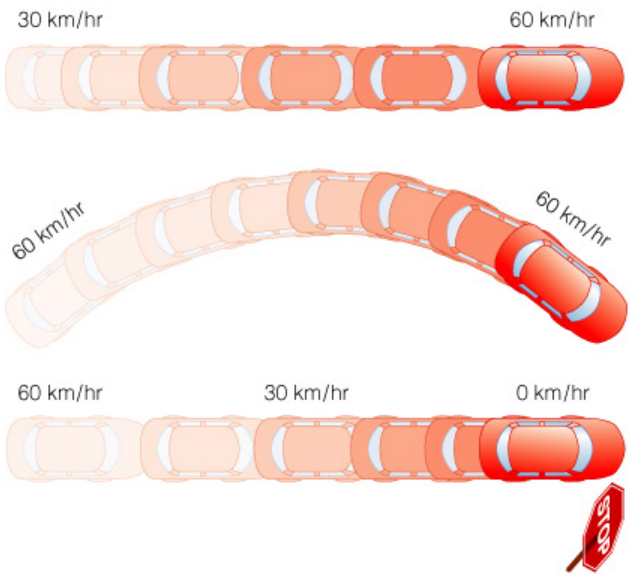
Lectures 6&7 - How the Universe Works

Understanding ***Motion****,* ***Energy****, and* ***Gravity***

How do we describe motion?



Precise definitions to describe motion:

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

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

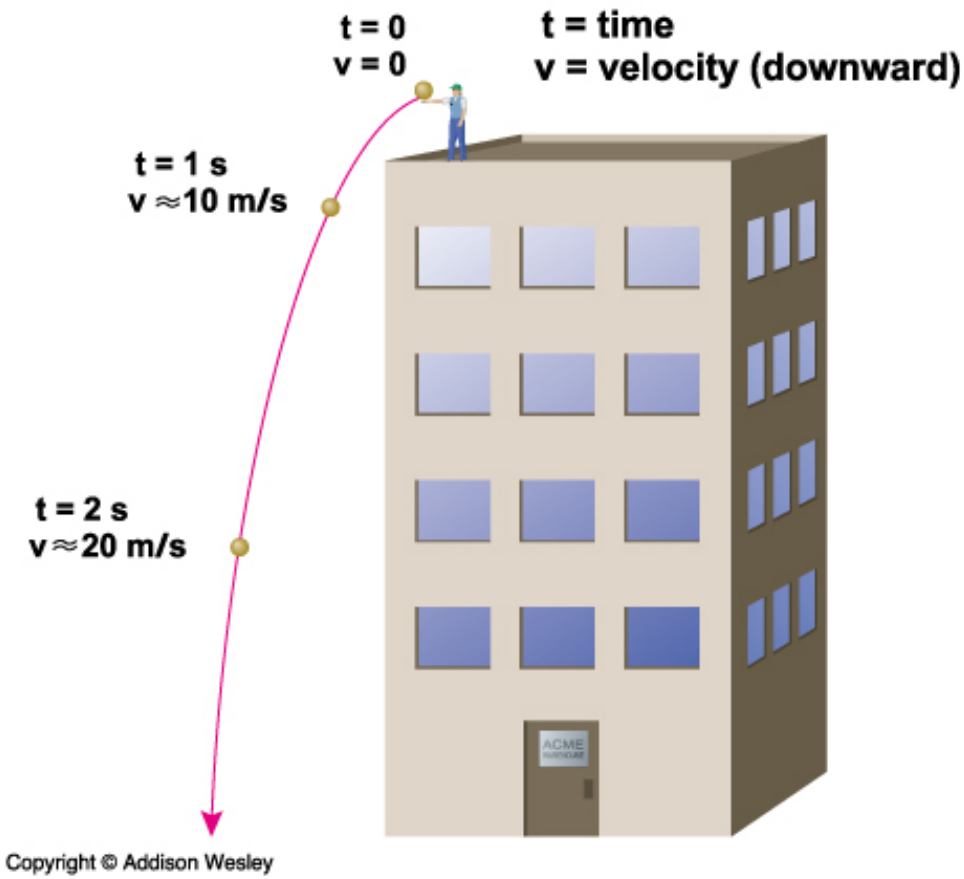
example: speed of 10 m/s

- **Velocity**: Speed and direction
  example: 10 m/s, due east

- **Acceleration**: Any change in velocity (speed **or** direction); units of speed/time (m/s^2)

Acceleration of Gravity

- On Earth, force of gravity *g* causes *acceleration* ≈ **10 m/s²**; speed increases 10 m/s with each second of falling.
- Acceleration is the *same* for all falling objects, regardless of their mass (neglecting air resistance)



The Acceleration of Gravity

- Galileo showed that the acceleration of gravity is the *same* for all falling objects, regardless of their mass.
- Proven in space!

Apollo 15 demonstration

Momentum and Force

Linear motion:

- **Momentum** = mass × velocity.
- **Force** = mass × acceleration
- A **force** changes momentum, which means an acceleration (change in velocity).

Circular motion

- The *rotational* momentum of a spinning or orbiting object is known as **angular momentum.**

Thought Question

Is there a net force for each of the following?

A. A car coming to a stop.
B. A bus speeding up.
C. An object moving at constant speed (no friction).
D. A moon orbiting Jupiter.

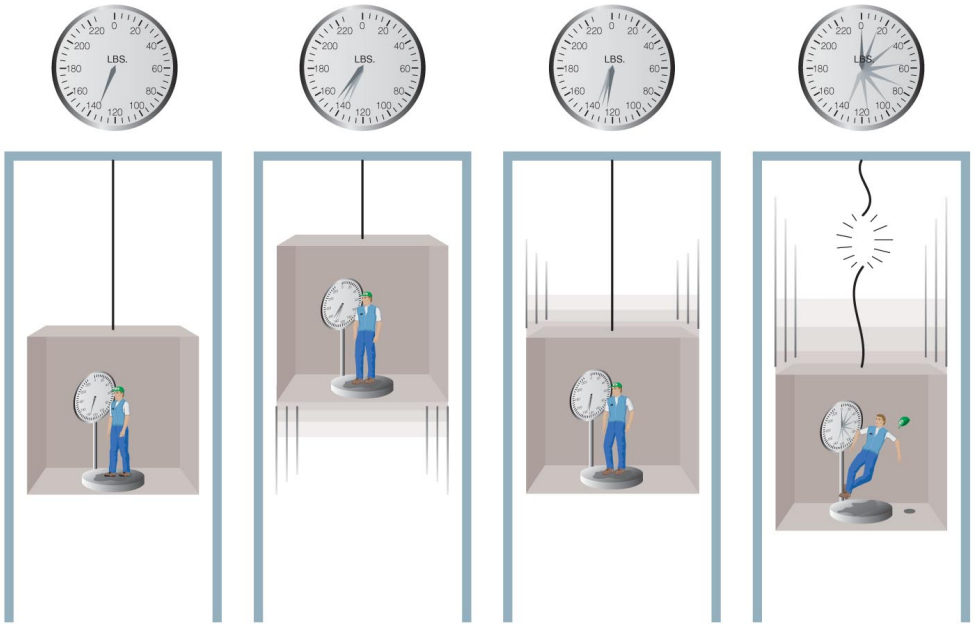
Thought Question

Is there a net force for each of the following?

A. A car coming to a stop. **Yes**
B. A bus speeding up. **Yes**
C. An object moving at constant speed. **No**
D. A moon orbiting Jupiter. **Yes**

How is mass different from weight?

- **Mass**—the *amount* of matter in an object
- **Weight**—the (gravitational) *force* that acts on a mass



You are weightless in free-fall!

Interactive Figure

Think/Pair/Share

On the Moon,

A. your weight is the same, your mass is less.
B. your weight is less, your mass is the same.
C. your weight is more, your mass is the same.
D. your weight is more, your mass is less.

Think/Pair/Share

On the Moon,

A. your weight is the same, your mass is less.
B. your weight is less, your mass is the same.
C. your weight is more, your mass is the same.
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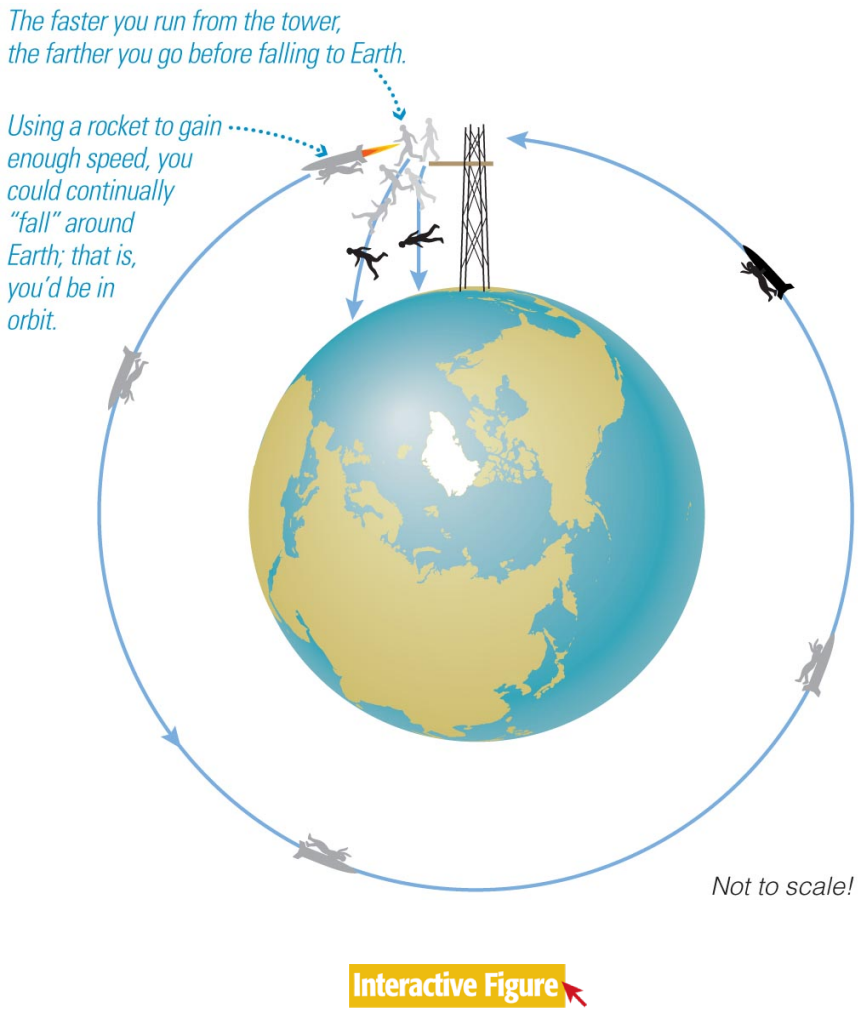
Why are astronauts weightless in space?

- Is there no gravity in space?
- Weightlessness is due to a state of free-fall.



What have we learned?

Begin 3 minute review

What have we learned?

- How do we describe motion?
  - Speed = distance / time
  - Speed and direction => **velocity**
  - Change in velocity => **acceleration**
  - **Momentum** = mass x velocity
  - **Force** causes change in momentum, producing acceleration.
- How is mass different from weight?
  - Mass = *quantity* of matter
  - Weight = *force* acting on mass
  - Objects are weightless in free-fall

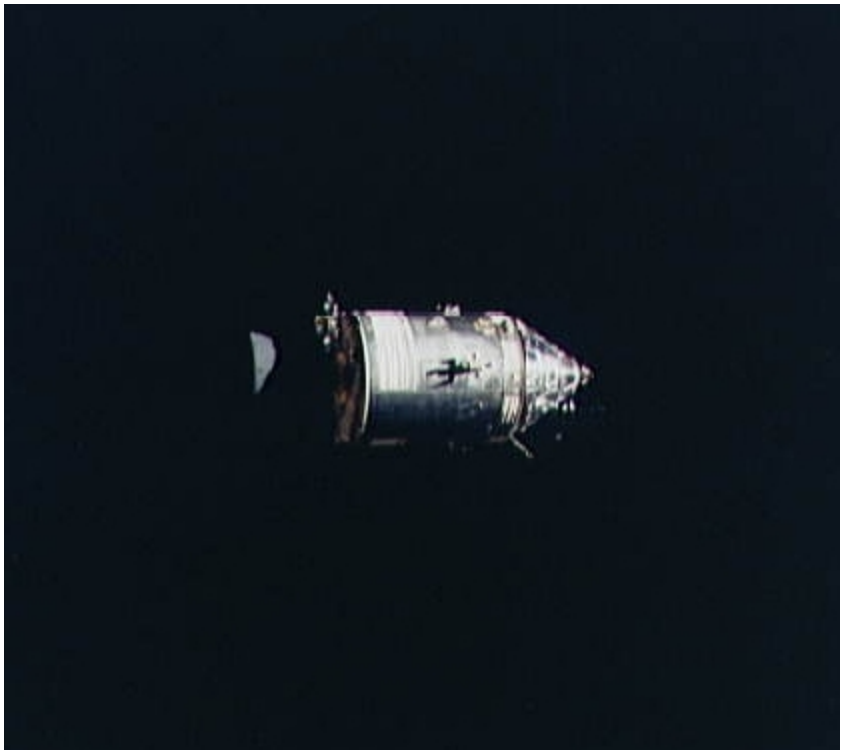
How did Newton change our view of the universe?

Sir Isaac Newton
(1642–1727)

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

What are 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.

A spacecraft keeps moving in space with no fuel – why?

What are Newton's three laws of motion?

Newton's second law of motion

Force = mass × acceleration

Example:

Force = 1 kg x 10 m/s^2
= 10 kg m/s^2
= 10 newtons

A baseball's mass is accelerated by the force from the pitcher's arm.

What are Newton's three laws of motion?

Newton's third law of motion

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

The Space Shuttle is propelled upward by a force equal and opposite to the force with which the rocket exhaust is expelled out of the engines.

Think/Pair/Share

Is the force the Earth exerts on you larger, smaller, or the same as the force you exert on it?

A. Earth exerts a larger force on you.
B. You exert a larger force on Earth.
C. Earth and I exert equal and opposite forces on each other.
D. Neither exerts a force on the other

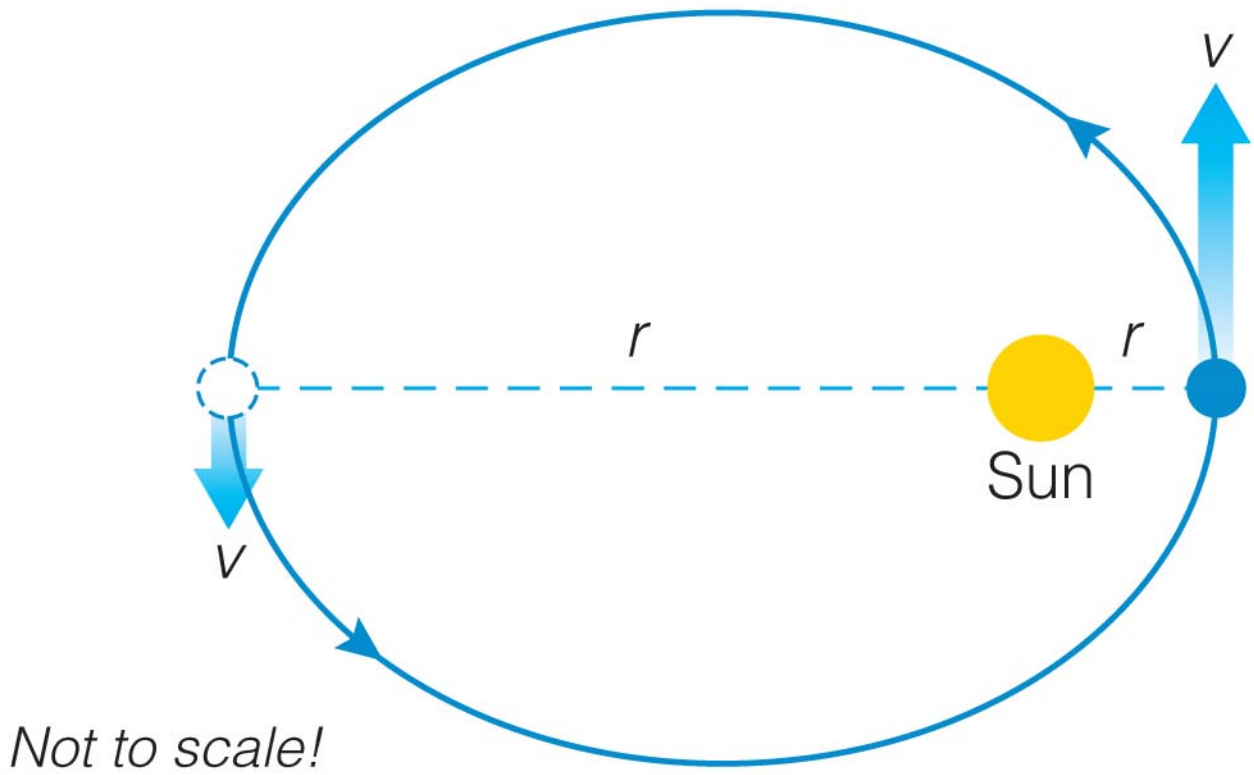
Think/Pair/Share

Is the force the Earth exerts on you larger, smaller, or the same as the force you exert on it?

A. Earth exerts a larger force on you.
B. You exert a larger force on Earth.
C. **Earth and I exert equal and opposite forces on each other.**
D. Neither exerts a force on the other

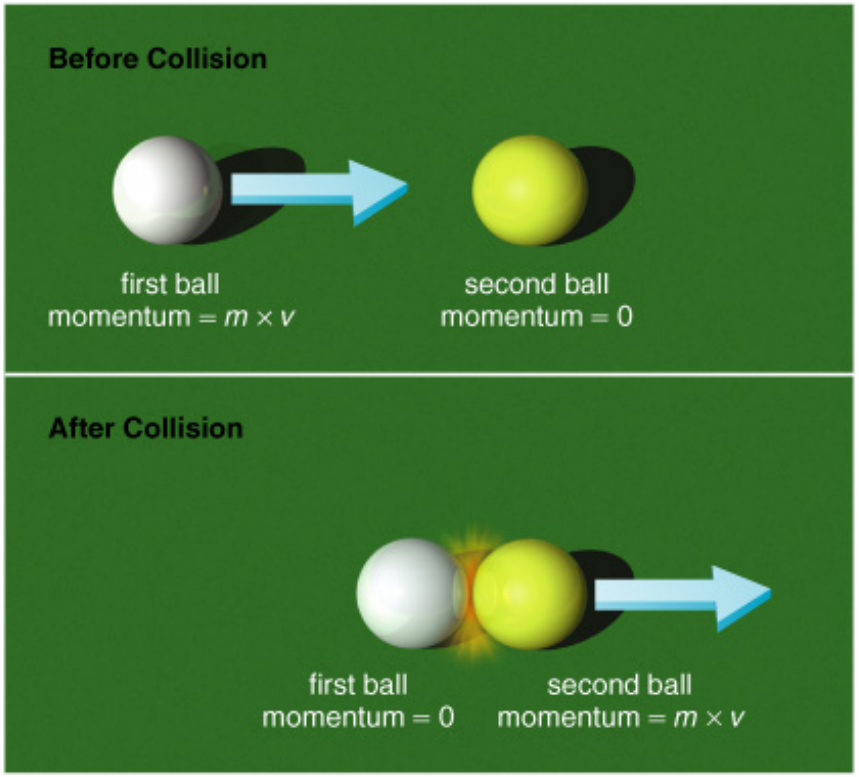
Force = mass × acceleration

What keeps a planet rotating and orbiting the Sun?



Conservation of Momentum

Objects continue at constant velocity because of **conservation of momentum**.



Momentum = mass × velocity.

- The *total* momentum of interacting objects does change unless a force acts on them.
- Interacting objects *exchange* momentum through equal and opposite forces.

Conservation of *Angular* Momentum

angular momentum = mass × velocity × *radius*

- The angular (rotational) momentum of an object does not change unless a force acts on it.
- Earth experiences no force as it orbits the Sun, so its rotation and orbit will continue indefinitely.

Angular momentum conservation explains why *objects rotate faster as they shrink in radius*.

What have we learned?

Begin 3 minute review

What have we learned?

- How did Newton change our view of the universe?
  - He discovered laws of motion and gravitation.
  - He realized these same laws of physics were identical in the universe and on Earth.
- What are Newton's three laws of motion?
  - 1. 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.
- Why do objects move at constant velocity if no force acts on them?
  - Conservation of momentum
- What keeps a planet rotating and orbiting the Sun?
  - Conservation of angular momentum

Where do objects get their energy?

Conservation of energy:

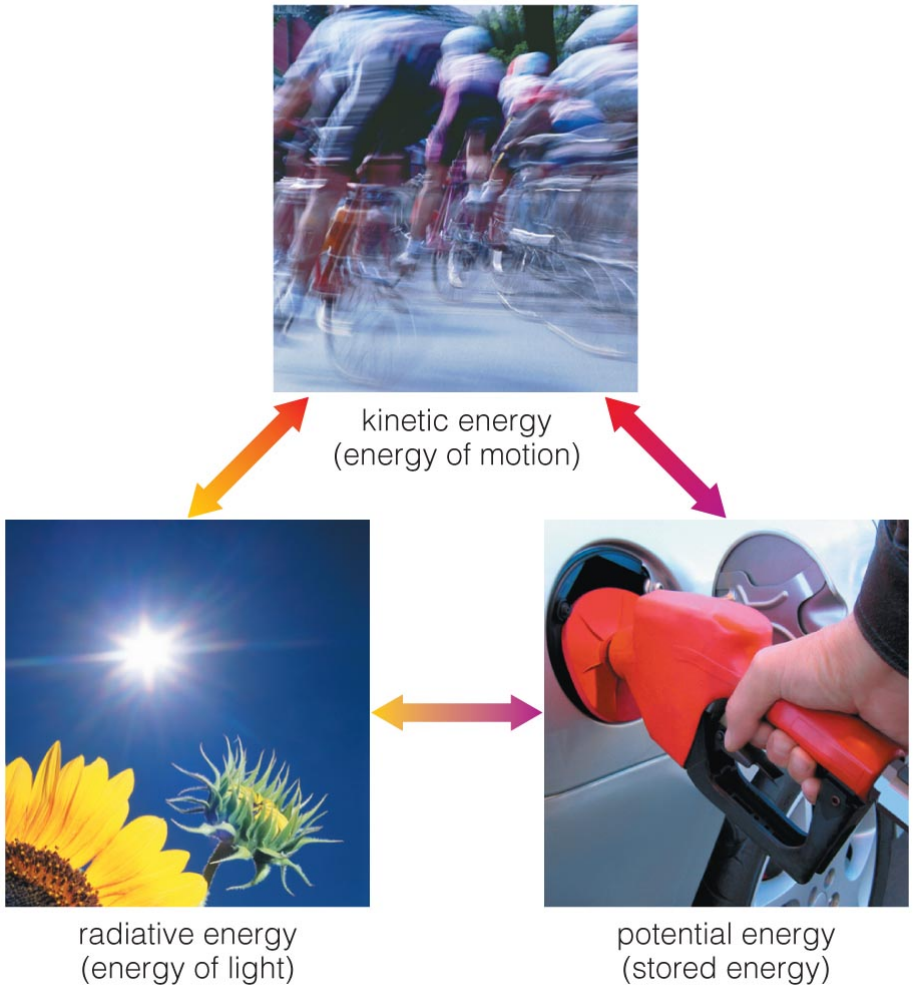
- Energy is conserved (cannot appear/disappear)
  - — Can transfer from one object to another.
  - — Can change in form from three types:

Types of Energy

- Kinetic (motion)
- Radiative (light)
- Potential (stored)

Energy can change type, but cannot be created or destroyed.

Energy can be converted from one form to another.



Kinetic Energy

- Kinetic (motion) – energy of *motion*
  - Depends on mass
  - Depends on velocity^2 (speed)

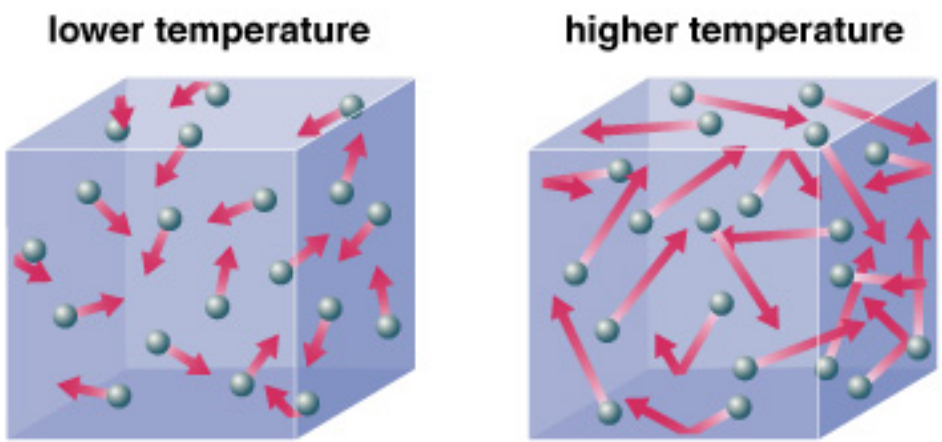
Kinetic energy = ½ mv^2

Kinetic Energy

Thermal Energy:
the total *collective* kinetic energy of all particles in an object

Thermal energy is related to temperature but it is NOT the same.

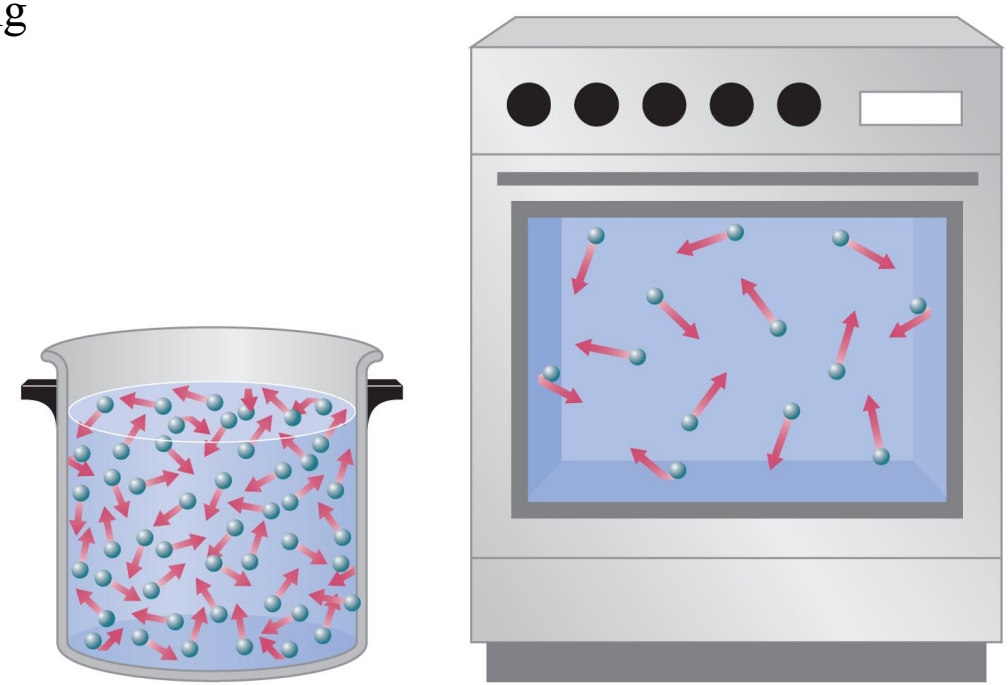
Thermal energy = *total* kinetic energy of all particles
Temperature - *average* kinetic energy of all particles in an object



Kinetic Energy

Thermal energy - depends on both *temperature* AND *density.*

Example: Higher density of boiling water will injure you faster than the higher temperature of an oven

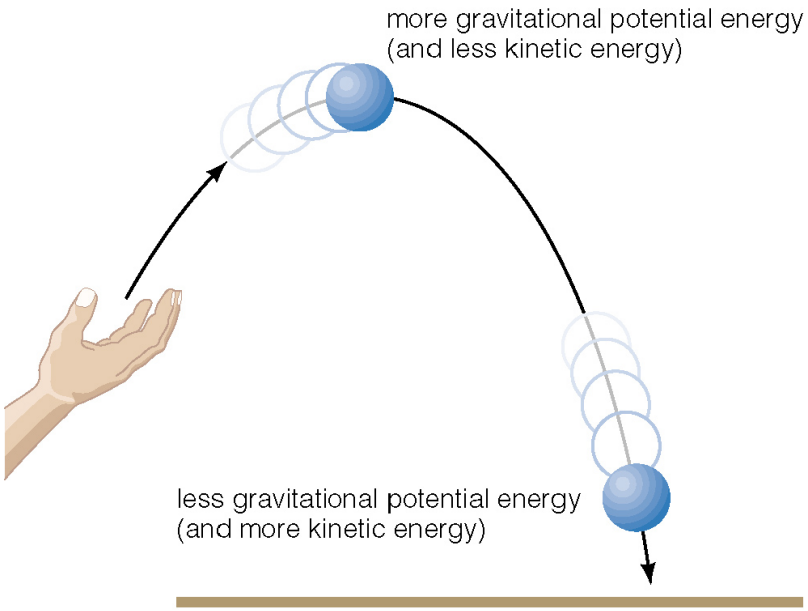


Radiative Energy

- Sources of light (Sun) emit radiative energy – *particles of light*
- This energy can be captured and changed into electricity
- The energy of light particles can heat other objects by changing their energy into thermal energy

Gravitational Potential Energy

- It depends on…
  - — an object's **mass** (m).
  - — the strength of **gravity** (g).
  - — the **distance** an object could potentially fall (height).

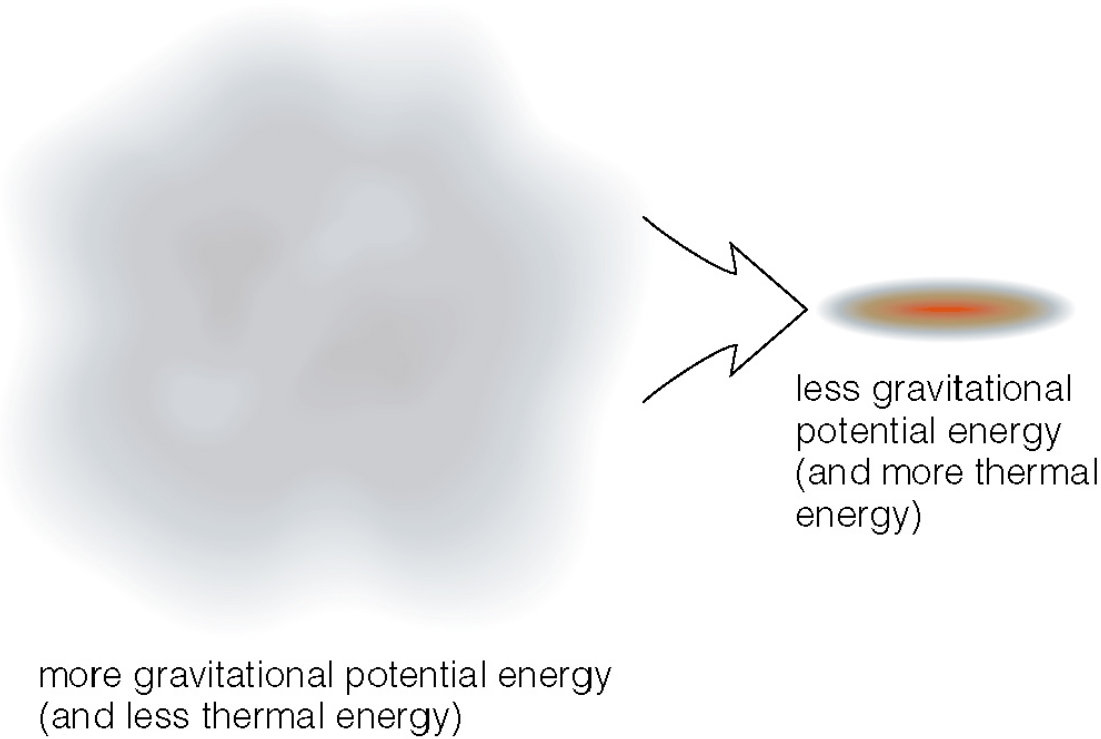


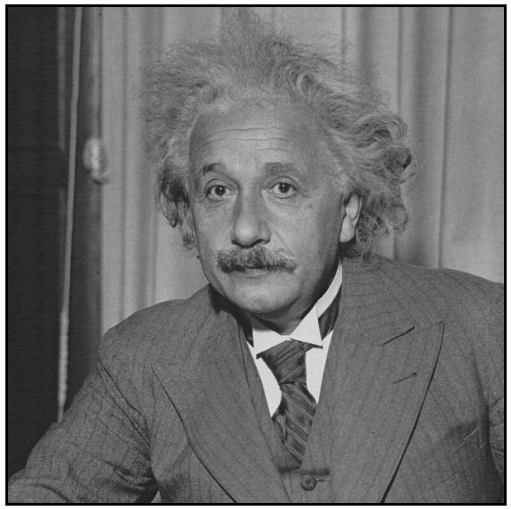
Interactive Figure

As gravitational potential energy increases, kinetic energy decreases and vice versa (conservation of energy). **Potential and kinetic energy always add to a fixed total.**

Gravitational Potential Energy

- Particles in a gas cloud have gravitational *potential* energy
- A contracting cloud converts gravitational potential energy to thermal energy. (S*tellar formation)*.





Mass = Energy

Mass itself is a form of potential energy.

$$E = mc^2$$

- A small amount of mass contains and can release a great deal of energy.
- Concentrated energy can spontaneously turn into particles (in particle accelerators).

Just a few pounds of matter can release enormous energy!

What have we learned?

Begin 3 minute review

What have we learned?

- What keeps a planet rotating and orbiting the Sun?
  — Conservation of *angular* momentum
- Where do objects get their energy?
  - Conservation of energy: energy cannot be created or destroyed but only transformed from one type to another.
  - Energy comes in three basic types:
    - Kinetic – energy of motion
    - Radiative – energy of light
    - Potential – stored energy
  - Mass = energy ($E = mc^2$)