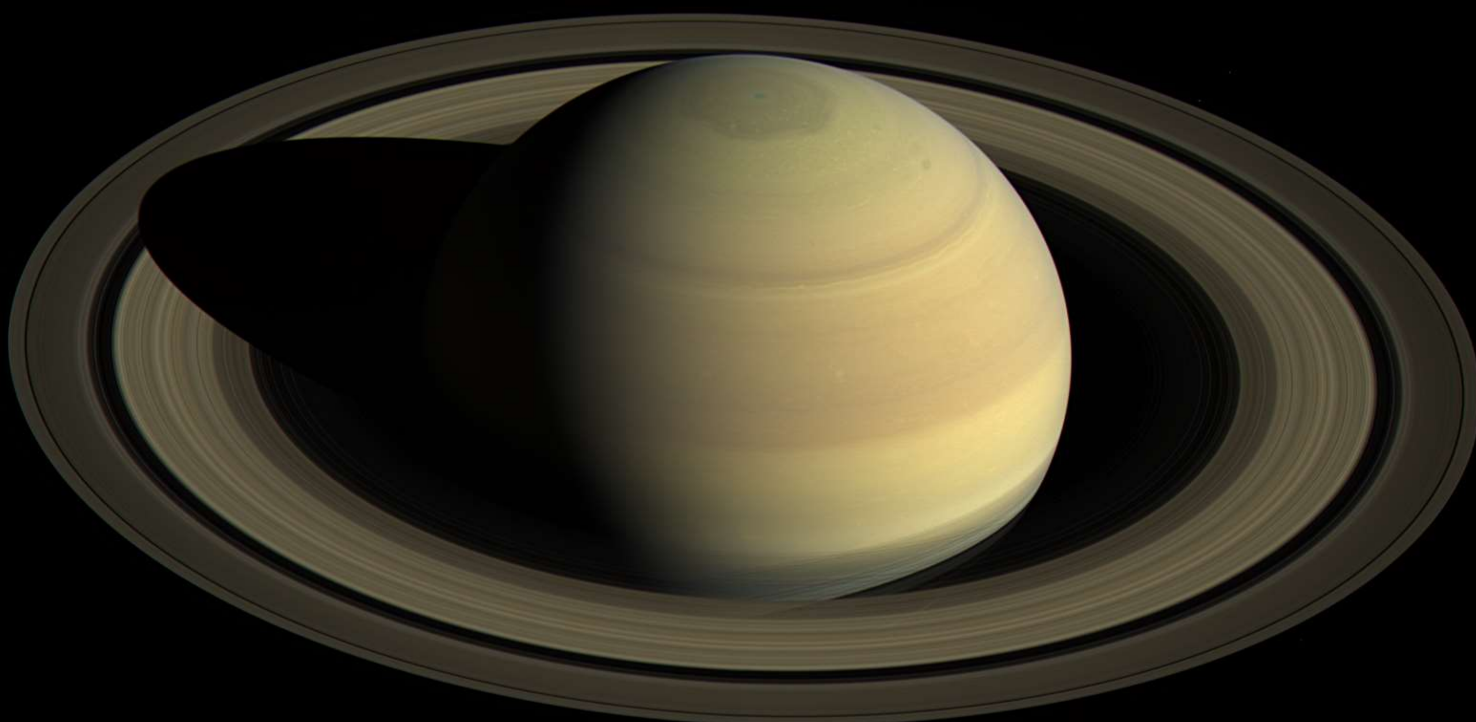
AST 2002
Introduction to Astronomy



A Few Quick Things…

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3pm. PSB 316

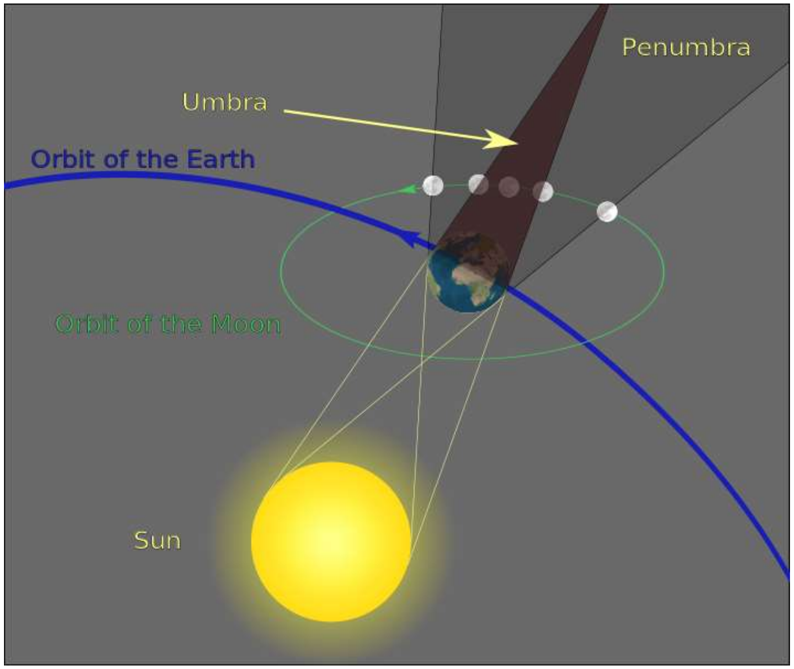
My office hours: Mon 3-4pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term is on Friday 9th February.
https://ucfsga.com/services/free-scantrons-and-blue-books/

Tonight:
Knights Under the Stars event at Robinson Observatory:
Wed 31st Jan, 7:00 – 8:30 pm.

Rare Blue Super Moon Event Today at 7:52am

- Blue moon (2nd moon in a month)
- Super Moon (at perihelion)
- Red 'Blood' Moon (total eclipse)



Today: The Force of Gravity

Last Time:

- Inertia & Momentum
- Mass, Weight, weightlessness & orbits
- Newton’s three laws of Motion

Topics Covered:

- Conservation Laws
- 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?
- How does gravity cause tides?

Newton & Newton's Laws of Motion

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.**

1st Law: An object in motion will not alter its course unless another force acts upon on (inertia)

- ***An object will move in a straight line unless acted on by another force…***

2nd Law: Net forces cause a change in the motion of an object (acceleration, where F=ma)

- ***If an object's motion is changing, a force must be acting on it…***

3rd Law: Forces are paired and are equal in strength but act in the opposite direction (action-reaction pairs)

- ***The forces must be equal and opposite…***

iClicker Question

(Code = BC)

Question: If you take off in a rocket that is accelerating upwards…

A. your mass increases and your weight stays the same

B. your weight increases and your mass stays the same

C. both your weight and mass increase

D. both your weight and mass stay the same

E. both your weight and mass decrease

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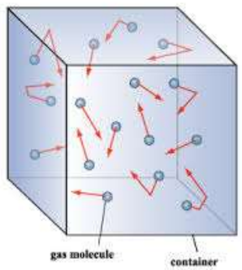
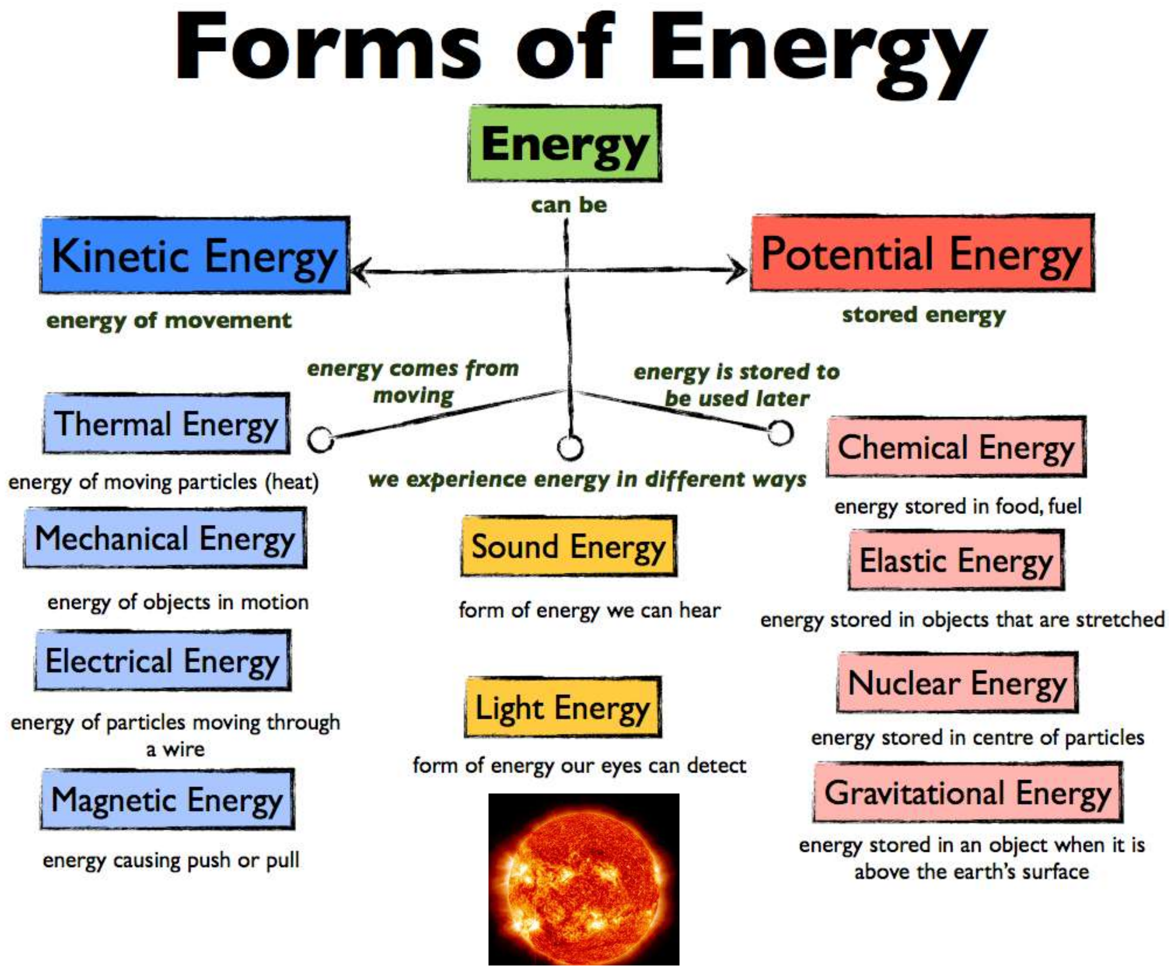
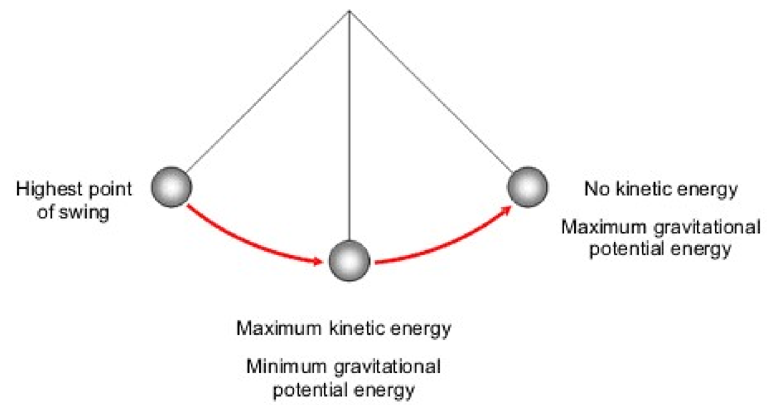
Law of Conservation of Energy

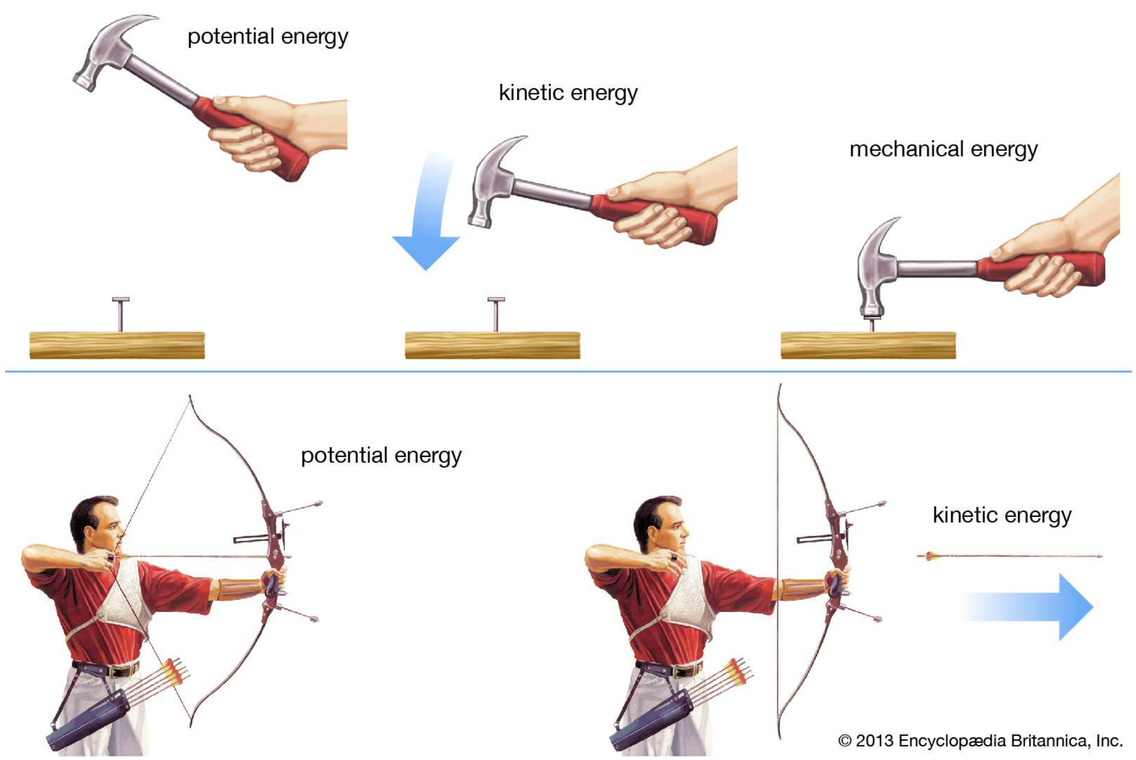
"energy can neither be created nor destroyed; rather, it can only be transformed from one form to another"

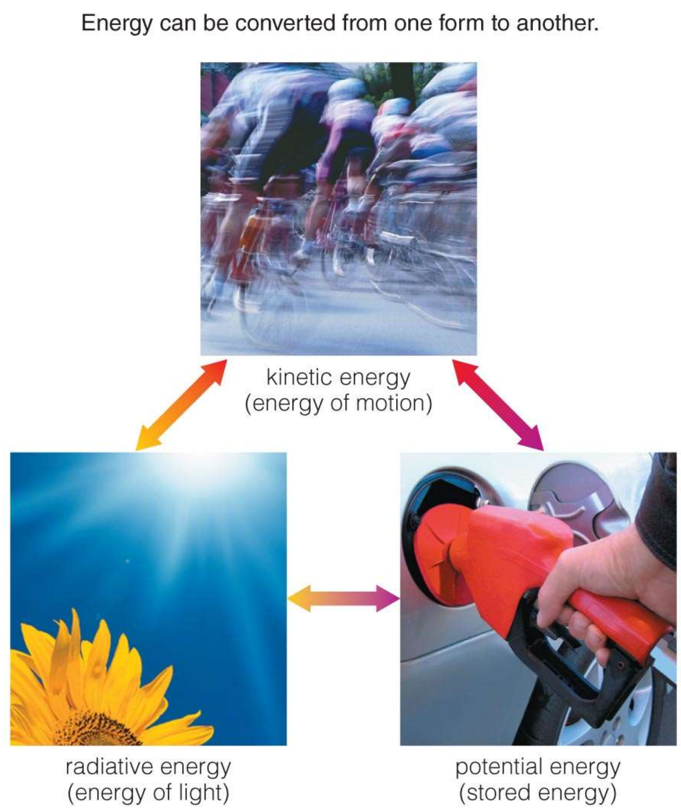




Transfer of Energy Between Different Forms



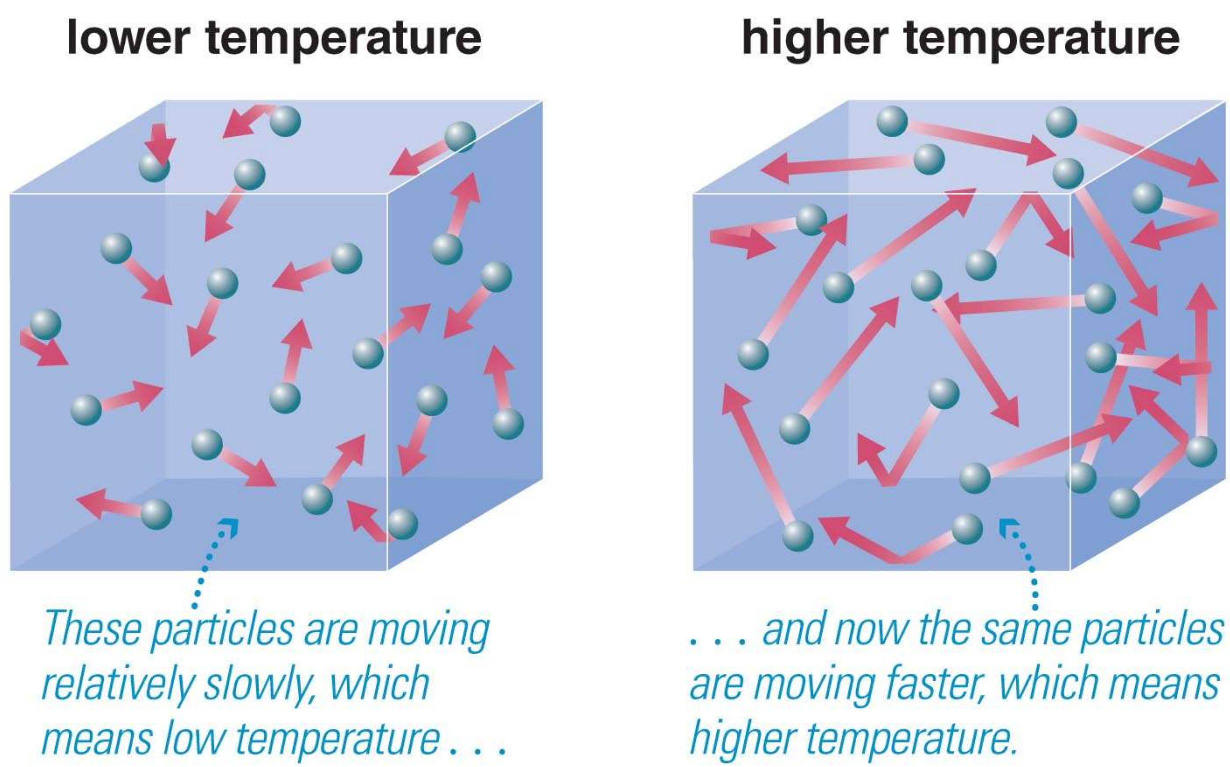




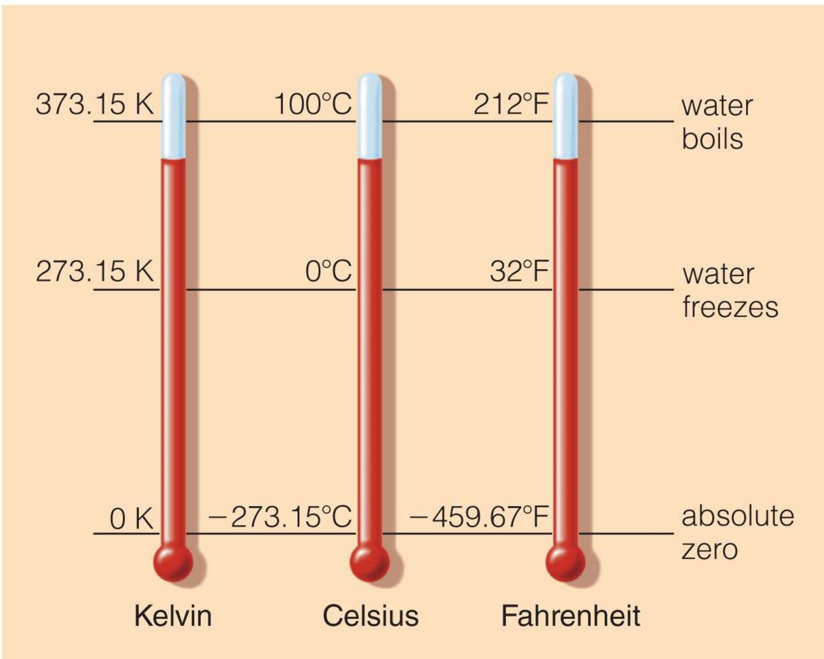
Thermal Energy & Temperature

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.



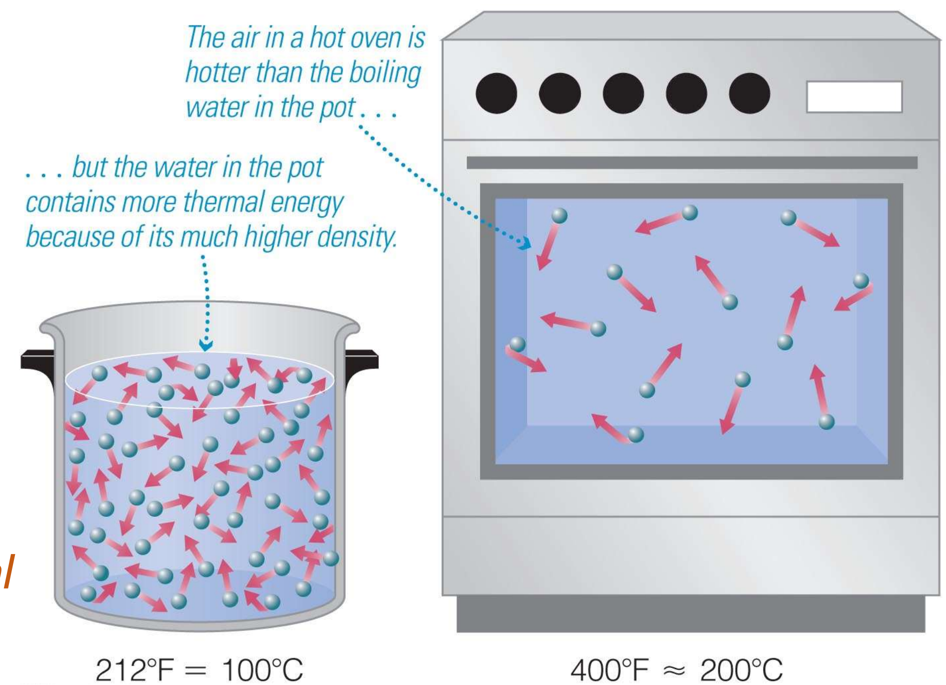
Temperature Scales



Nothing moves at zero degrees Kelvin

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.

Thought Question: What would give a person a more severe burn? Exposure to steam at 100 °C or water at 100 °C?

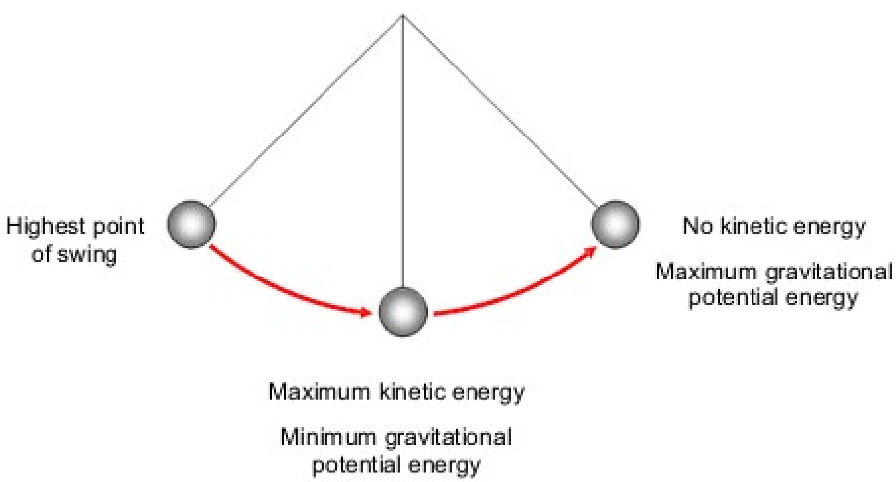


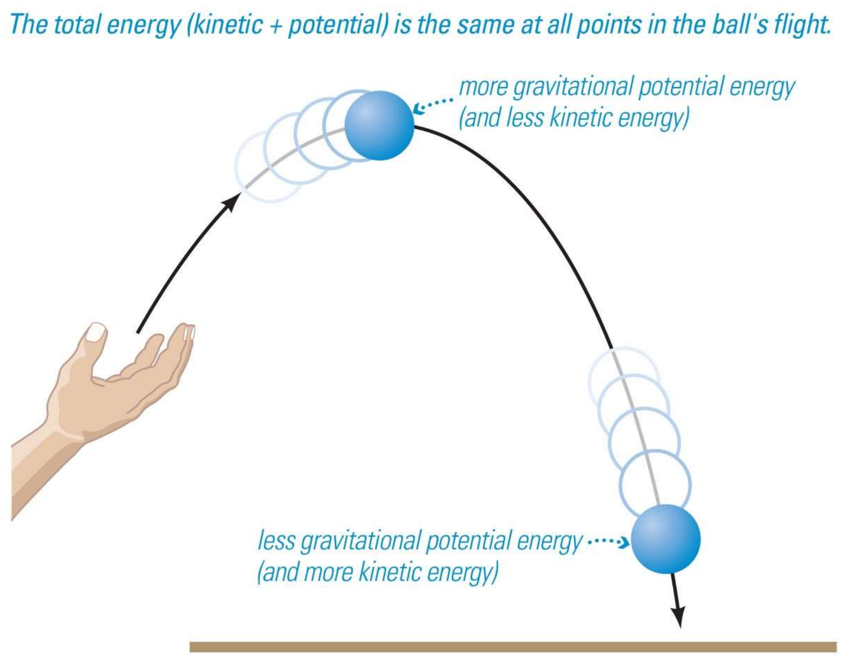
Gravitational Potential Energy

On Earth, it depends on…

- an object's mass (*m*).
- the strength of gravity (*g*).
- the distance an object could potentially fall.

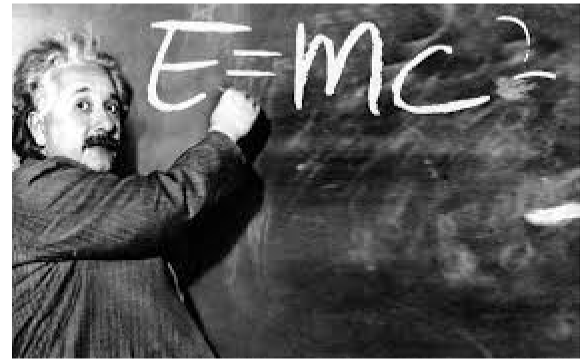
E.g., Pendulum





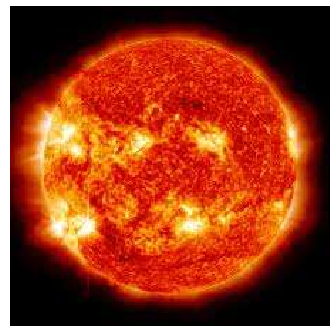
a The ball has more gravitational potential energy when it is high up than when it is near the ground.

The Relationship between Mass and Energy

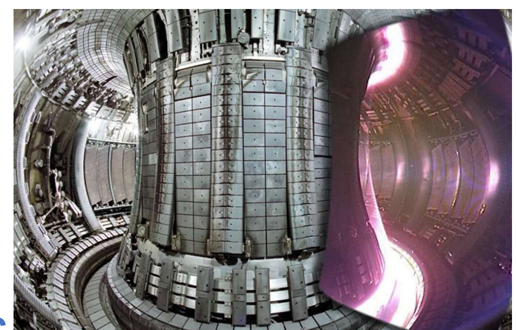


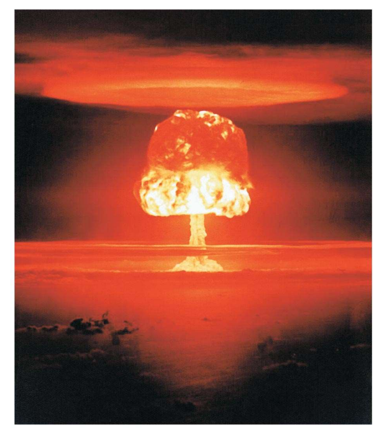
- According to Einstein's famous equation, Mass itself is a form of potential energy.

$$E = mc^2$$



- A small amount of mass can release a great deal of energy.
    - Nuclear Fission power plant
    - Nuclear Fusion power plant
    - Nuclear Weapons (both)
    - Nuclear Fusion within Stars





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

iClicker Question

Question: When a ball is dropped, some of the ball's energy changes from

A. kinetic energy to gravitational potential energy
B. gravitational potential energy to kinetic energy
C. radiative energy to kinetic energy
D. gravitational potential energy to radiative energy

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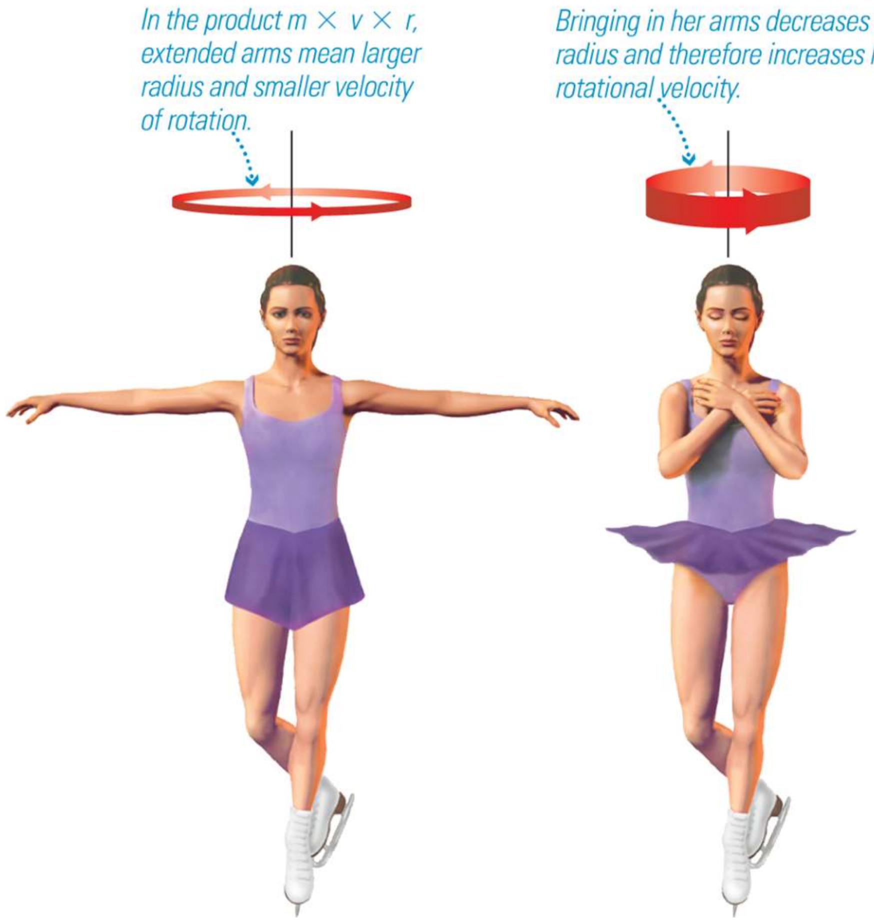
Conservation of Angular Momentum

Orbital angular momentum = mass × velocity × radius



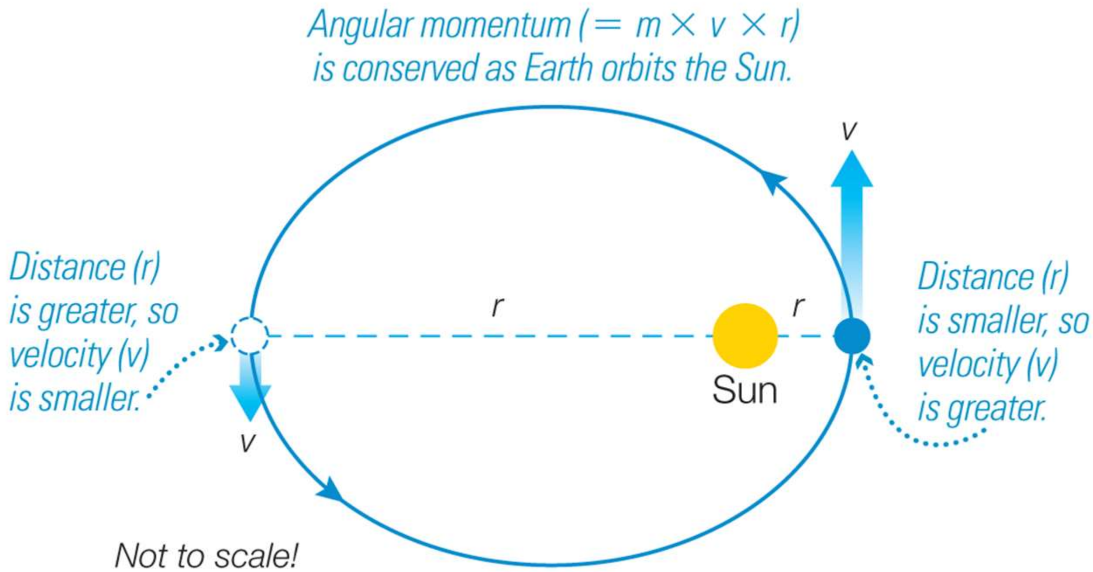
Example: Figure Skater

Example: Solar System Formation

What is Orbital Angular Momentum?

Orbital angular momentum = mass × velocity × radius

How does this help explain Kepler's 2nd law?



Angular momentum is conserved over the orbit

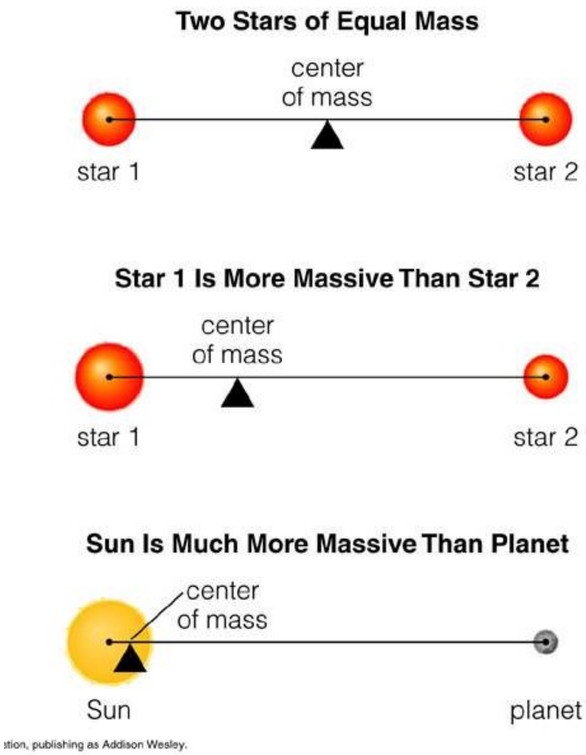
↓ **in radius,**

↑ **in velocity…**

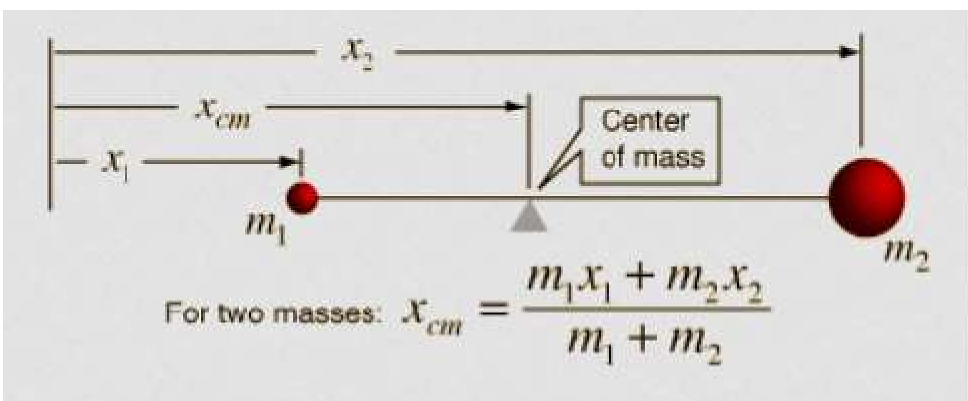
Because Earth's angular momentum at any point in its orbit depends on the product of its speed and orbital radius (distance from the Sun), Earth's orbital speed must be faster when it is nearer the Sun (and radius is smaller)

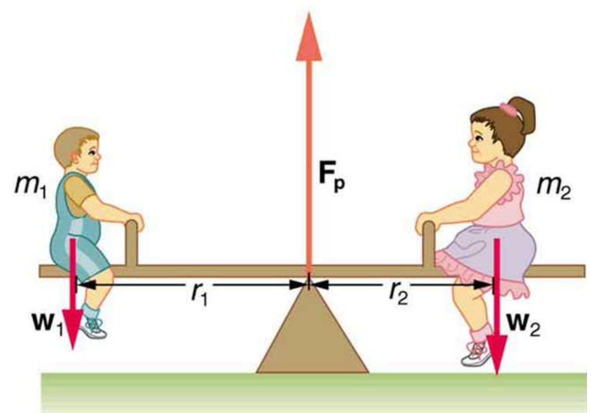
Earth needs no fuel or push of any kind to keep orbiting the Sun – it will keep orbiting as long as nothing comes to take orbital momentum away

Center of Mass



Objects attracted by gravity orbit around their center of mass



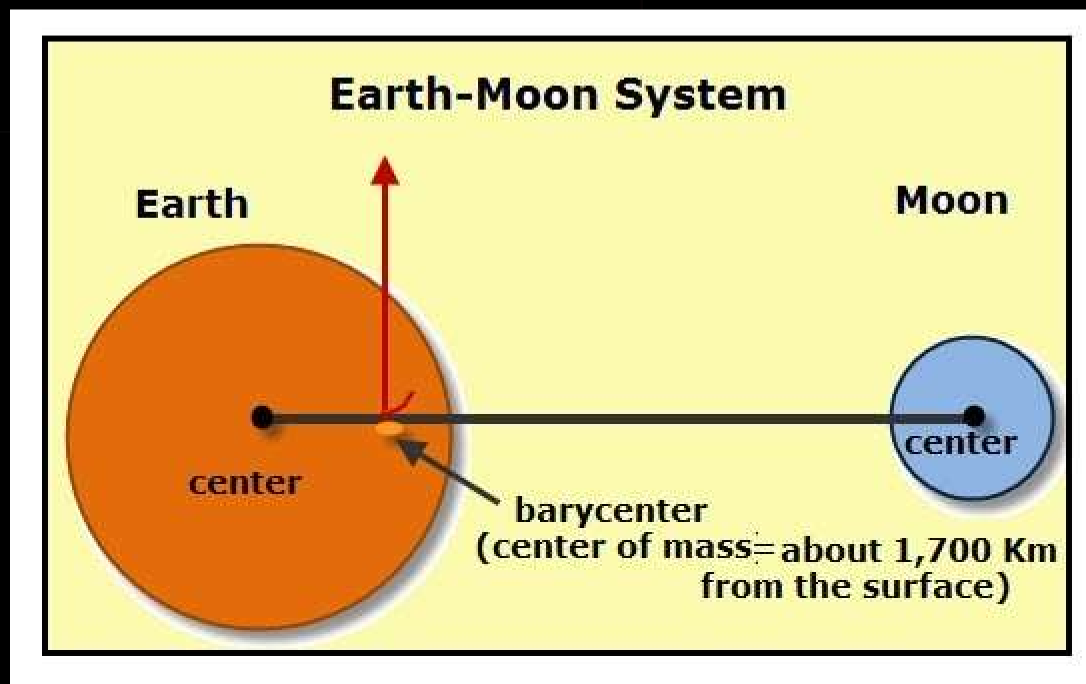


Barycenters

A Barycenter is the center of mass of two or more bodies that are orbiting each other, which is the point around which they both orbit

Jupiter doesn't orbit the Sun!

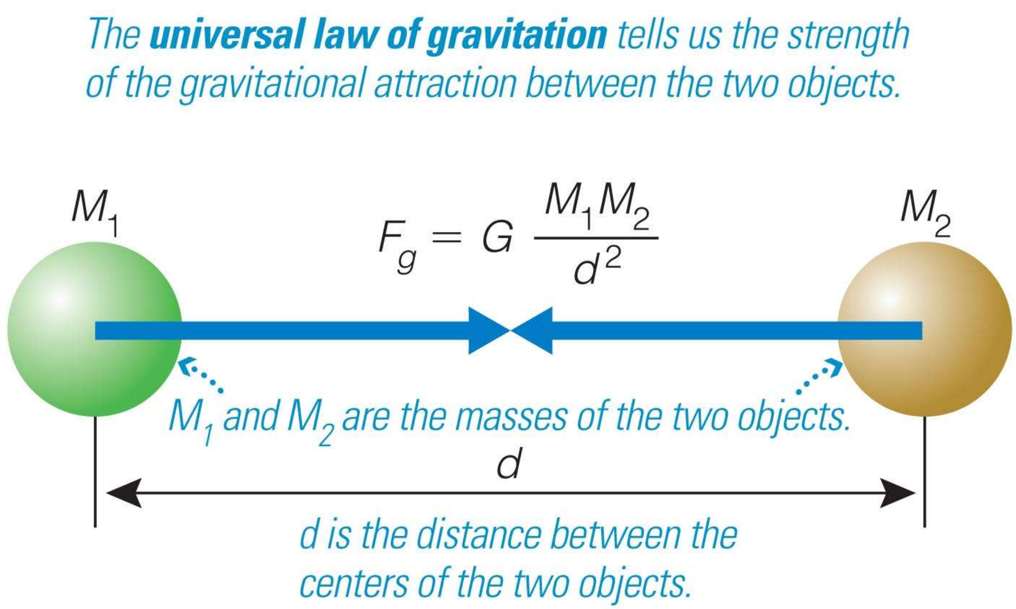
The Barycenter lies at 1.07 solar radii from the center of the Sun…



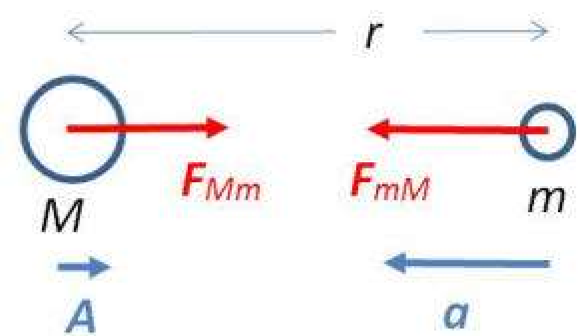
What determines the strength of gravity?

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.



The Force between two objects must be the same



But the acceleration each experiences may be different (F=ma)

iClicker Question

Question: Is the force (of gravity) that Earth exerts on you larger, smaller, or the same as the force you exert on it?

A. Earth exerts a larger force on you.

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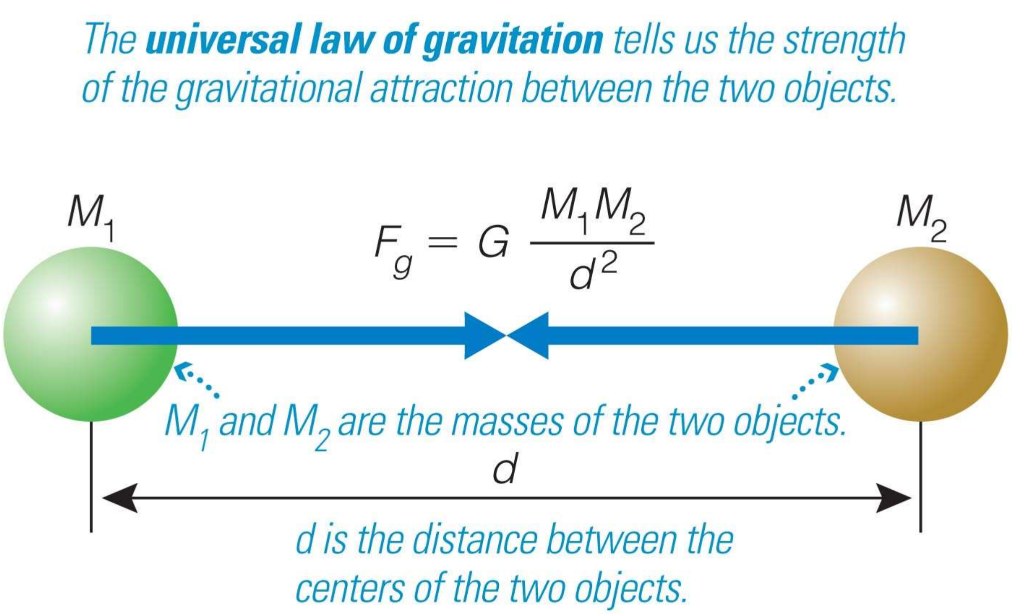
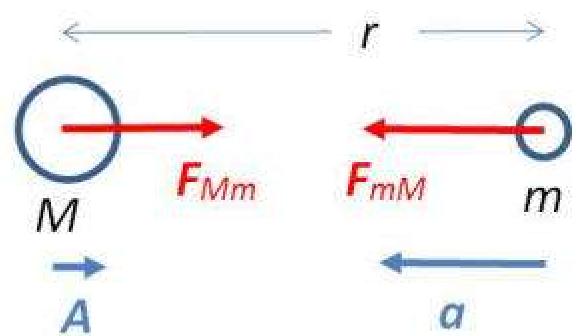


The Force between two objects must be the same



But the acceleration each experiences may be different (F=ma)

Newton's Version of Kepler's 3rd Law

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

p = orbital period, in seconds

a = average orbital distance (between centers), in meters

$(M_1 + M_2)$ = sum of object masses, in kg

G is the gravitational constant, $6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}$

Example: Use the fact that Earth orbits the Sun at an average distance of 1 AU over the period of 1 year to calculate the Sun's mass.

$$p_{Earth}^2 = \frac{4\pi^2}{G(M_{Sun} + M_{Earth})} a_{Earth}^3$$

$M_{Sun} + M_{Earth} \sim M_{Sun}$ (> 3×10^6 M_{Earth})

1 AU = 1.5×10^{11} m

1 year = 3.15×10^7 seconds

Substitute:

$$p_{Earth}^2 \sim \frac{4\pi^2}{G \times M_{Sun}} a_{Earth}^3$$

Rearrange:

$$M_{Sun} \sim \frac{4\pi^2}{G \times p_{Earth}^2} a_{Earth}^3$$

Evaluate:

$$M_{Sun} \sim \frac{4\pi^2}{\left(6.67 \times 10^{-11} \frac{m^3}{kg \times s^2}\right) \times (3.15 \times 10^7\ s)^2} \times (1.5 \times 10^{11} m)^3 \quad \sim 2.0 \times 10^{30}\ kg$$

Newton's version of Kepler's third law & Orbits

If a small object orbits a larger one and you measure the orbiting object's orbital period AND average orbital distance THEN you can calculate the mass of the larger object.

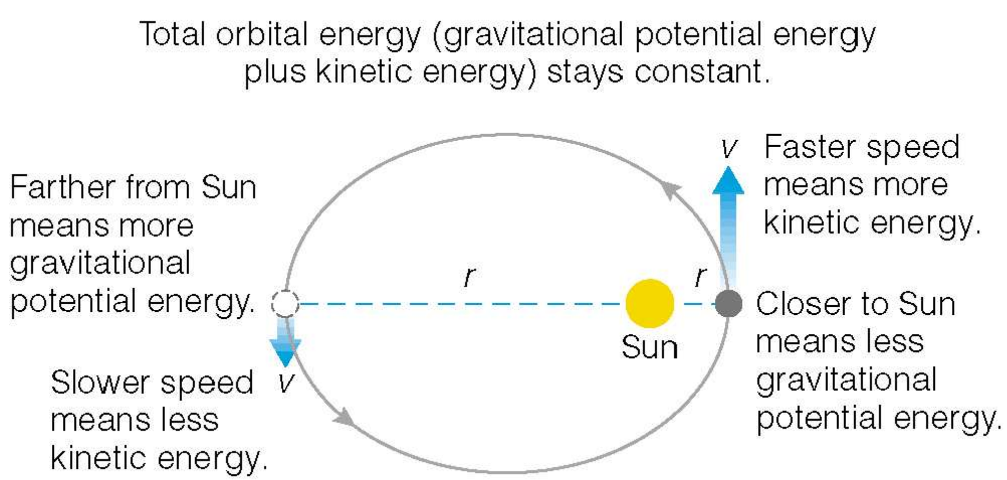
Examples:

- Calculate the mass of the Sun from Earth's orbital period and average distance.
- Calculate the mass of Earth from orbital period and distance of a satellite.
- Calculate the mass of Jupiter from orbital period and distance of one of its moons.

What else can we learn from Conservation Laws?

- Orbits cannot change spontaneously *(would orbit continuously)*
- An object's orbit can only change if it somehow gains or loses orbital energy =

  kinetic energy + gravitational potential energy

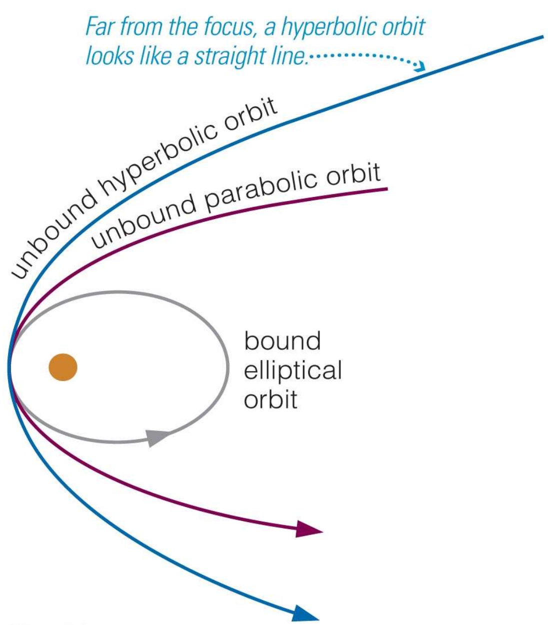


How does Newton's law of gravity extend Kepler's laws?

Kepler's first two laws apply to all orbiting objects, not just planets.

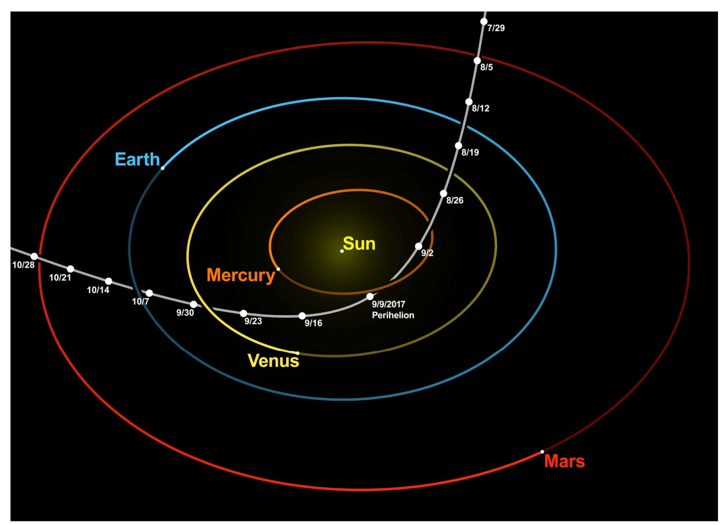
Ellipses are not the only orbital paths. Orbits can be:

- bound orbits (ellipses)
- Unbound orbits
    - parabola
    - hyperbola



An Interstellar Visitor:

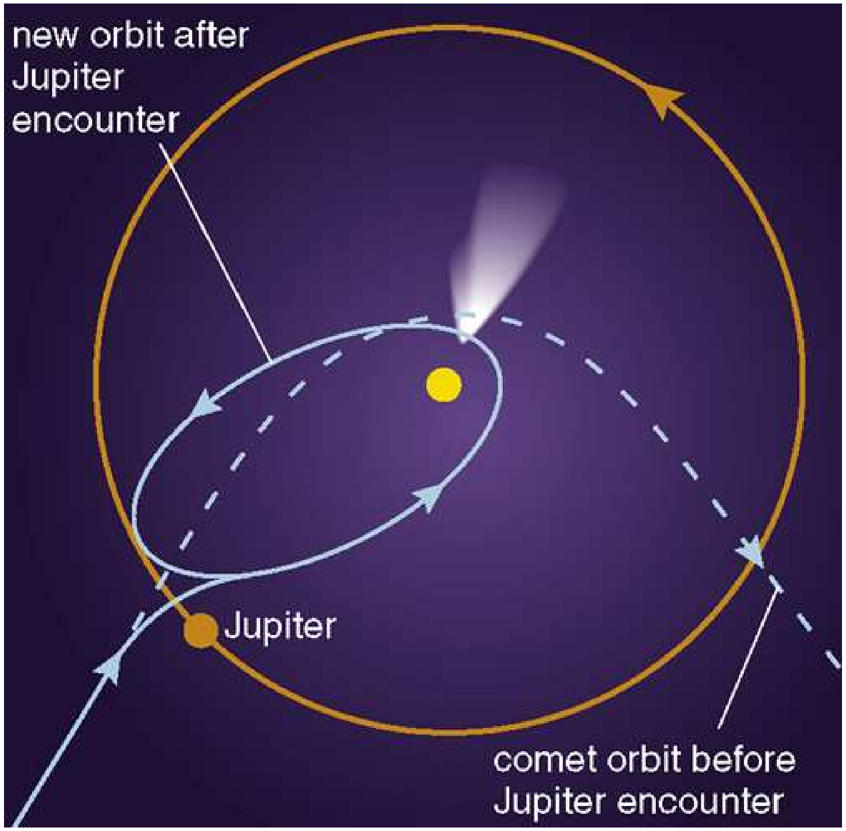
- ‘Oumuamua was found on an unbound hyperbolic trajectory on 19th Oct 2017 *(it will not return to our Solar System)*



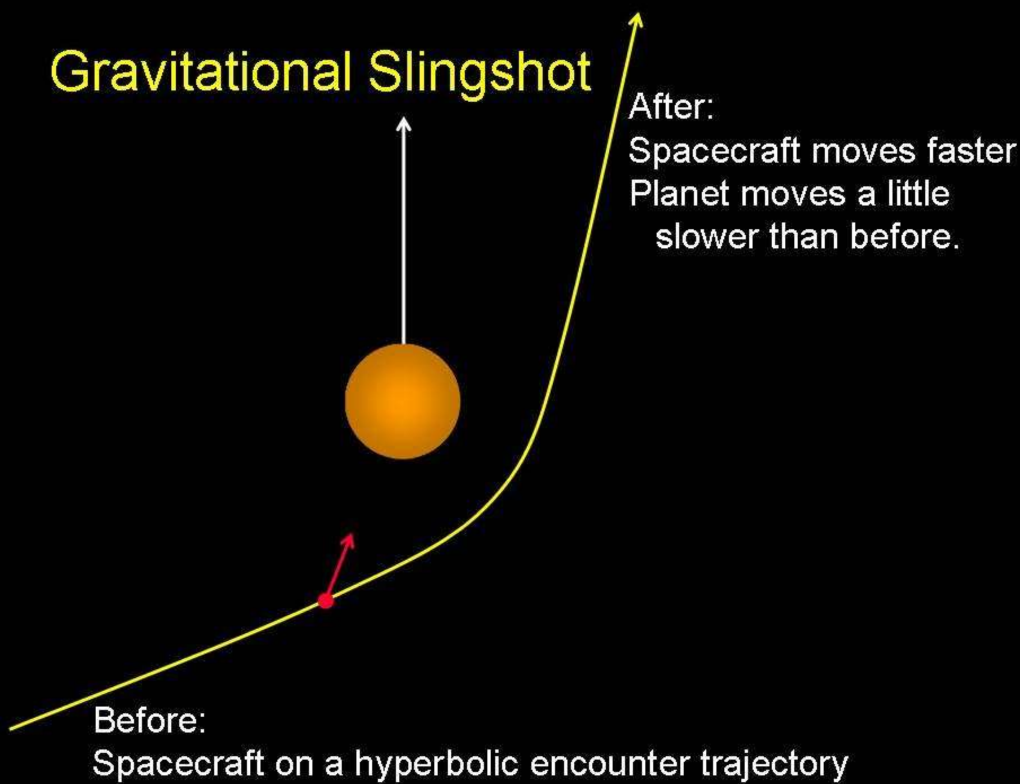
How Can you Change the Orbital Energy (or Path of an Object?)

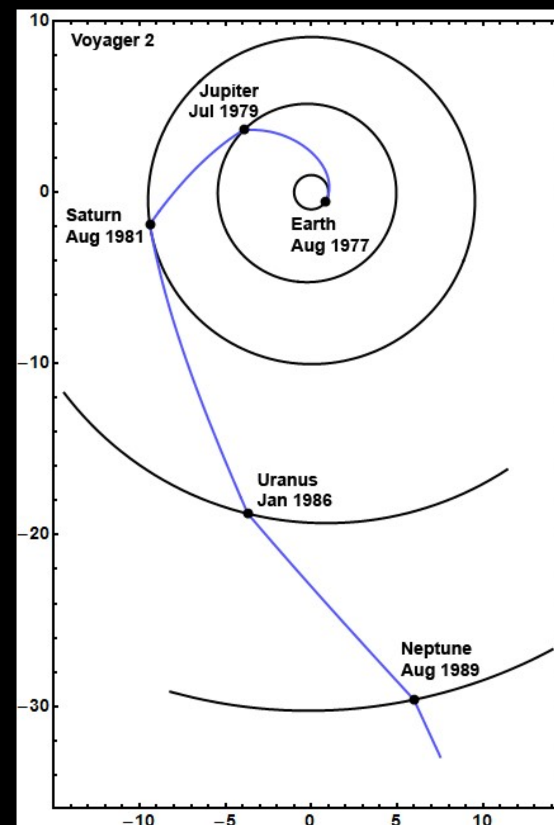
⇒ So what can make an object gain or lose orbital energy?

- Friction or atmospheric drag (satellites crashing)
- A gravitational encounter (e.g., with Jupiter)
  - Can help explain some captured moon (e.g., Triton at Neptune, Phobos/Deimos at Mars)
- Rockets…. By applying what is commonly known as 'delta-V' or ΔV



The Charm of Gravity Assists…

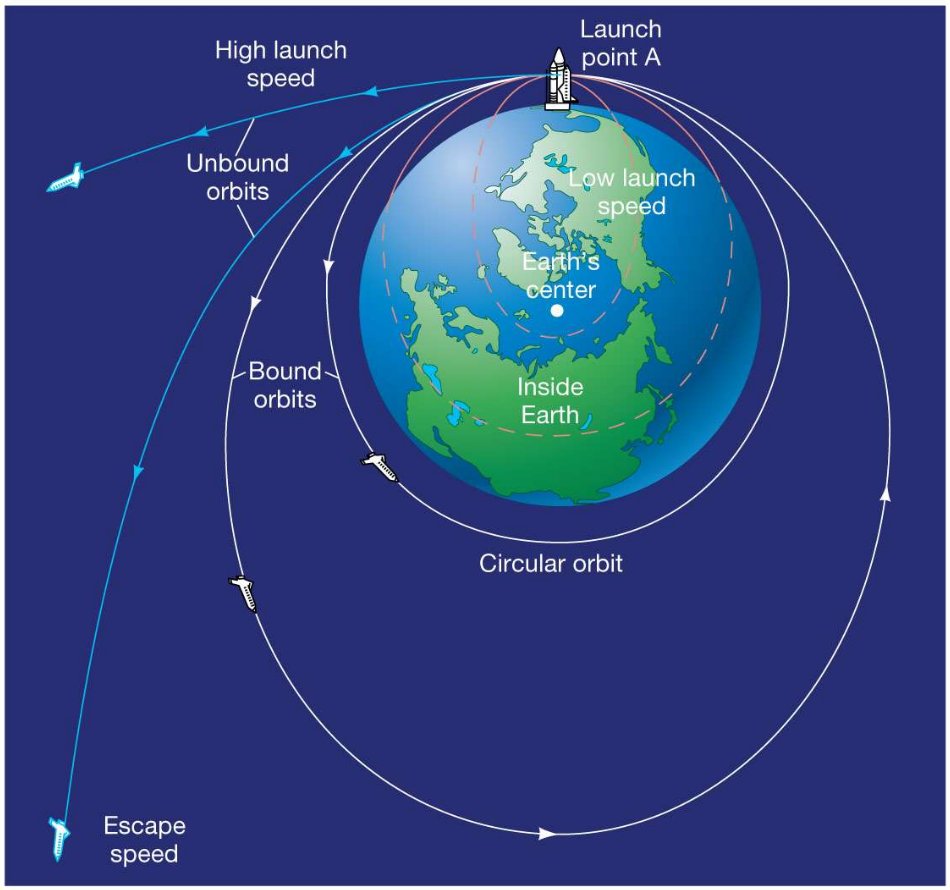




Voyager 2 used gravitational slingshots at Jupiter, Saturn and Uranus to get to Neptune

What is Escape Velocity?

Minimum velocity needed to break orbit – independent of mass – for Earth it is 11.2 km/s



Example 2 – Escape Velocity

Let's use the concept of gravitational potential energy and work out another classic problem: What initial velocity is required in order for the object to leave the Earth's orbit.

$\vec{R_i} = 6.378 \times 10^6 m$

$M_E = 5.972 \times 10^{24} kg$

Using conservation of energy we know that:

$$K_i + U_i = K_f + U_f$$

$$K_i + U_i = \quad U_f$$

We also know that the potential energy due to gravity takes the form:

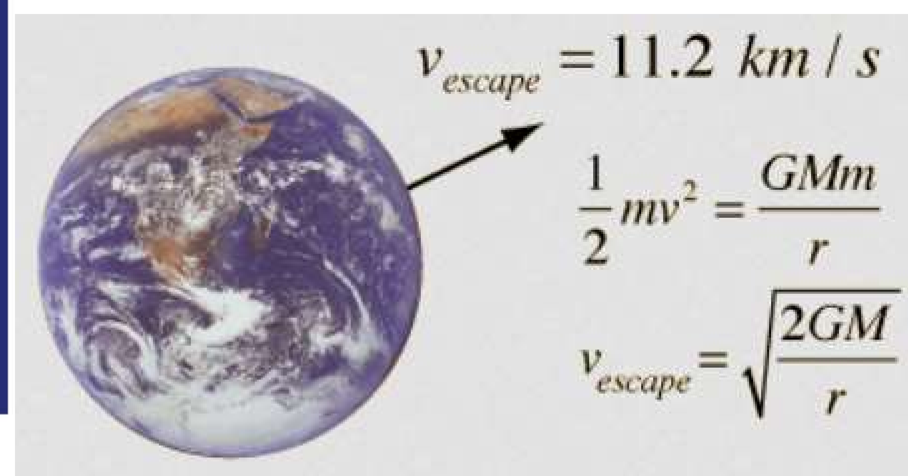
$$U_{gravity} = -\frac{Gm_1M_2}{R}$$

Substituting everything in:

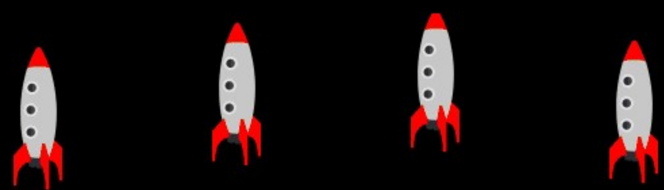
$$\frac{1}{2}m_1v_i^2 - \frac{Gm_1M_E}{R_i} = -\frac{Gm_1M_E}{R_f}$$

$R_f = \infty$ when the object has escaped the Earth's gravity.

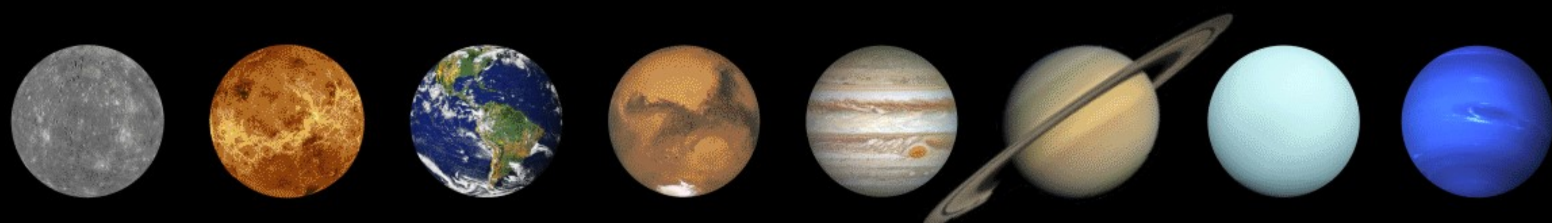
$$\frac{1}{2}m_1v_i^2 = -\frac{Gm_1M_E}{\infty} + \frac{Gm_1M_E}{R_i}$$



How fast a rocket would have to go to leave every planet



Rockets are Mostly (90%) Fuel!

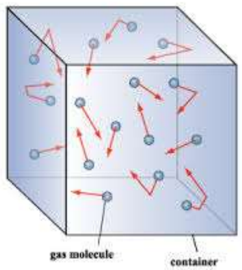


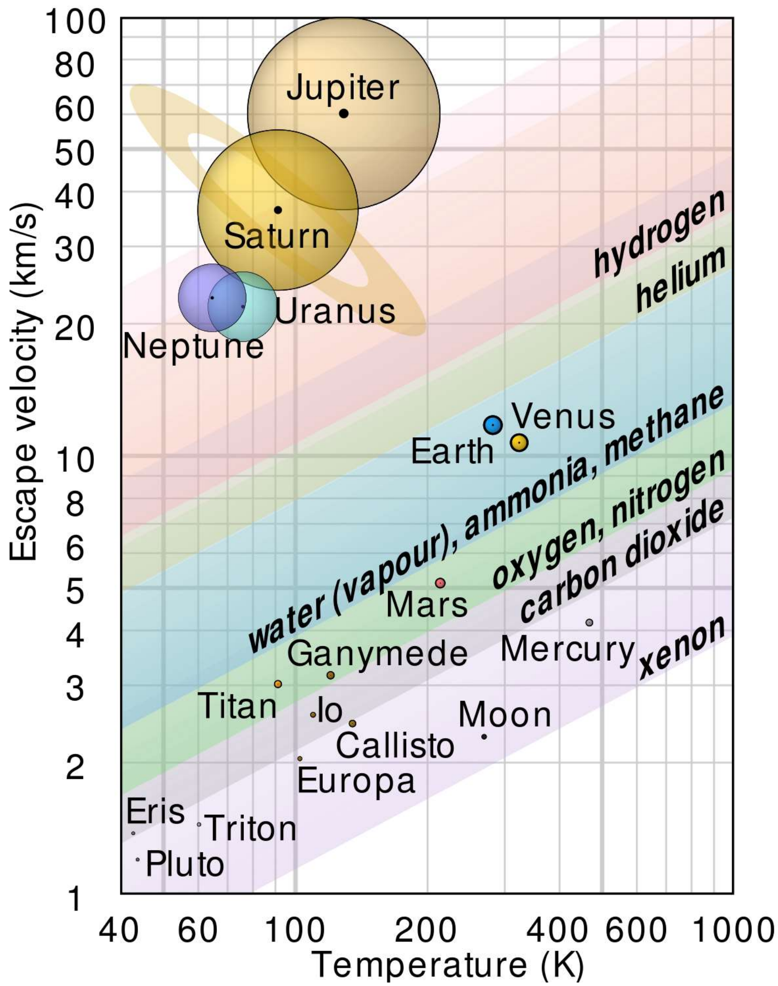
Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
9,507 mph	23,175 mph	25,031 mph	11,252 mph	134,664 mph	80,731 mph	47,826 mph	52,702 mph

SOURCE: NASA

TECH INSIDER

Escape Velocity and Thermal Energy

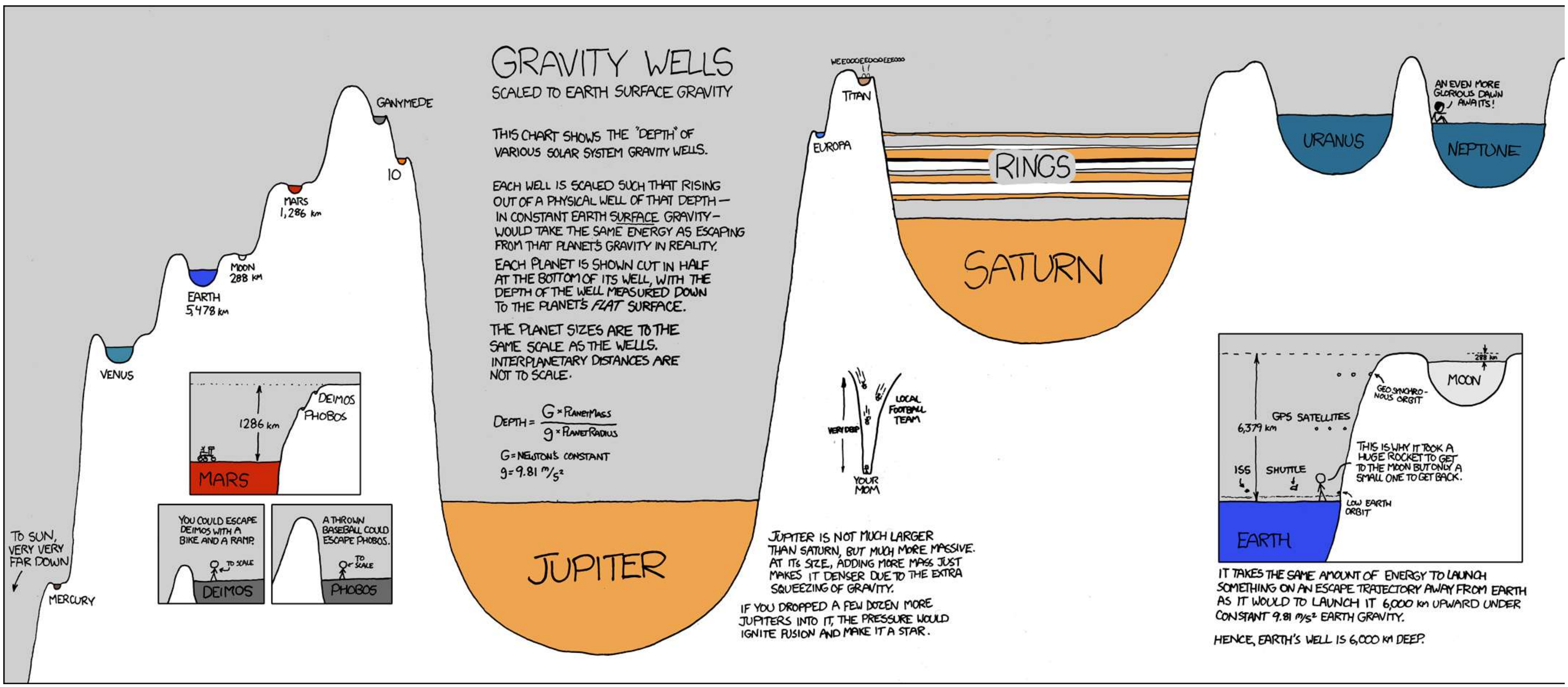




- Kinetic Energy = ½ mv^2
- For the same temperature, lighter atoms have more kinetic energy.
- A higher fraction will have sufficient velocity to escape the planets gravity for smaller atoms, and/or higher temperatures.

Gravity Wells *(Not Tested Material)*

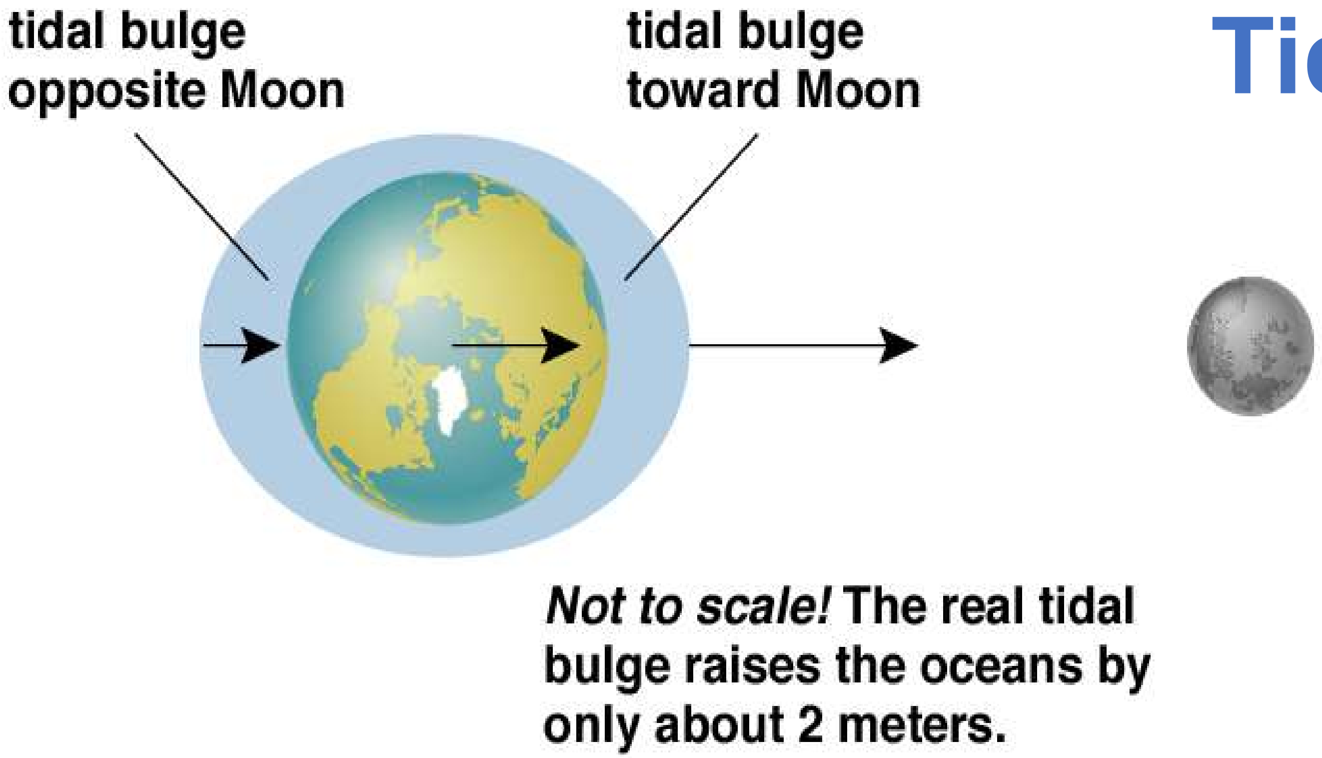
https://xkcd.com/681/



Tides

- **Every place on Earth passes through high tides twice per day as the Earth rotates.**
- **High tides occur every 12 hours 25 minutes**
  - **remember, the Moon moves!**
- **The Sun's tidal effect on Earth is not as strong. Remember the inverse square law….the Sun is a long way away.**

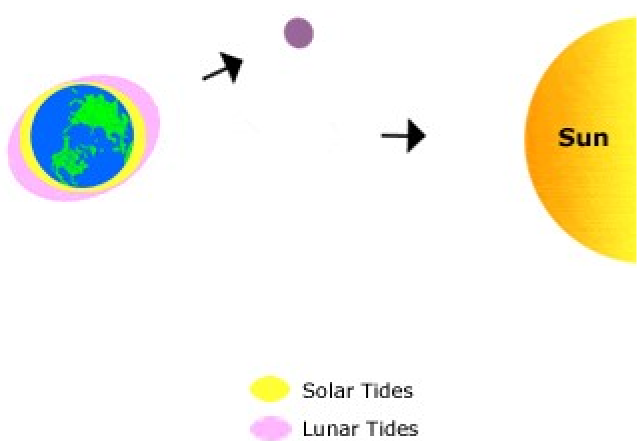
Tides



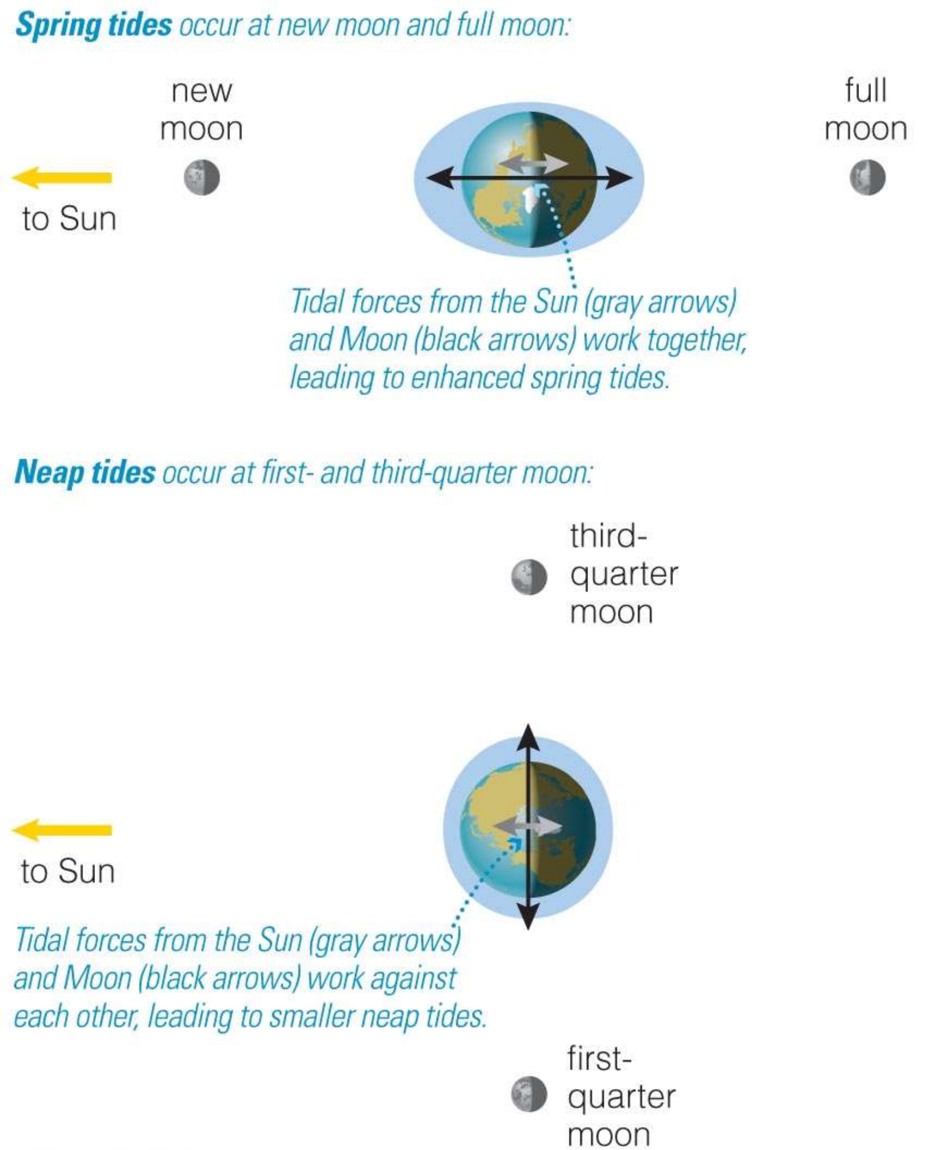
- Gravitational force decreases with $(\text{distance})^2$
  - The Moon’s pull on Earth is strongest on the side facing the Moon, and weakest on the opposite side.
- The Earth gets stretched along the Earth-Moon line.
- The oceans rise relative to land at these points.

Tides and Phases

Size of tides depends on the phase (relative position) of the Moon.



https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html



End of Todays Lecture