Today

- Energy
- Gravity

Events

- Homework Due Next time
- Practice Exam posted

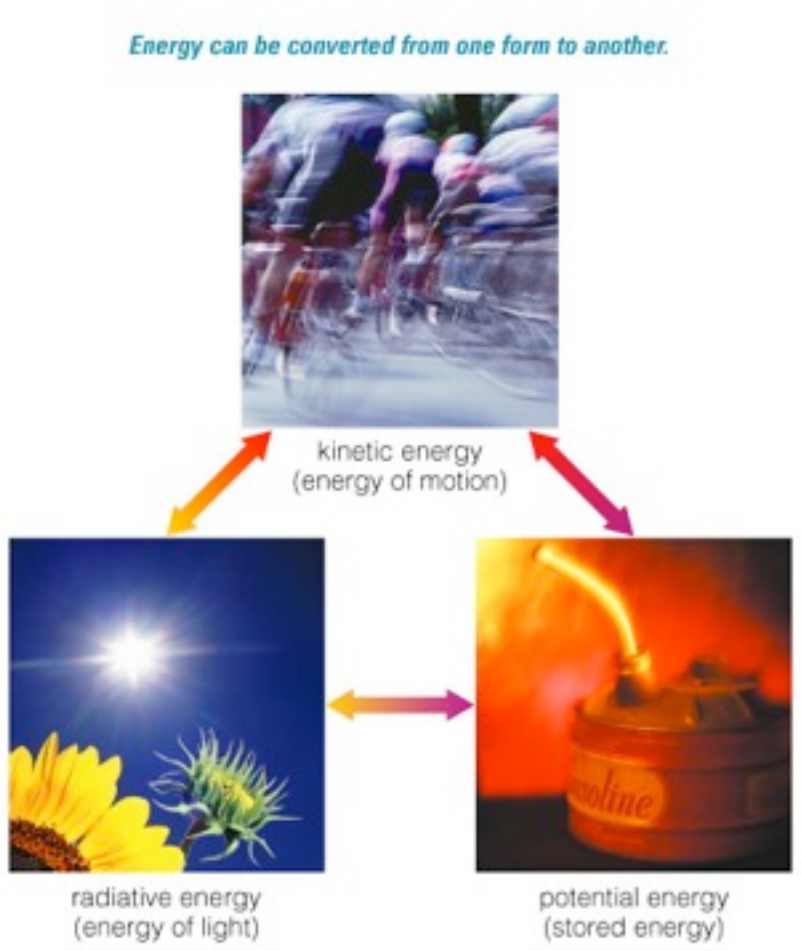
Autumn is here!

- Autumnal equinox occurred at 11:09pm last night
  - night and day very nearly equal today
  - days getting shorter
- Moon is full right now ("Harvest moon")
  - Rises as sun sets
    - sunset: 7:21pm (why not 6:00pm?)
    - moonrise: 7:07pm (why not exactly at sunset?)
- Jupiter at Opposition, close to full moon
  - near perihelion: closest approach since 1963
  - moving retrograde

Basic Types of Energy

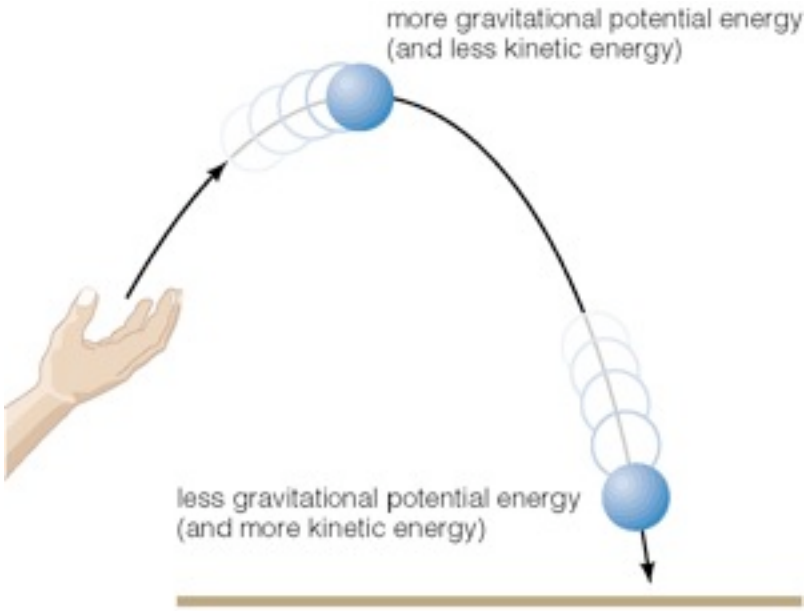
- Kinetic (motion)
- Radiative (light)
- Stored or potential

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.



Gravitational Potential Energy at top

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

Kinetic Energy at bottom

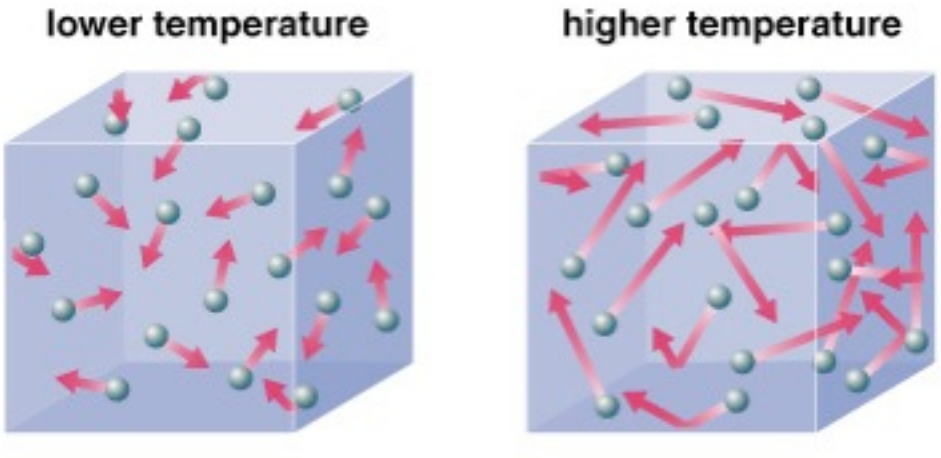
C8-03 Galileo's pendulum

Thermal Energy:

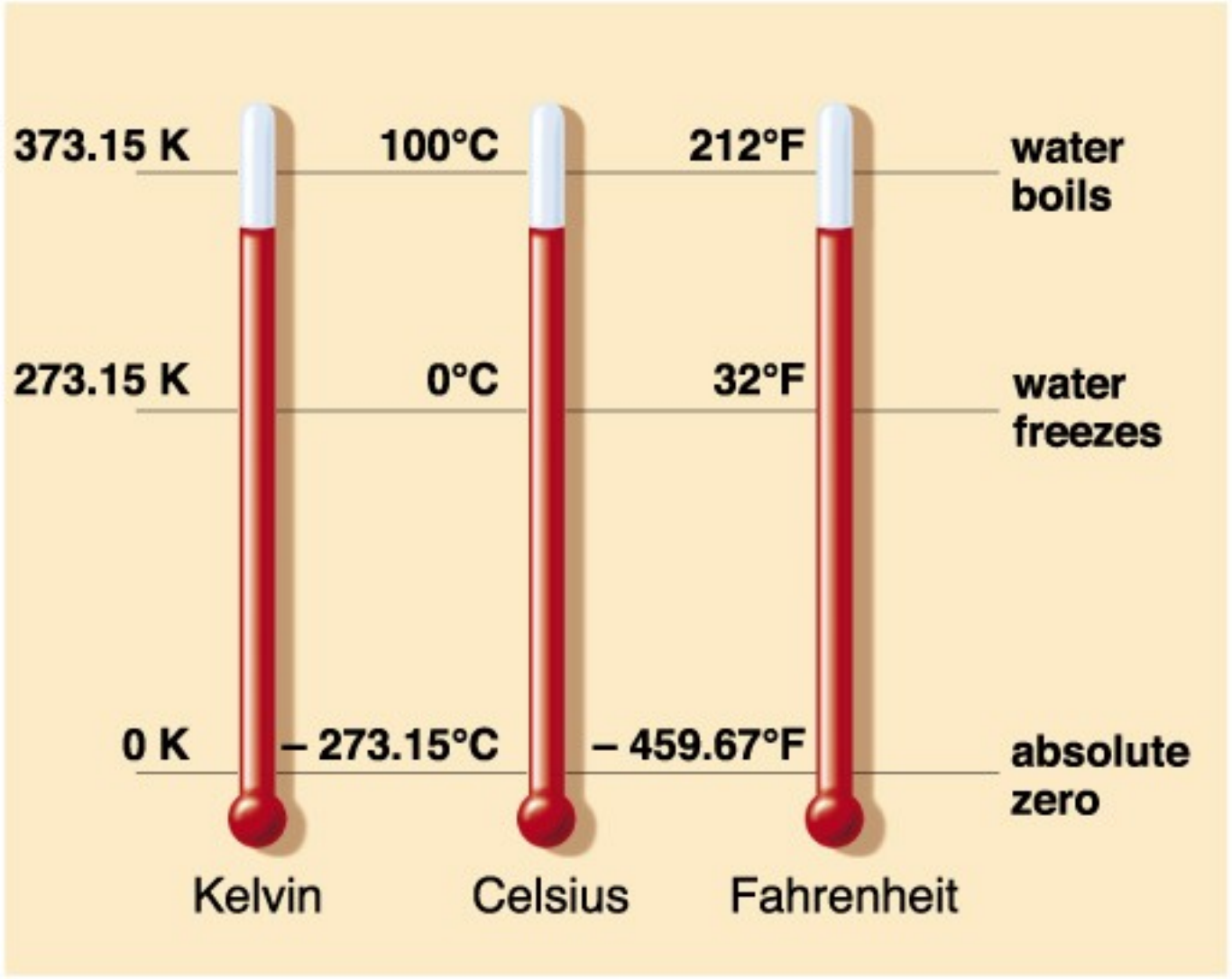
the collective kinetic energy of many particles (for example, in a rock, in air, in water)

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

Temperature is the *average* kinetic energy of the many particles in a substance.

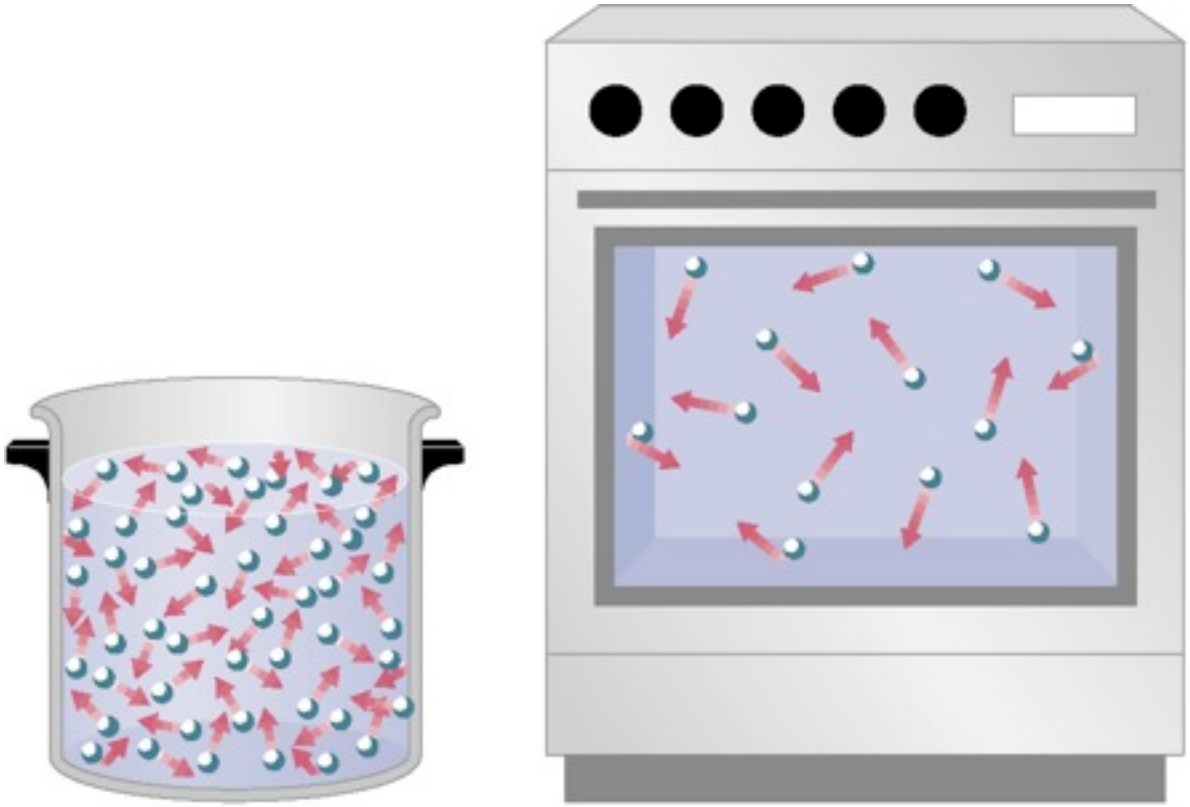


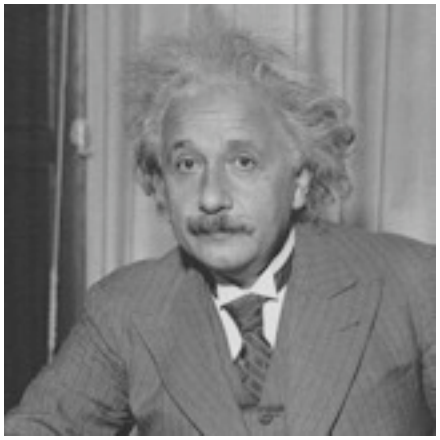
Temperature Scales



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:





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.
- Concentrated energy can spontaneously turn into particles (for example, in particle accelerators).
- Total mass-energy is conserved.

Conservation of Energy

- Energy can be neither created nor destroyed.
- It can change form or be exchanged between objects.
- The total energy content of the universe is the same today as it was at the beginning of time.

4.4 The Force of Gravity

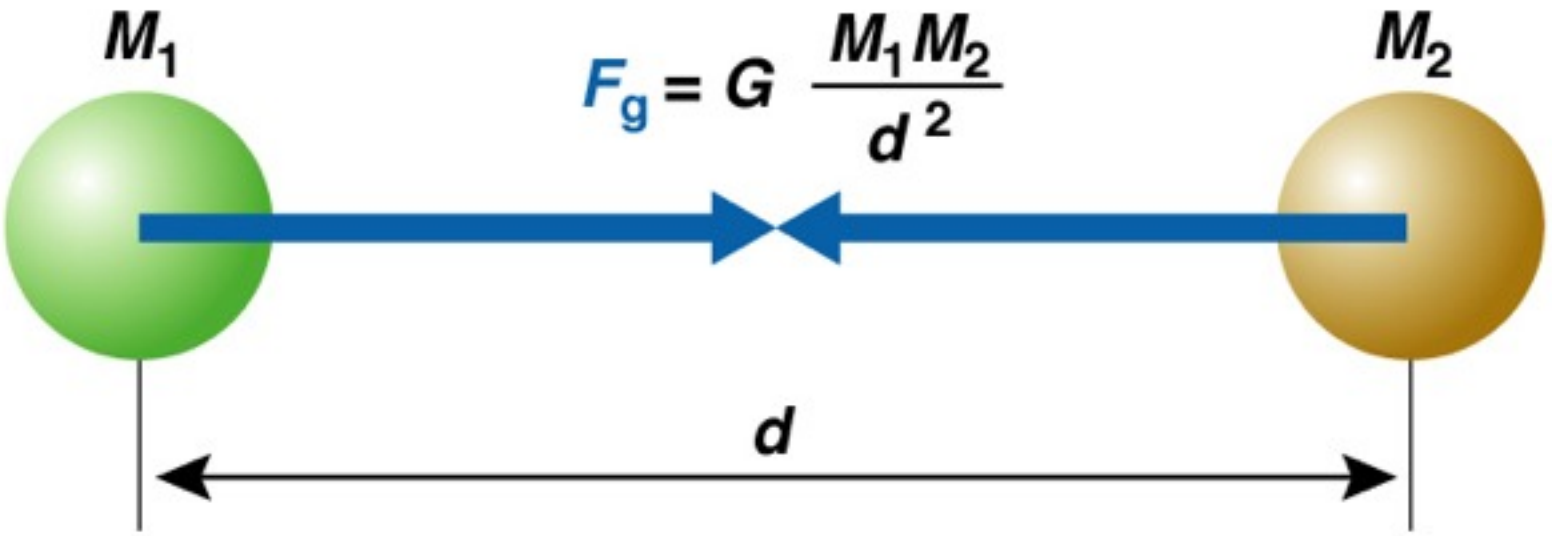
Our goals for learning:

- What determines the strength of gravity?
- How does Newton's law of gravity extend Kepler's laws?
- How do gravity and energy together allow us to understand orbits?
- Why are large objects spherical?
- How does gravity cause tides?

What determines the strength of gravity?

The **Universal Law of Gravitation:**

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



Newton's version of Kepler's Third Law

$$P^2 = \frac{4\pi^2}{G} \frac{a^3}{(M_1 + M_2)}$$

p = orbital period

a = average orbital distance (between centers)

(M_1 + M_2) = sum of object masses

(e.g., the mass of the sun)

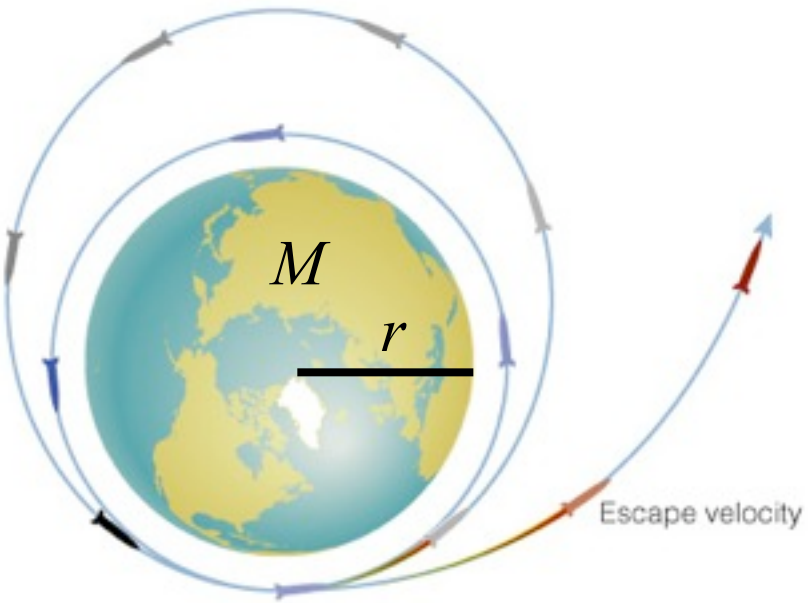
derive

Orbits of the Moons of Jupiter

Moon	P (days)	a (km)	a^3/P^2 (solar masses)
Io	1.8	4×10^5	0.001
Europa	3.6	7×10^5	0.001
Ganymede	7.2	1×10^6	0.001
Callisto	16.7	2×10^6	0.001

Jupiter is 0.001 solar masses

Escape Velocity



- An orbit can be changed by adding or removing energy.
- If an object gains enough orbital energy, it may escape (change from a bound to unbound orbit).
- **Escape velocity** from Earth ≈ 11 km/s from sea level (about 40,000 km/hr).

Circular & Escape velocity

Circular velocity:

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

(minimum energy orbit)

Escape velocity:

$$v_{esc} = \sqrt{\frac{2GM}{r}} = \sqrt{2} v_{circ}$$

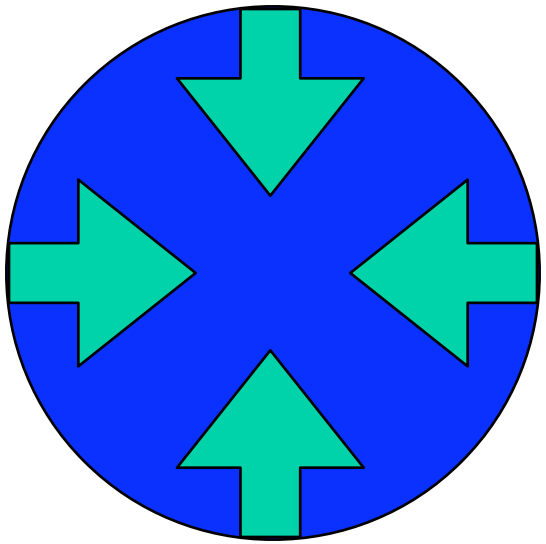
(maximum energy orbit
where object becomes unbound)

Examples:

Object	circular speed at surface	escape speed from surface
Earth	7.8 km/s	11 km/s
Sun	436 km/s	617 km/s
Moon	1.7 km/s	2.4 km/s

Why are stars and planets spherical?

- Gravity pulls - it is an attractive force
- IF self-gravity is the most important force holding an object together, it must be spherical.



Example: Earth

- Diameter of Earth: 12,756 km
- Mt. Everest: 8.848 km above sea level
- Mariana Trench: 10.934 km below
- Maximum variation: 19.782 km

$$\frac{\text{maximum variation}}{\text{diameter}} = \frac{19.782}{12,756}$$

$$= 0.0015$$

- a very smooth sphere!

- Gravity makes individual objects round
  - about 100 km in diameter is where objects start to become dominated by self-gravity
    - planets round
    - asteroids still lumpy

This holds for individual objects.
What about multiple objects?

Summary

- Kepler's Laws follow naturally from Newton's Universal Law of Gravity
- Gravitationally bound objects are spherical
  - e.g., planets, stars