Chapter 4: Making Sense of the Universe: Understanding Motion, Energy, and Gravity

Making Sense of the Universe: Understanding Motion, Energy, and Gravity

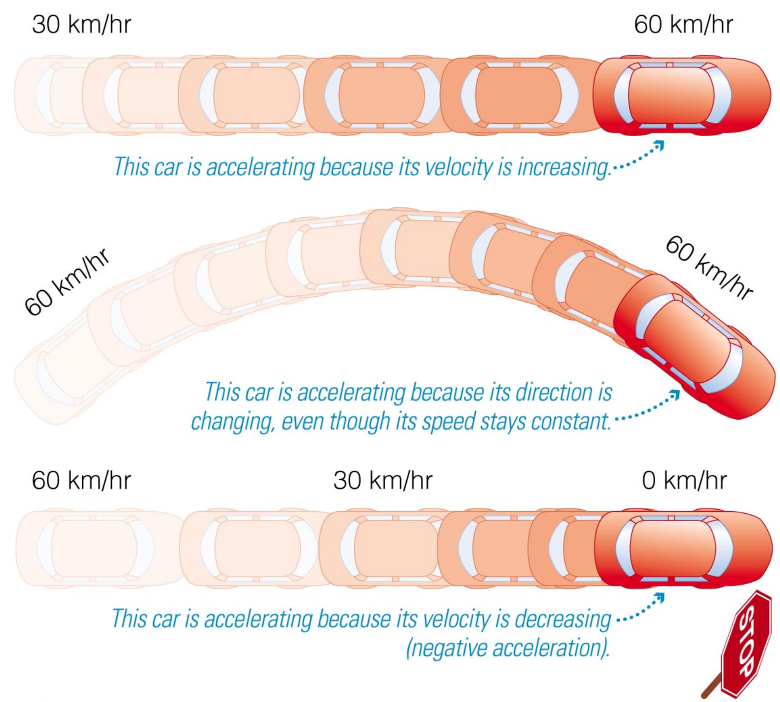
4.1 Describing Motion: Examples from Daily Life

- Our goals for learning:
  - **How do we describe motion?**
  - **How is mass different from weight?**

How do we describe motion?

- Precise definitions to describe motion:
- **Speed:** Rate at which object moves

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



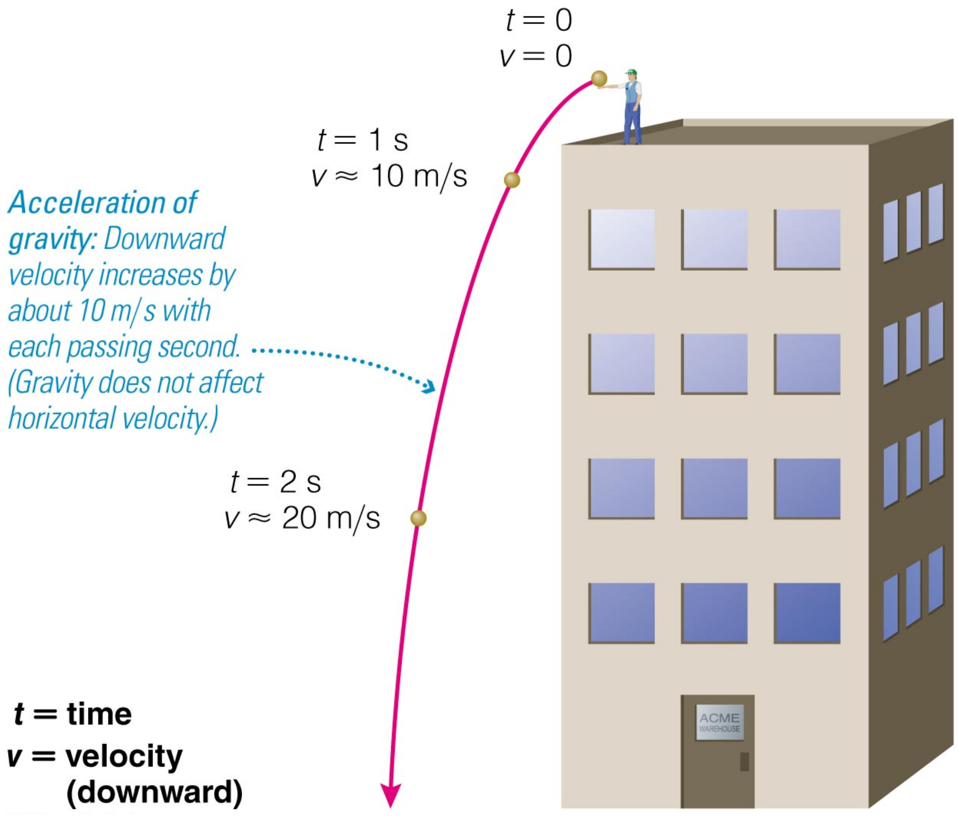
Example: 10 m/s

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

- **Acceleration:** Rate of change in velocity
  units of speed/time (m/s^2)

The Acceleration of Gravity

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, $g \approx 10$ m/s^2: speed increases 10 m/s with each second of falling.



The Acceleration of Gravity (g)

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

Momentum and Force

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

Thought Question

For each of the following is there a net force on the object described? Y/N

1. A car coming to a stop
2. A bus speeding up
3. An elevator moving up at constant speed
4. A bicycle going around a curve
5. A moon orbiting Jupiter

Thought Question

For each of the following is there a net force on the object described? Y/N

1. A car coming to a stop: Y
2. A bus speeding up: Y
3. An elevator moving at constant speed: N
4. A bicycle going around a curve: Y
5. A moon orbiting Jupiter: Y

How is mass different from weight?

- **Mass** – a measure of the amount of matter in an object
- **Weight** – the *force* that a scale exerts upon an object

A free fall does make
you feel weightless!

Mass and weight

A mass (1 kilogram)

The weight of this 1 kg (the force exerted on it by Earth)

An example of <u>apparent</u> weightlessness

Thought Question

On the Moon:

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

Thought Question

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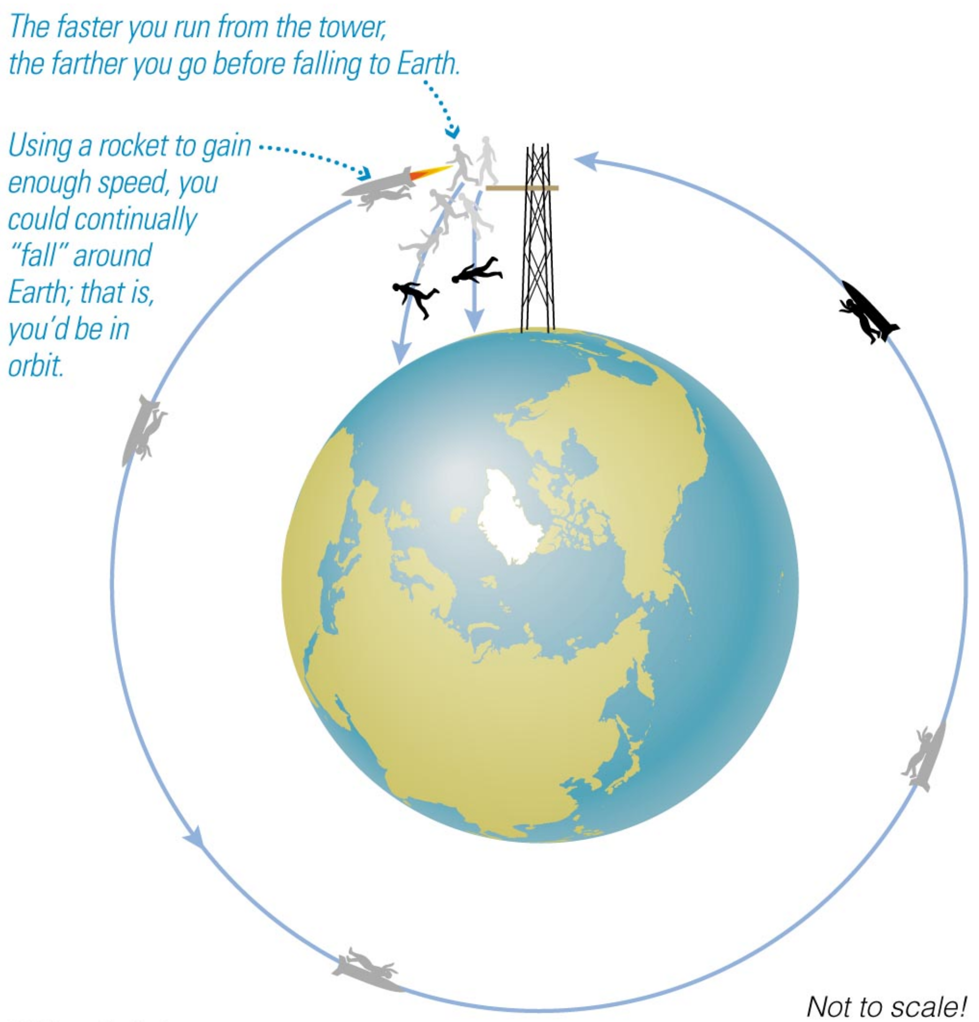
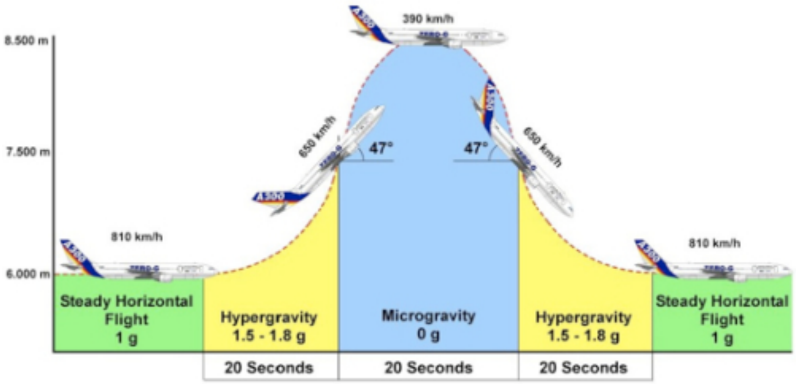
Why are astronauts weightless in space?

- There *is* gravity in space.
- Weightlessness is felt due to a constant state of free-fall.
- An orbit around Earth is, in principle, a constant free fall



A simulation of weightlessness in Earth's atmosphere

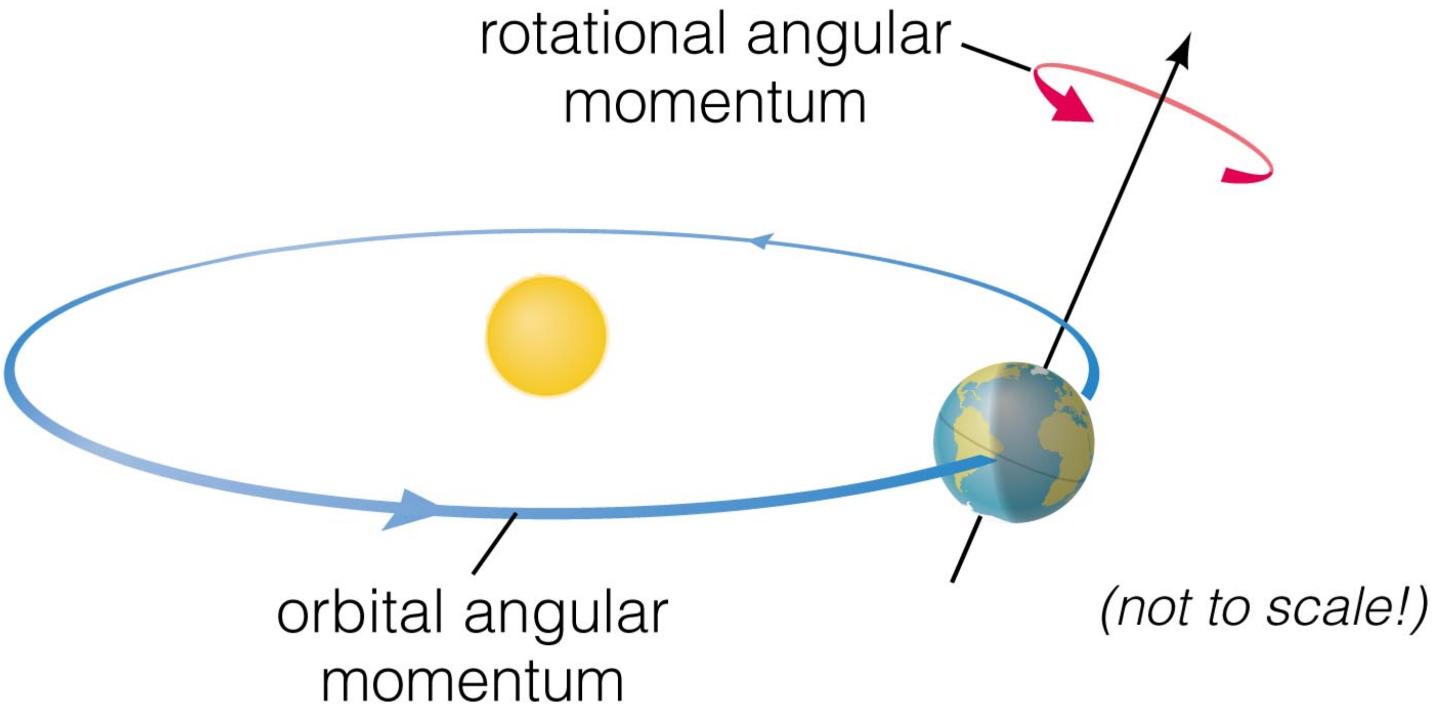


A typical parabolic flight: ~ 20 - 30 seconds of free fall

ScienceBob @ Youtube

Moving in Circles

- **Angular momentum** describes objects that are spinning or moving in circles.
- A special force, a **torque**, is needed to change an object's angular momentum.



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.

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

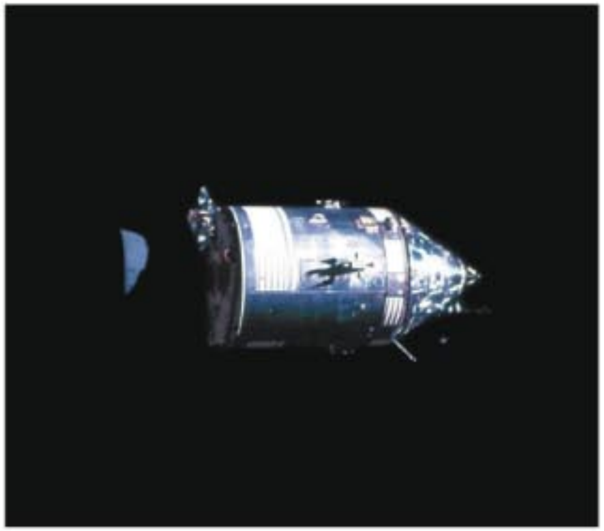
- Our goals for learning:
  - **How did Newton change our view of the universe?**
  - **What are Newton's three laws of motion?**

How did Newton change our view of the universe?

- Realized the same physical laws that operate on Earth also operate in the heavens
  - one *universe*
- Discovered laws of motion and gravity
- Much more: experiments with light, first reflecting telescope, calculus…

Sir Isaac Newton
(1642–1727)

What are Newton's three laws of motion?



Example: A spaceship needs no fuel to keep moving in space.

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

Newton's Second Law of Motion

- There are two equivalent ways to express Newton's Second Law of Motion
  - Force = mass x acceleration
  - Force = rate of change in momentum

Example: *A baseball accelerates as the pitcher applies a force by moving his arm. (Once the ball is released, the force from the pitcher's arm ceases, and the ball's path changes only because of the forces of gravity and air resistance.)*

Newton's third law of motion:

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

Example: *A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back.*

Thought Question

How does the force the Earth exerts on you compare with 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 you exert equal and opposite forces on each other.

Thought Question

How does the force the Earth exerts on you compare with 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 you exert equal and opposite forces on each other.**

Thought Question

A compact car and a Mack truck have a head-on collision. Are the following **true** or **false**?

1. The *force* of the car on the truck is equal and opposite to the force of the truck on the car.
2. The *momentum* transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck.
3. The *change of velocity* of the car is the same as the change of velocity of the truck.

Thought Question

A compact car and a Mack truck have a head-on collision. Are the following **true** or **false**?

1. The *force* of the car on the truck is equal and opposite to the force of the truck on the car. **T**
2. The *momentum* transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck. **T**
3. The *change of velocity* of the car is the same as the change of velocity of the truck. **F**

What have we learned?

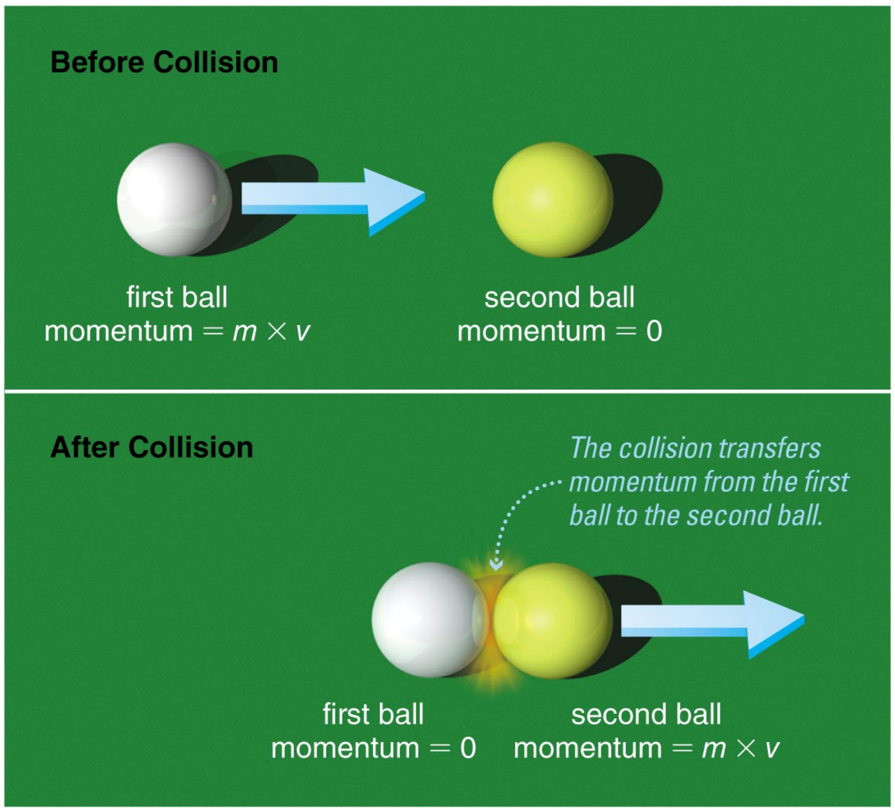
- **How did Newton change our view of the universe?**
  - He discovered laws of motion and gravitation.
  - He realized these same laws of physics were identical in the universe and on Earth.
- **What are Newton's three laws of motion?**
  1. Object moves at constant velocity if no net force is acting.
  2. Force = mass x acceleration
  3. For every force there is an equal and opposite reaction force.

4.3 Conservation Laws in Astronomy

- Our goals for learning:
  - **Why do objects move at constant velocity if no force acts on them?**
  - **What keeps a planet rotating and orbiting the Sun?**
  - **Where do objects get their energy?**

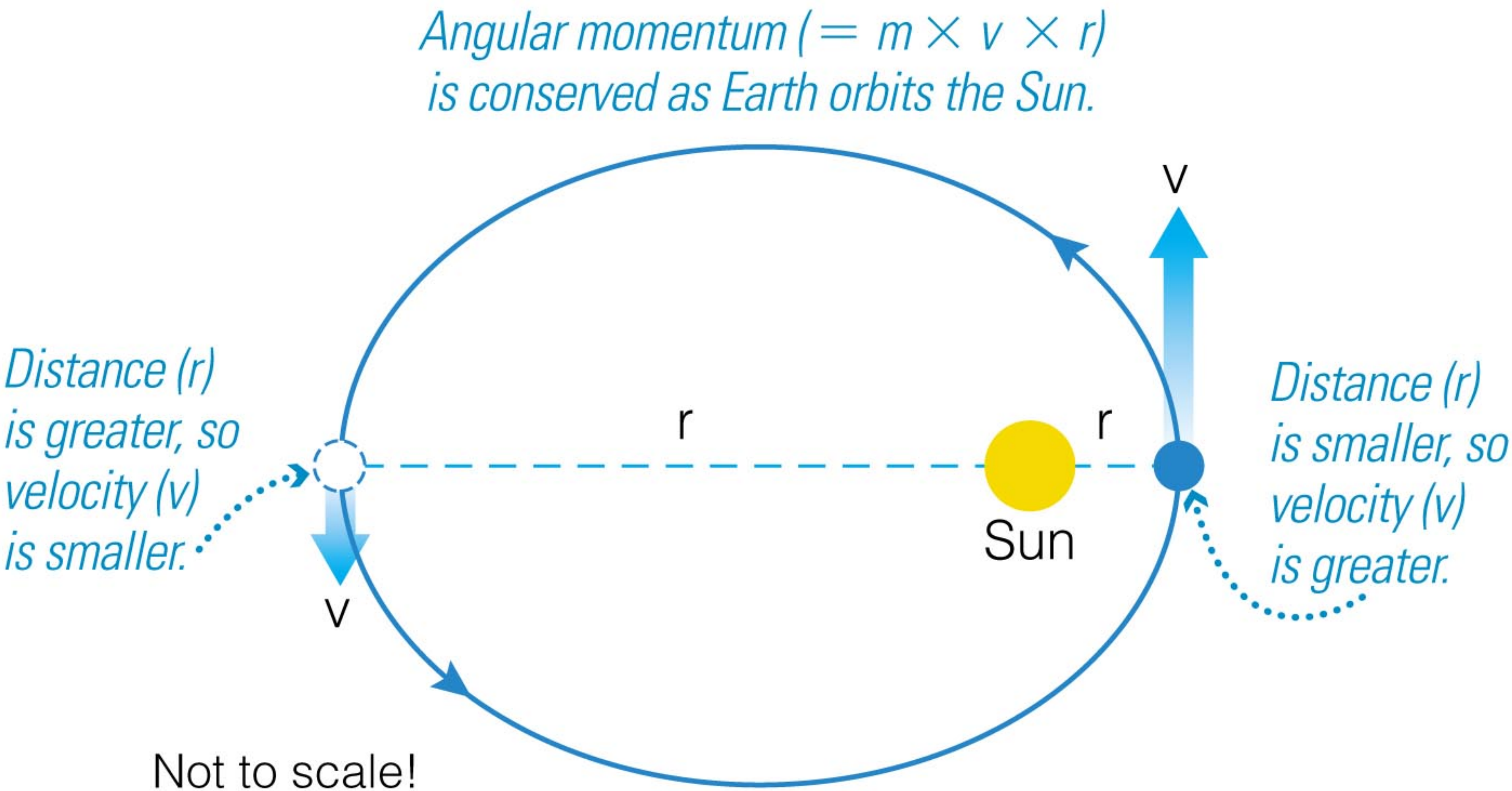
Why do objects move at constant velocity if no force acts on them?

- Objects continue at constant velocity because of **conservation if 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.

What keeps a planet rotating and orbiting the Sun?

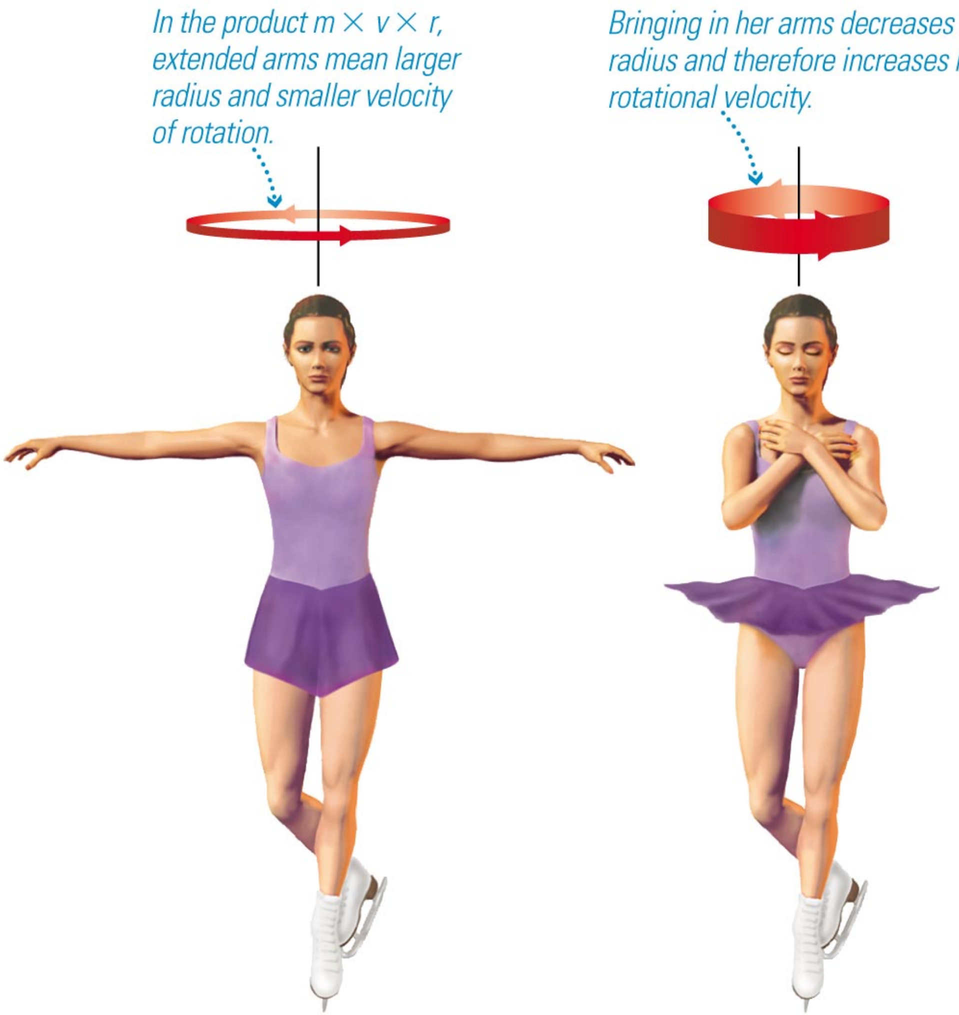


Conservation of Angular Momentum

Angular momentum = mass x velocity x radius

- 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.



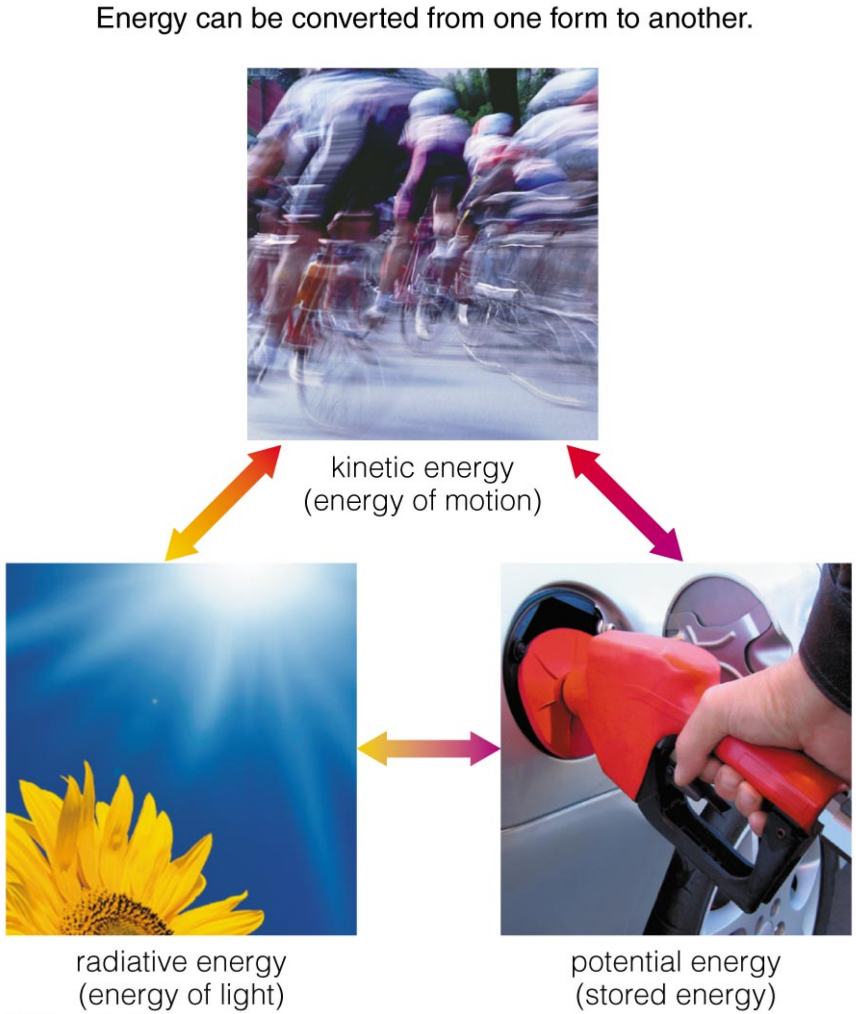
Where do objects get their energy?

- Energy makes matter move.
- Energy is conserved, but it can:
  - transfer from one object to another
  - change in form

Basic Types of Energy

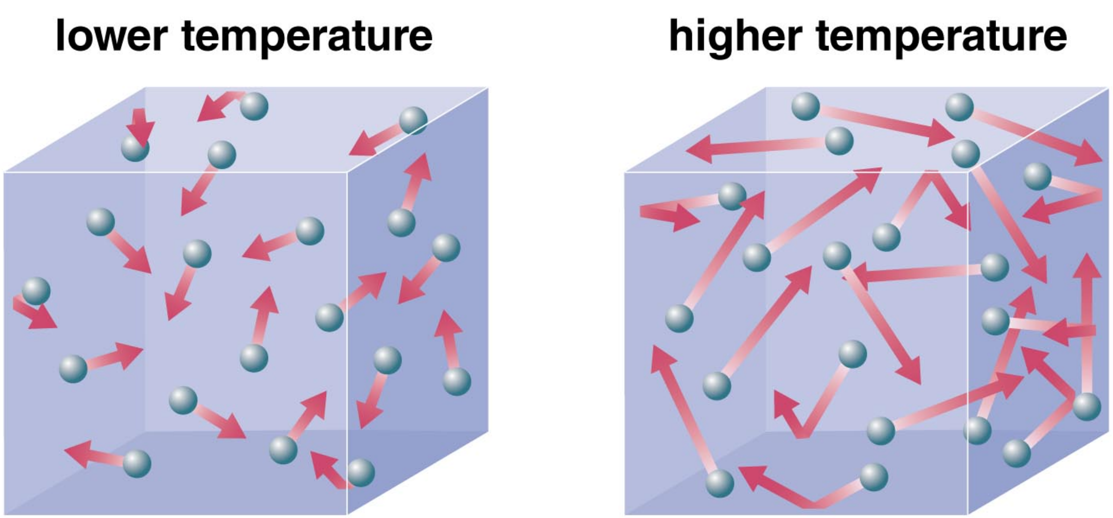
- Kinetic (motion)
- Radiative (light)
- Potential (stored)

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

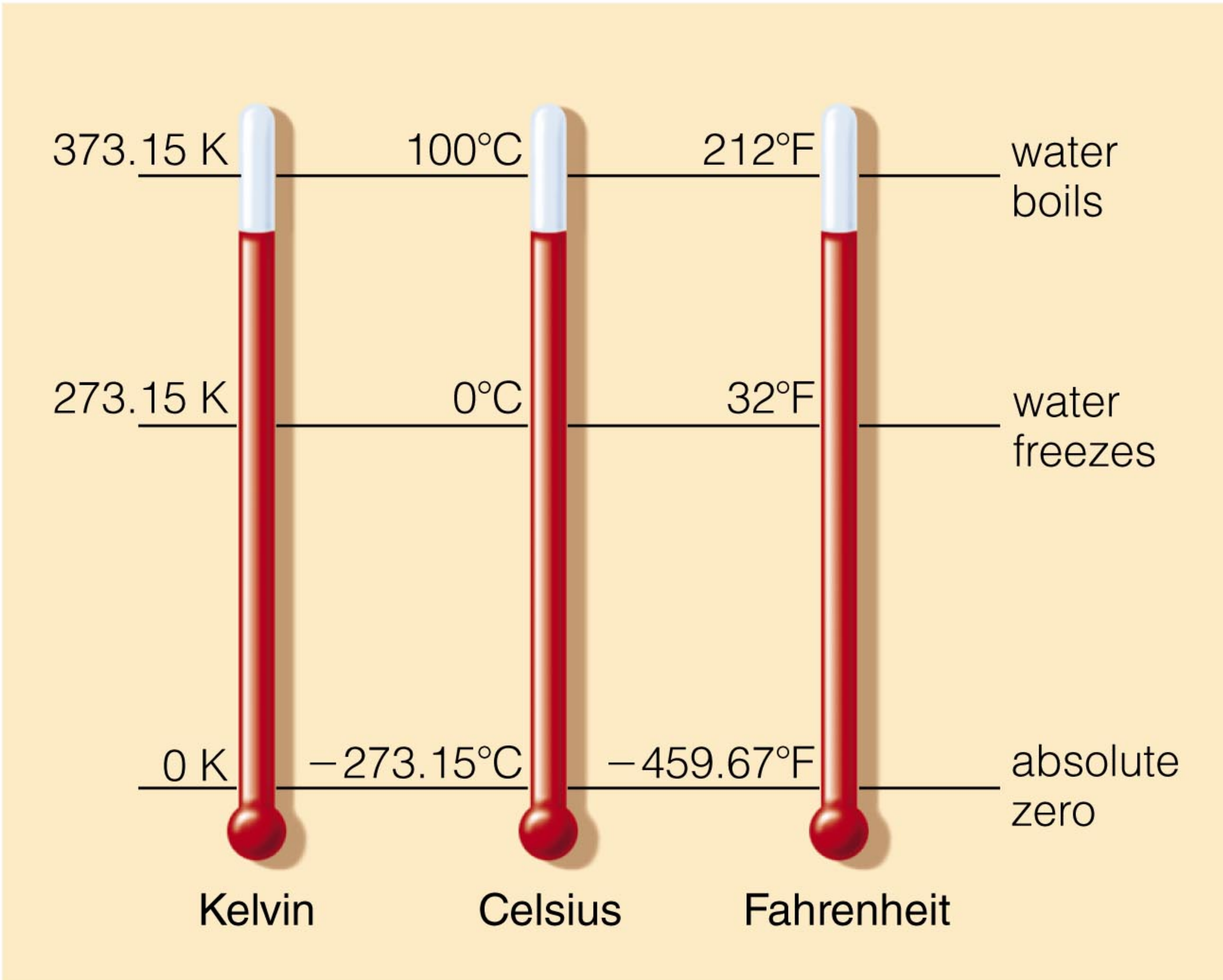


Thermal Energy:

- The collective kinetic energy of many particles (for example, in a rock, in air, in water)
  - Thermal energy is related to temperature but it is NOT the same.
  - **Temperature** is a measure of the *average* kinetic energy of the many particles in a substance.

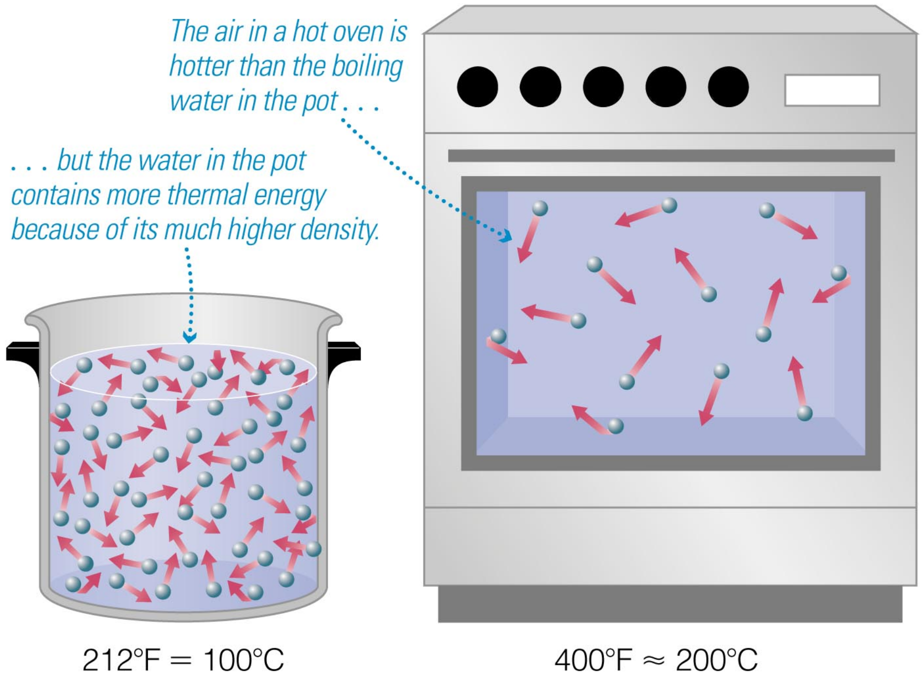


Temperature Scales



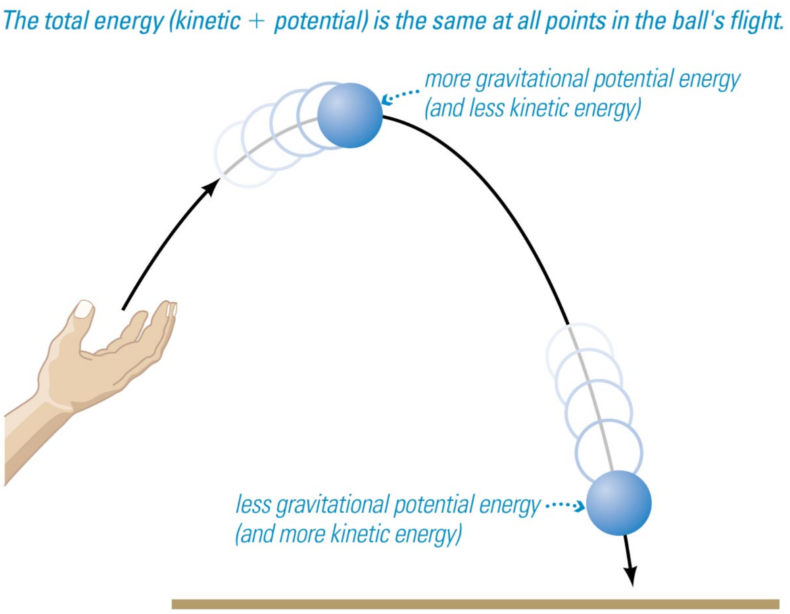
Temperature Scales

- Thermal energy is a measure of the total kinetic energy of all the particles in a substance. It therefore depends on both *temperature* AND *density*.
  - Example:



Gravitational Potential Energy

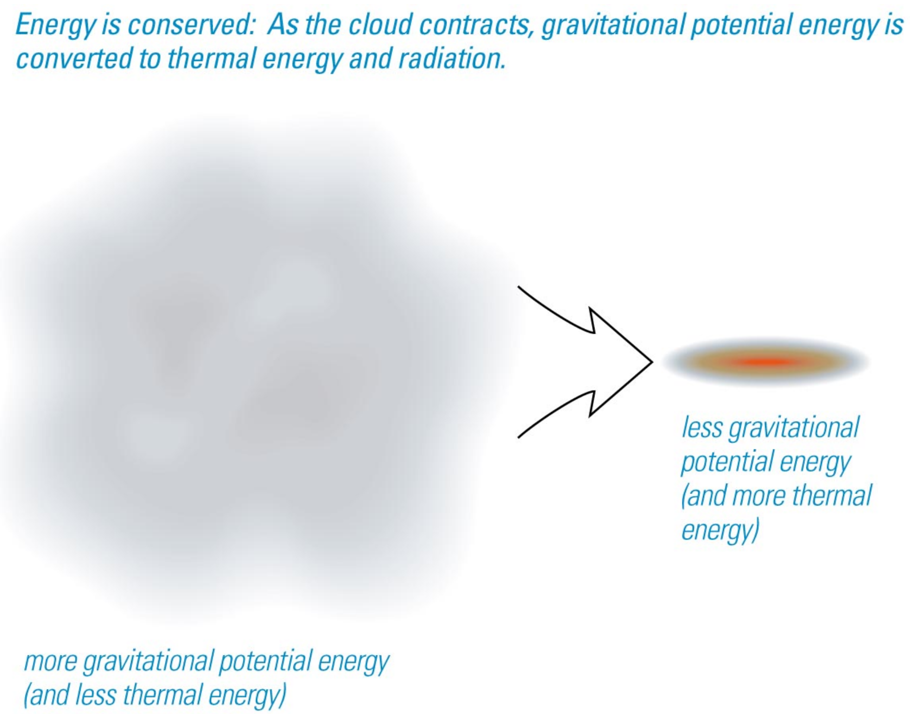
- On Earth, depends on:
  - object's *mass (m)*
  - strength of gravity *(g)*
  - distance object could potentially fall



a The ball has more gravitational potential energy when it is high up than when it is near the ground.

Gravitational Potential Energy

- In space, an object or gas cloud has more gravitational energy when it is spread out than when it contracts.
  - A contracting cloud converts gravitational potential energy to thermal energy.



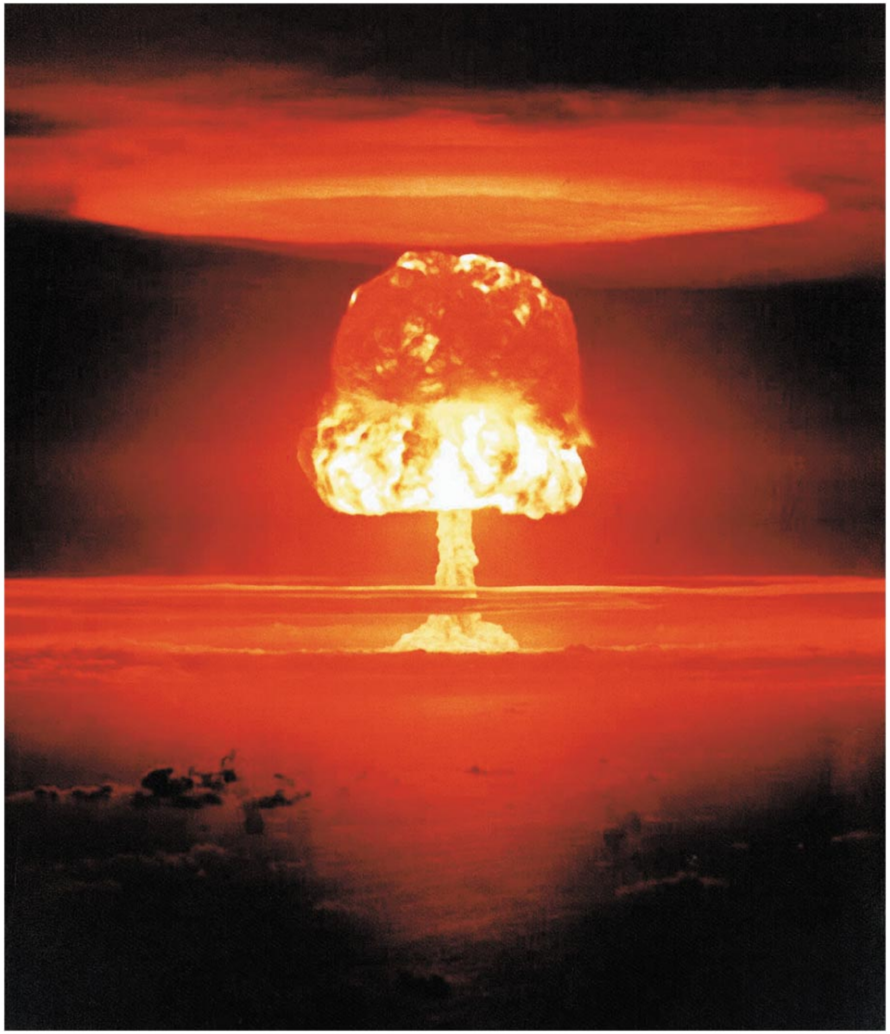
b A cloud of interstellar gas contracting because of its own gravity has more gravitational potential energy when it is spread out than when it shrinks in size.

Mass-Energy

- Mass itself is a form of potential energy:

$$E = mc^2$$

- A small amount of mass can release a great deal of energy (for example, an H-bomb).
- Concentrated energy can spontaneously turn into particles (for example, in particle accelerators).



Conservation of Energy

- Energy can be neither created nor destroyed.
- It can change form or be exchanged between objects.
- The total energy content in an isolated system is always the same.