Gravity and Forces

Sept 9, 2002

1) Review
2) Kepler's Laws
3) Newton's Laws
4) Gravity
5) Examples

Review

- Lots of motion
- The Moon revolves around the Earth
- Eclipses
  - Solar
  - Lunar
  - the Sun, Earth and Moon must all be in a line
- Did you know that all this motion and tilting was happening?

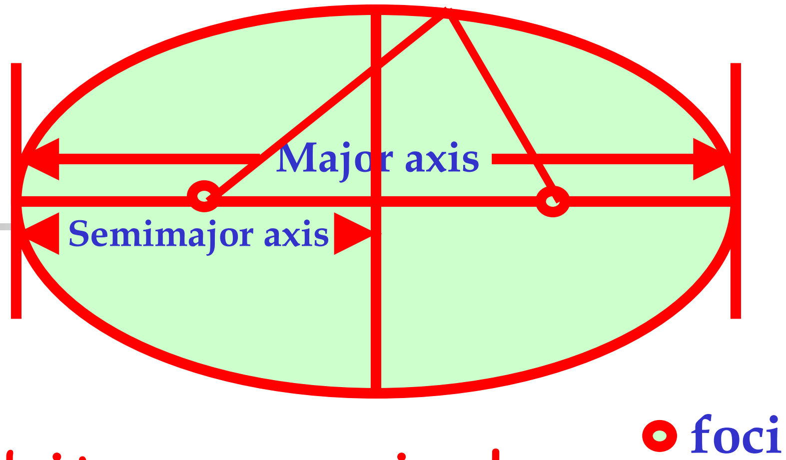
Nicholas Copernicus

- Early people believed the Earth was the center of the Universe and that the Sun, Moon, stars and other celestial bodies revolved around the Earth
- Nicholas Copernicus (1473-1543) was the first recorded person to suggest the Earth revolved around the Sun
  - He suggested the planets went around in circles
  - didn't publish this until the year he died
- Not readily accepted

Brahe and Kepler

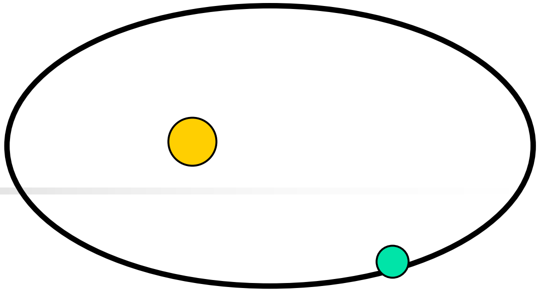
- Tycho Brahe (1546-1601)
  - Brahe spent decades observing and recording the positions of the planets in the sky
- Johannes Kepler (1571-1630)
  - Compared the data from Brahe to Copernicus' theory of planets revolving around the Sun in circular orbits
  - The data did NOT support this theory
    - What does the scientific method say we should do?

Ellipses



- Kepler began by assuming orbits were circles, but that didn't work so he tried ellipses
- An ellipses is a flattened out circle
  - *eccentricity* is a measure of how flat it is
- For a circle, the distance from the center is constant, eccentricity = 0
- For an ellipse, the distance from one focal point to the edge to the other focal point is constant
- An ellipse can be defined by its semimajor axis and its eccentricity

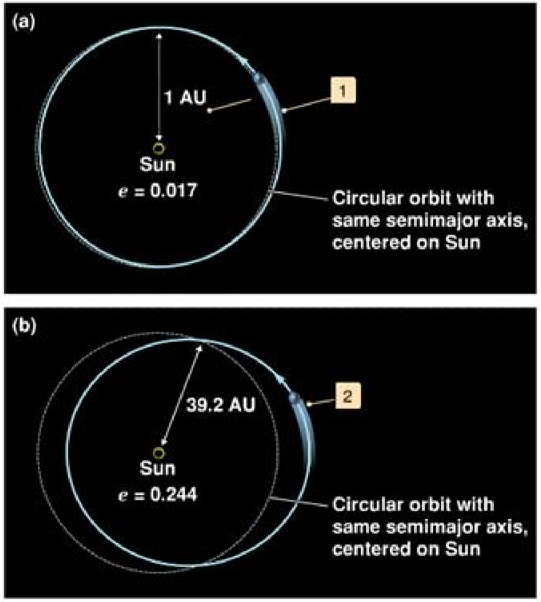
Kepler's First Law



- Kepler's First Law of planetary motion

Planets move in orbits which are ellipses with the Sun at one of the focal points

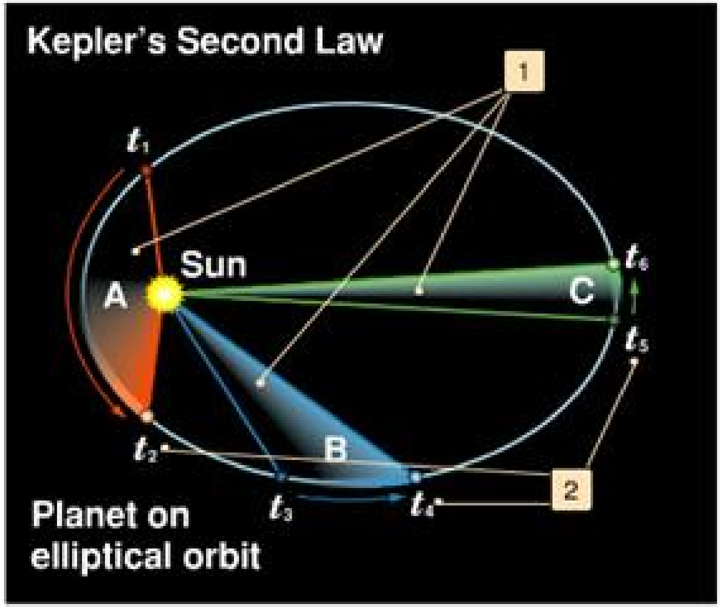
- This is an empirical theory
  - it doesn't explain why
  - but, it matched the data
- Earth has a fairly circular orbit
  - Earth's eccentricity = 0.017
- Pluto has a more elliptical orbit
  - Pluto's eccentricity = 0.224



Kepler's Second Law

Planets sweep out equal areas in equal times

- Planets move fastest when they are closest to the Sun
- They move slowest when they are farthest from the Sun



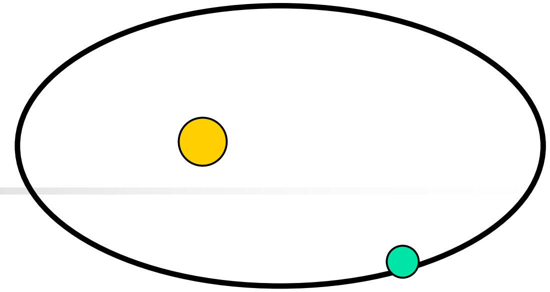
Kepler's Third Law

The square of a planet's orbital period equals the cube of the orbit's semi-major axis

$$(P_{years})^2 = (A_{AU})^3$$

- Orbital period = time the planet takes to go around the Sun once
  - measured in years
- Length of semi-major axis of orbital ellipse
  - measured in astronomical units (AU)

But WHY???



- Kepler's Laws
  - do an excellent job of describing the motion of the planets
  - but they don't tell us why the planets do this
- Science tries to learn how and why
- Two great scientists helped answer these questions
  - Galileo Galilei (1564-1642)
  - Sir Isaac Newton (1642-1723)
- Newton's Laws of Motion

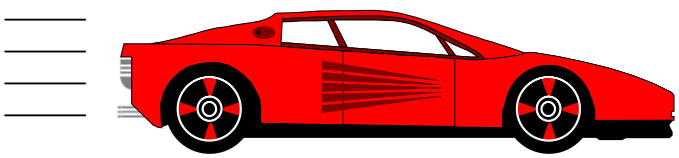
Newton's First Law

An object at rest will stay at rest,
an object in motion will remain in motion

- …unless an unbalanced force acts upon it
- The first part seems obvious
  - you stay in your seat unless you make yourself get up or someone/something pushes you
  - you do not go mysteriously flying out of your seat
- The second part seems less obvious
  - you are used to an object sliding across the floor and slowing down
  - but it really does want to keep moving
- Now we need some definitions…

Definitions

- Distance (m) and Time (s)
- Speed (m/s)
  - how fast you are moving
- Velocity (m/s)
  - speed + direction
- Acceleration (m/s^2)
  - how quickly your velocity is changing
- Mass (kg)
  - a measure of how much matter an object has
  - different than weight, but related
- Inertia
  - the amount an object resists changes in motion



Newton's Second Law

An unbalanced force will change an object's motion

- The change in motion (acceleration) will be proportional to the amount of force
  - the harder you push the more the motion will change
  - the harder you push the greater the acceleration

F=ma

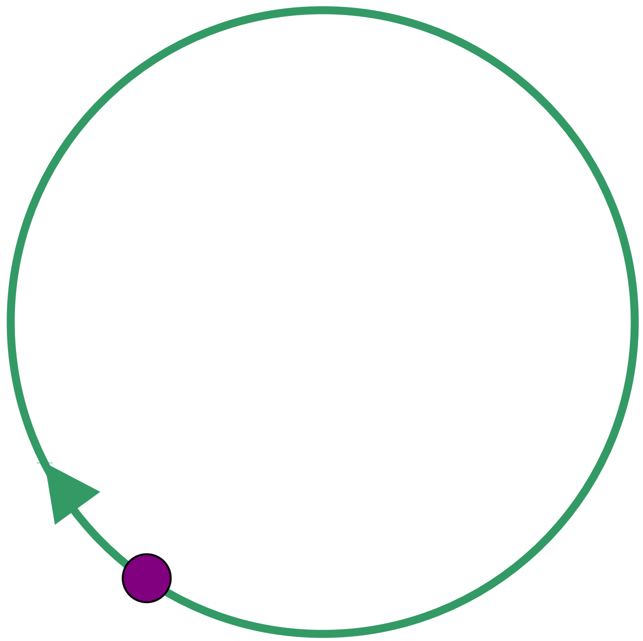
$$a = \frac{F}{m}$$

Newton's Third Law

For every action there is
an equal and opposite reaction

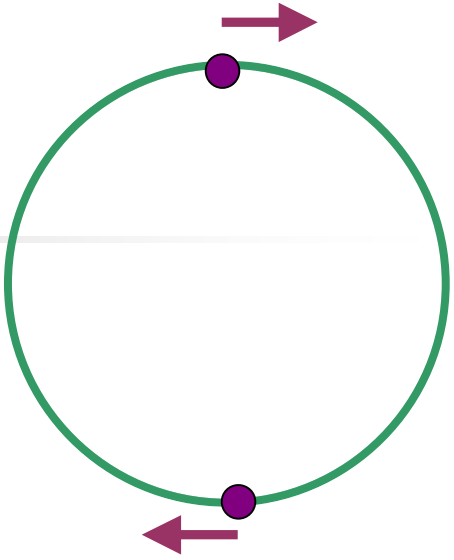
- Not intuitively obvious
- Examples,
  - two carts
  - baseball hitting a bat or tennis ball hitting a racket
  - Earth pulls on the Moon, Moon pulls on the Earth
  - Space Shuttle launch
    - gas goes one way, Shuttle the other

Circular Motion



Does a ball traveling around a circle with constant speed feel an acceleration?

Circular Motion (cont)

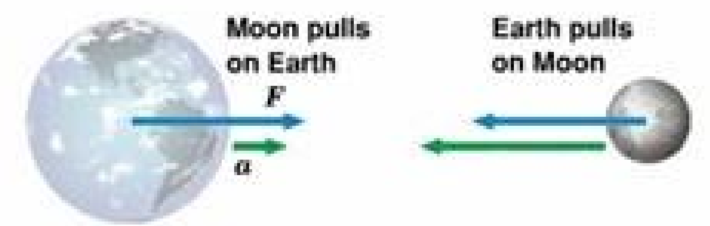


- YES, a ball moving in a circle is always accelerating
- Consider,
  - at the top of the circle the ball is moving to the right
  - at the bottom of the circle the ball is moving to the left
  - in a short time, the ball completely switches direction, there must be an acceleration
- The speed may not be changing, but the direction is
  - remember, velocity is speed and direction
- The acceleration is inward (towards the center of the circle) at all points on the circle
- This is the way planets move around the Sun

Gravity

- All objects with mass feel an attraction to each other due to gravity
  - So if you've been strangely attracted to someone sitting next to you, this may be why
- Gravity is the force which…
  - holds us to the Earth
  - causes a rock to fall towards the ground
  - causes the Earth to go around the Sun
  - causes the Sun to be pulled towards the center of the Milky Way galaxy, and much more
- Gravity acts without the objects needing to touch
  - "action at a distance"

Gravity (cont)

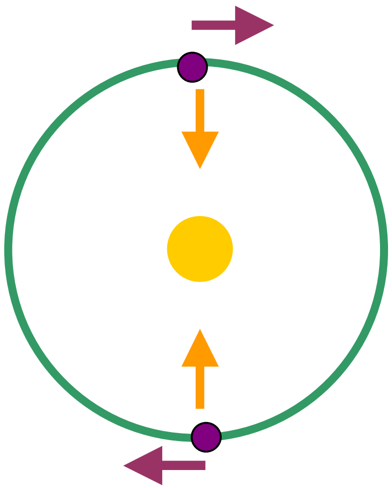


- Gravity acts between 2 objects
- The amount of force depends on
  - the mass of the 2 objects
    - the heavier the masses, the greater the force
  - the distance between the 2 objects
    - the closer together, the greater the force
  - a constant of Nature

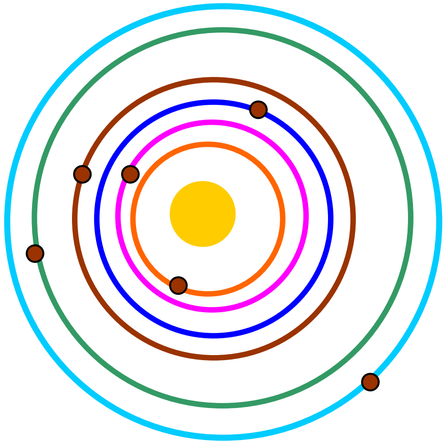
$$F = G\frac{M_1 M_2}{r^2}$$

- Important – BOTH objects feel this force and are attracted to each other
  - the Moon is pulled towards the Earth and the Earth is pulled towards the Moon

Gravity and Orbits



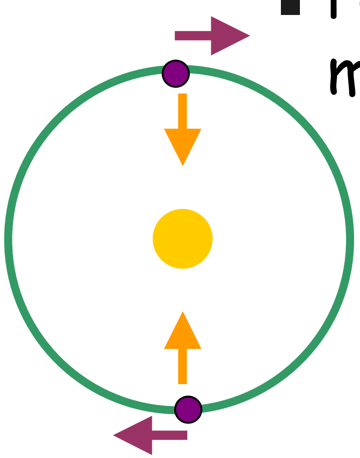
- Gravity provides the force which causes the planets to orbit the Sun
- The planets want to fly off into space (Newton's First Law)
- But gravity pulls them towards the Sun and changes their direction



- It's even more complicated because the planets pull on each other which causes variations in the orbits

Why doesn’t the Earth Fall Into the Sun?

- In fact, it does fall into the Sun every moment of every day
  - in order for the Earth is revolve around the Sun, it needs the Sun to pull it inward
  - if the Sun didn’t pull the Earth inward, it would go flying off into space
    - remember an object in motion wants to continue in motion along the same straight path it is going



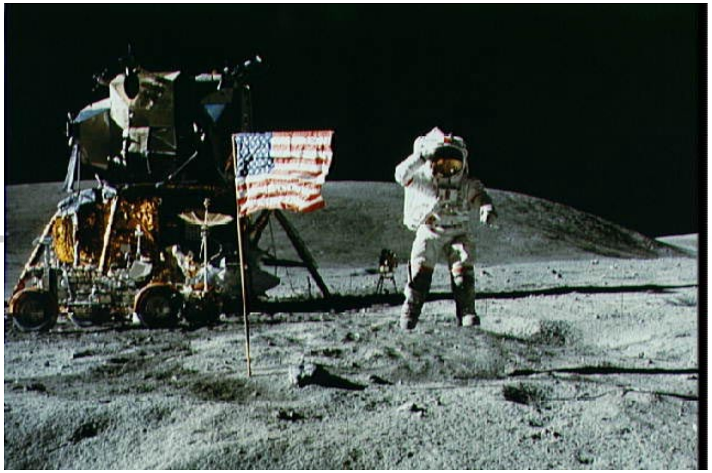
Measuring the Mass of the Earth

- From Newton, we know F=ma and $F = G\frac{M_1 M_2}{r^2}$
- We also know
  - All objects are accelerated towards the Earth at the same rate ($a = 9.80\ m/s^2$), from Galileo
  - $G = 6.67\times10^{-11}\ Nm^2/kg^2$ from laboratory measurements
  - The radius of the Earth is $r = 6.38\times10^6$ m, from measuring the curvature of the Earth
  - $m = M_1$ = mass of an object on the Earth
  - $M_2 = M_e$ = mass of the Earth
- From this we measure the mass of the Earth to be 5.98×10^{24} kg
  - Pretty heavy, imagine how big of a bathroom scale you would need!

$$ma = G\frac{m M_e}{r^2}$$

$$M_e = \frac{a r^2}{G}$$

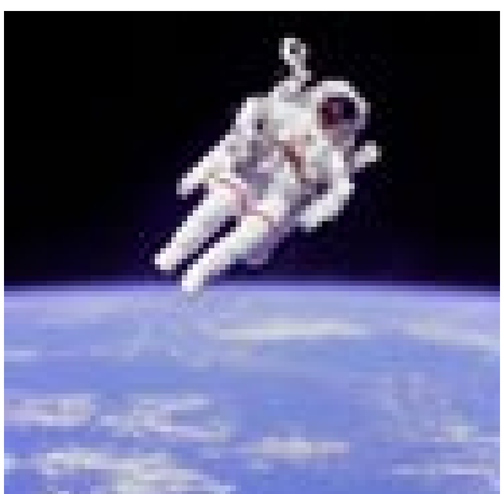
Weight



- Weight is a measure of how much an object is attracted to the Earth
  - it is really a measure of the gravitational force
- But if you travel to the Moon, your weight will decrease
  - this is because the Moon has less mass than the Earth and exerts a smaller force on you
  - the same is true if you go to another planet, although if the planet has more mass you will weigh more
- But in these cases your <u>mass</u> stays the same

"Weightlessness" in Orbit

- Astronauts in the Space Shuttle or International Space Station (ISS) appear to be weightless
  - but they are still within the Earth's gravitational pull
- They appear weightless because they (along with the shuttle or ISS) are in orbit
- They are "falling" to the Earth all the time, but this is just keeping them in orbit



Summary

- Kepler discovered empirical laws which described the motion of the planets, but didn't explain them
- Newton developed 3 laws of Nature which describe how the planets behave as well as how things on Earth act
- Gravity is the attraction of 2 objects with mass
  - it is responsible for the "ballet" of motion throughout the Universe