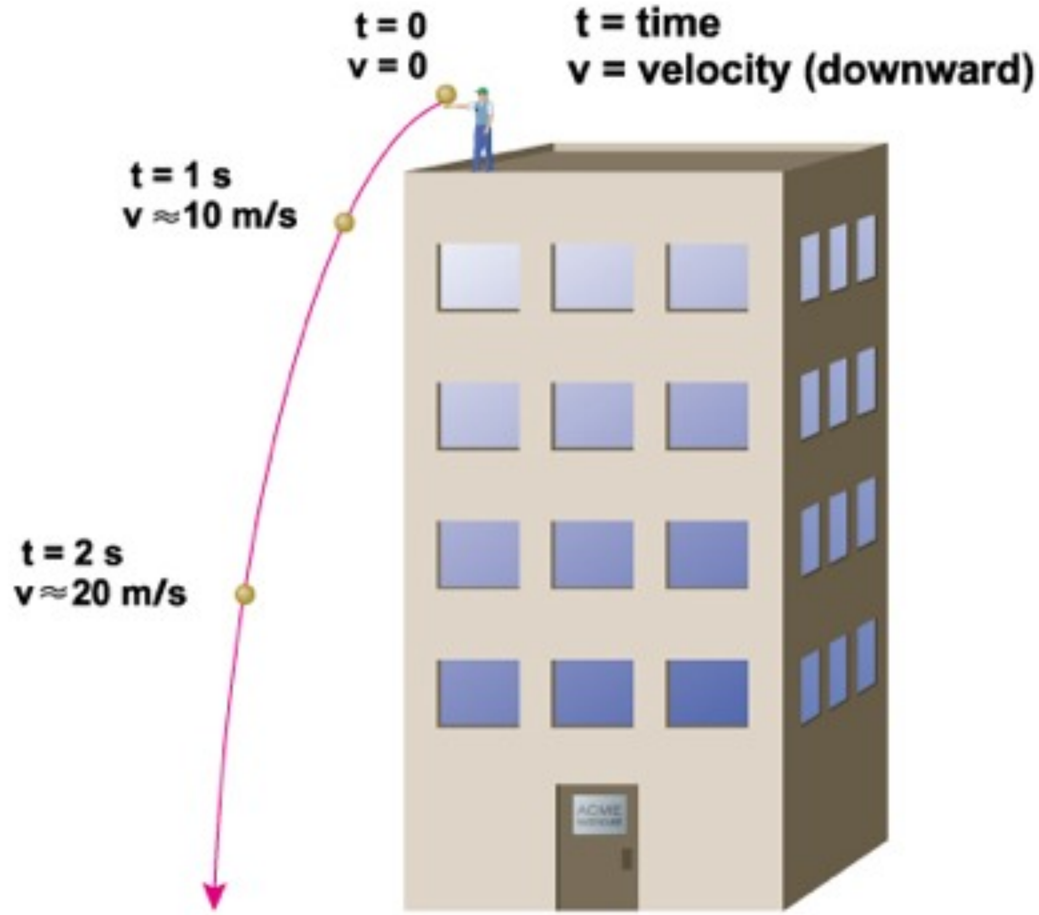
example: 10 m/s, due east

- **Acceleration**: Rate of change in velocity

$$\text{acceleration} = \frac{\text{speed}}{\text{time}} \quad \left(\text{units of } \frac{\text{m}}{\text{s}^2}\right)$$

Acceleration of Gravity

- All falling objects accelerate at the same rate (neglecting air resistance).
- On Earth, $g \approx 10\ m/s^2$: speed increases 10 m/s with each second of falling.



Acceleration of Gravity (*g*)

- Galileo showed that *g* is the *same* for all falling objects, regardless of their mass.

Apollo 15 demonstration

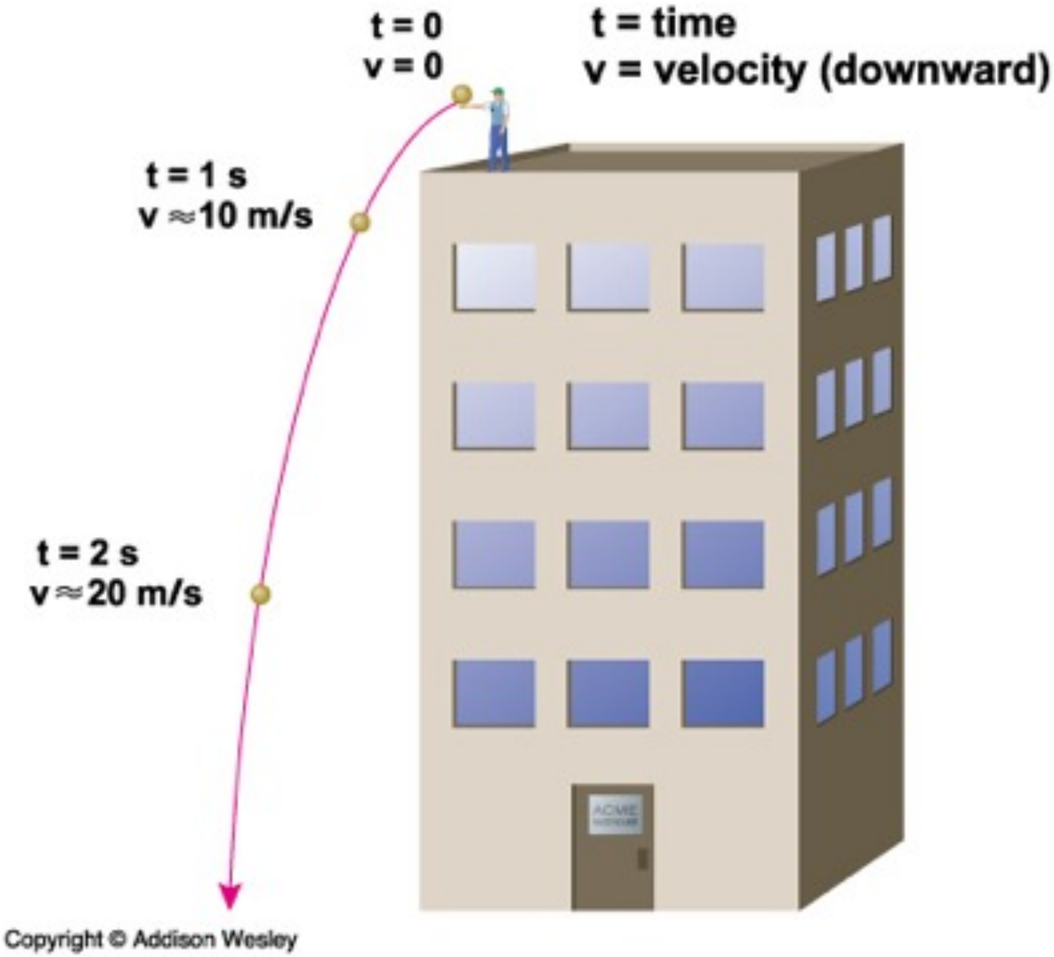
04_featherdrop_sound

C4-33, C4-42

Vertical & Horizontal motion independent

- All objects accelerate at the same rate, regardless of whether
  - they fall straight down, or
  - are moving horizontally

C2-21
C2-22

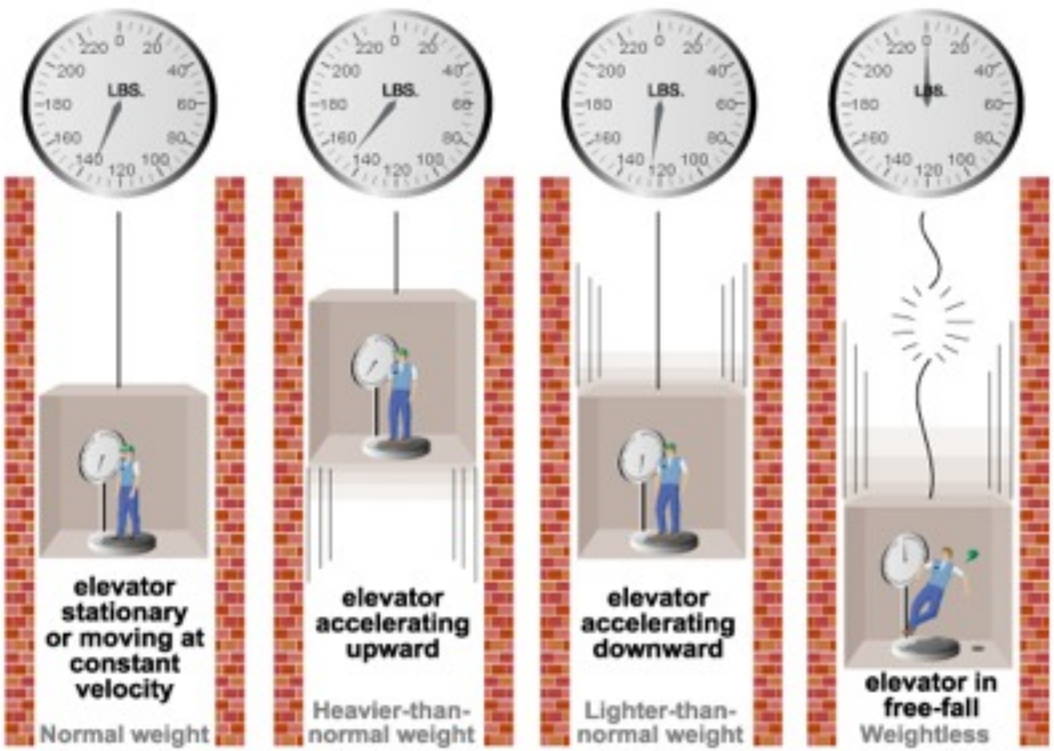


Momentum and Force

- Momentum = mass × velocity.
- A **net force** changes momentum, which generally means an acceleration (change in velocity).
- The rotational momentum of a spinning or orbiting object is known as **angular momentum.**

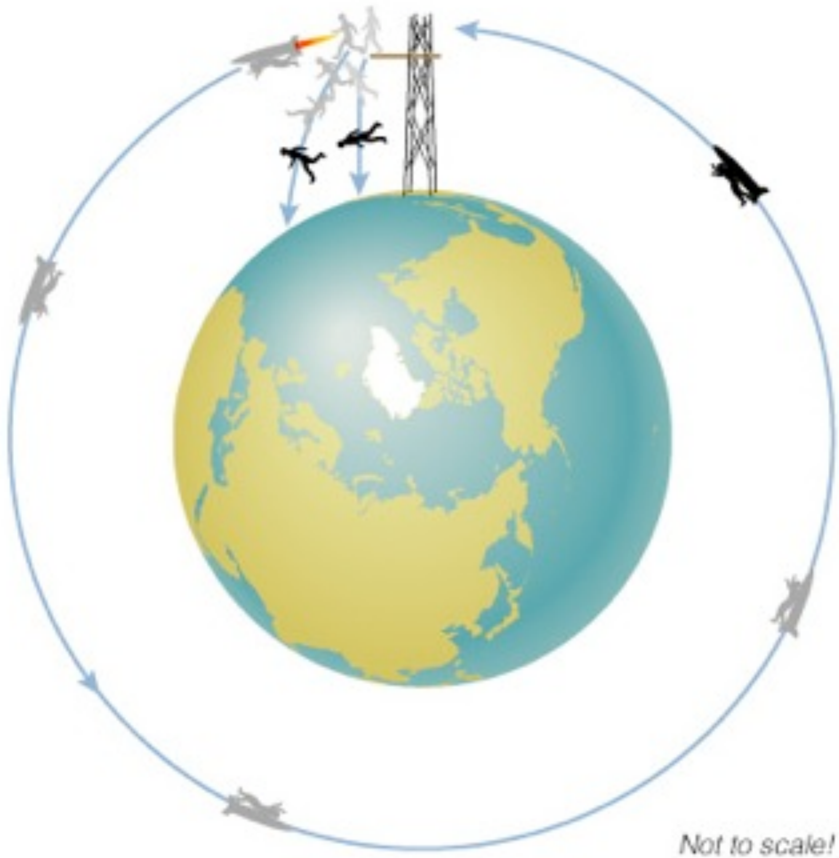
How is mass different from weight?

- **Mass**—the amount of matter in an object
- **Weight**—the *force* that acts upon an object



You are weightless in free-fall!

Why are astronauts weightless in space?



- There *is* gravity in space.
- Weightlessness is due to a constant state of free-fall.

C4-52

What have we learned?

- How do we describe motion?
  - Speed = distance / time
  - Speed and direction => **velocity**
  - Change in velocity => **acceleration**
  - **Momentum** = mass × velocity
  - **Force** causes change in momentum, producing acceleration

What have we learned?

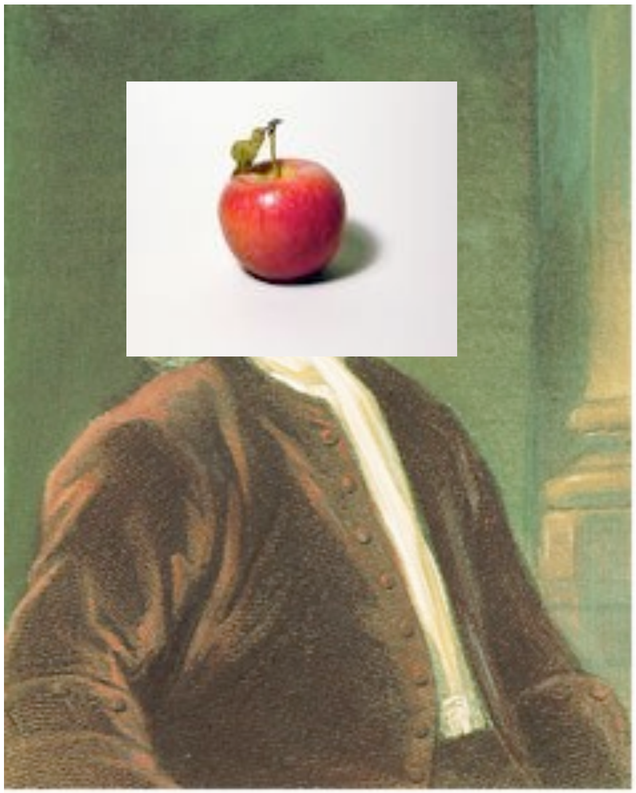
- How is mass different from weight?
  - Mass = quantity of matter
  - Weight = force acting on mass
  - Objects are weightless in free-fall

4.2 Newton's Laws of Motion

Our goals for learning:

- How did Newton change our view of the universe?
- What are Newton's three laws of motion?

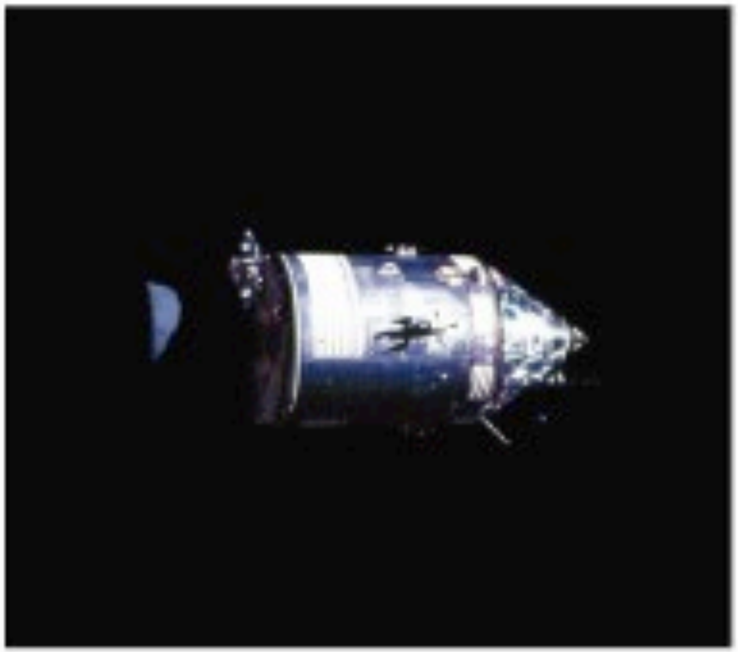
How did Newton change our view of the universe?



Sir Isaac Newton (1642–1727)

- He realized the same physical laws that operate on Earth also operate in the heavens:
  - ⇒ one *universe*
- He discovered laws of motion and gravity.
- Much more: Experiments with light; first reflecting telescope, calculus…

Newton’s three laws of motion



Newton’s first law of motion: An object moves at constant velocity unless a net force acts to change its speed or direction.

In the absence of an applied force, an object at rest remains at rest. An object in motion remains in motion with a constant velocity.

C3-04, C3-02, C3-12

Newton's second law of motion

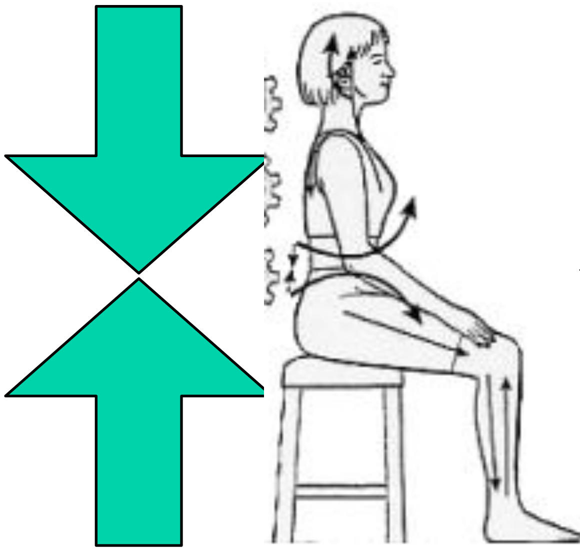
Force = mass × acceleration

$$F = ma$$

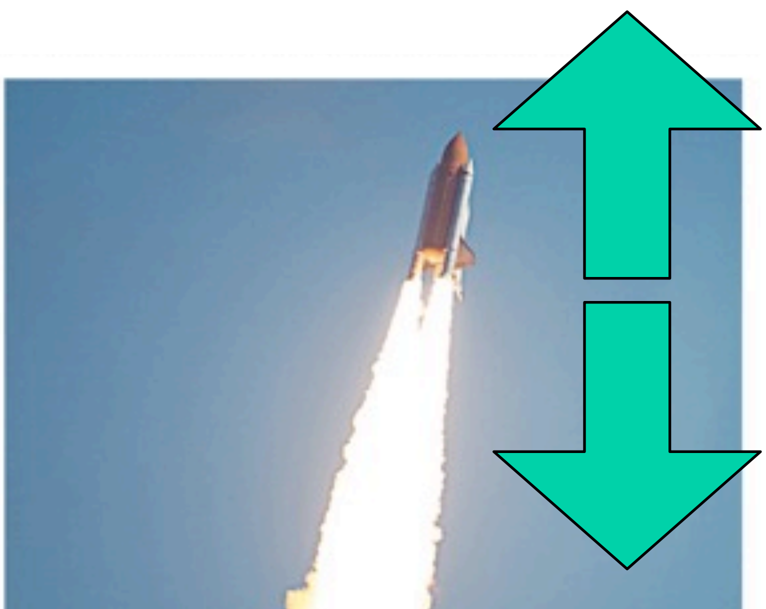
A force must be applied to change an object's state of motion (its momentum).

Newton's third law of motion

For every action, there is an *equal and opposite* reaction.



When seated, your weight is balanced by the reaction force of the chair.



As the rocket fires, the shuttle doesn't just sit there. It accelerates in reaction to the applied force.

C5-14 Rocket Trike

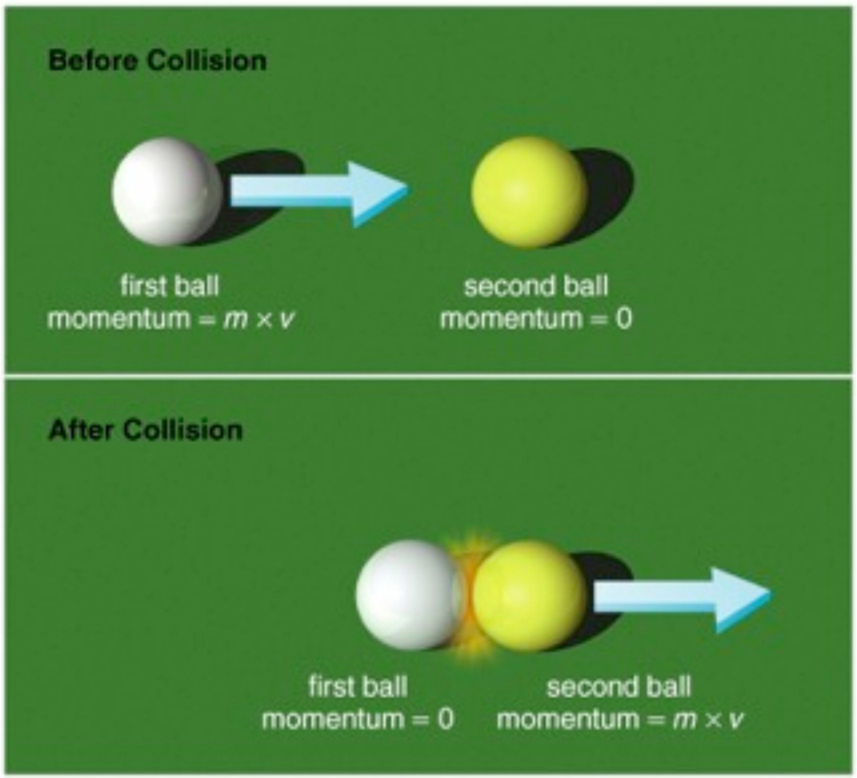
- Newton's Three Laws of Motion
  1. An object moves at constant velocity if no net force is acting.
  2. Force = mass × acceleration.
  3. For every force, there is an equal and opposite reaction force.

Conserved Quantities

You can not destroy conserved quantities, only transfer them from one object to another.

- Mass
- Energy
- Momentum
- Angular momentum

Conservation of Momentum



- The total momentum of interacting objects cannot change unless an external force is acting on them.
- Interacting objects exchange momentum through equal and opposite forces.

Conservation of Angular Momentum

angular momentum = mass × velocity × radius

$$\mathbf{L = mvr}$$

- The angular momentum of an object cannot change unless an external twisting force (torque) is acting on it.

- Earth experiences no twisting force as it orbits the Sun, so its rotation and orbit will continue indefinitely.

Angular momentum conservation also explains why objects rotate faster as they shrink in radius:

e.g, kinetic energy:

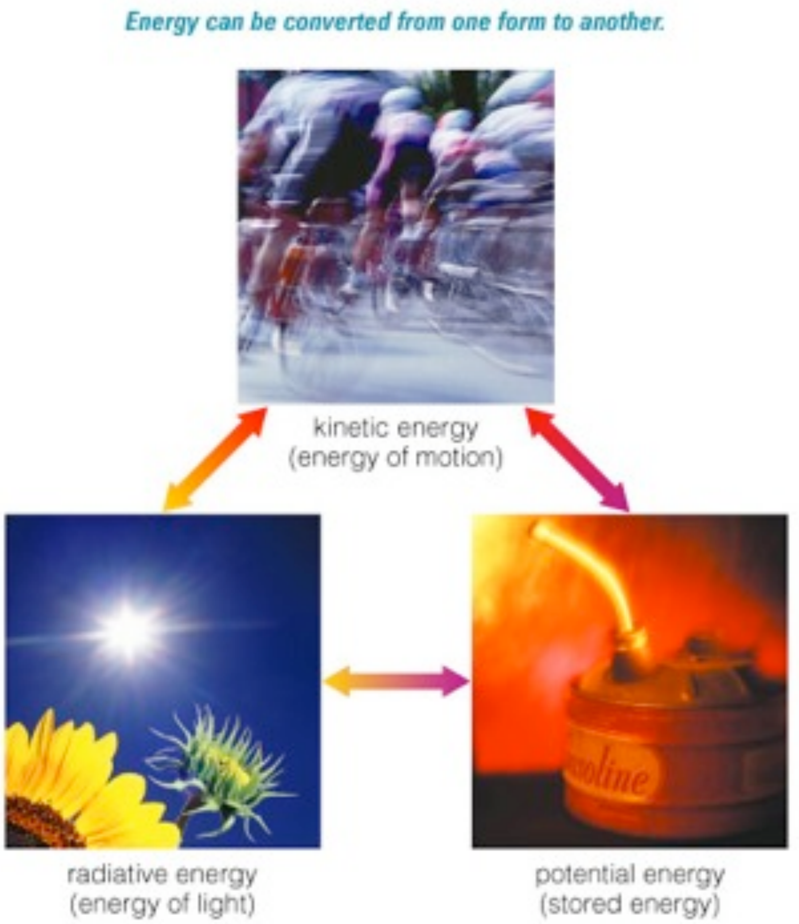
- Energy makes matter move.

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

- Energy is conserved, but it can…
  - —transfer from one object to another.
  - —change in form.

Basic Types of Energy

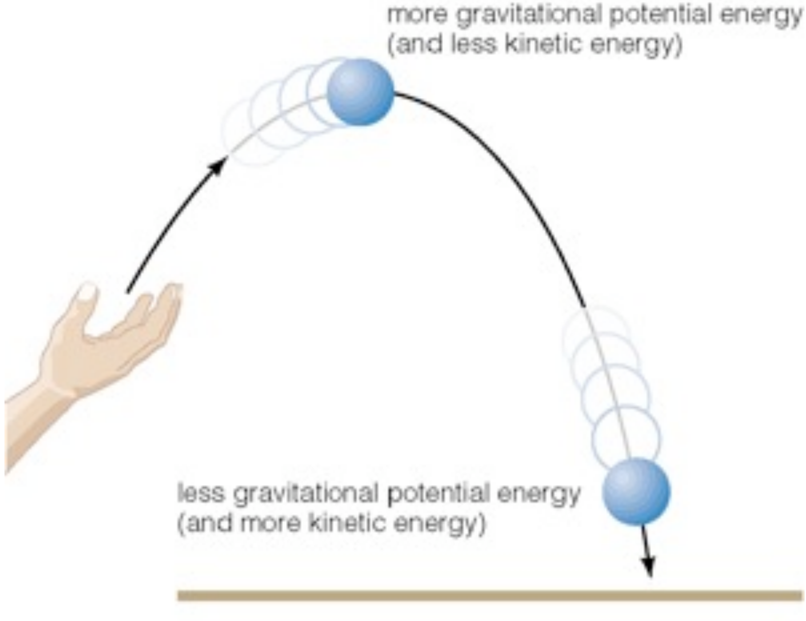
- Kinetic (motion)
- Radiative (light)
- Stored or potential



Energy can change type but cannot be destroyed.

Gravitational Potential Energy

- On Earth, it depends on…
  - — an object's mass (m).
  - — the strength of gravity (g).
  - — the distance an object could potentially fall.



$$E_P = mgh$$

C8-03

04_02OrbitTrajCannonball