

Astronomy 1

* Newton's First Law

- a body in motion stays in motion unless acted upon and a body at rest... in a straight line at the same speed (The Law of Inertia)
- inertia - tendency for an object to keep doing what it is doing
- also pertains to planets + moons
- inertia $\propto$ mass
- mass & weight are not the same thing
- weight depends on mass & gravity
- mass does not depend on gravity
- we use pounds for weight, mass is kilograms
- we measure force in newtons or mg
- in our system, we use slug for mass
- $2.2 \text{ lbs} = 1 \text{ kg}$
- weight on Moon = $\frac{1}{6}$ of Earth

* Newton's Second Law

- $F = ma$
- acceleration $\neq$ velocity $\neq$ speed
- velocity has direction
- acceleration is a change in velocity per second
- acceleration can be change of speed, direction, or both
- change in direction is acceleration
- circular motion at the same speed is acceleration
- Units
- velocity - $\frac{m}{s}$, $\frac{ft}{s}$, $\frac{miles}{hr}$, $\frac{yds}{yr}$ - distance per time
- acceleration - $\frac{m}{s^2}$, $\frac{ft}{s^2}$, $\frac{miles}{hr/sec}$ - distance per time squared
- $0 \rightarrow 60$ in 10 sec 6 mi/hr/sec

* Newton's Third Law

- every action has an equal & opposite reaction
- $F_1 = F_2$
- the Earth pulls on the sun as much as sun pulls on us

- mass of m_n is 330,000 times that of Earth
- acceleration of Earth = 330,000 acceleration of sun
- $A_\odot$ - sun
- $A_\oplus$ - earth
- * Newton's Law of Universal Gravitation (The Fourth Law)
- describes gravitational force between two objects
- $F_{\text{gravity}} = \frac{G m_1 \cdot m_2}{r^2}$ (r is distance)
- G is gravitational constant - 6.67×10^{-11}
- gravity's force increases linearly with mass
- if r goes to $2r$, then F_g goes to $1/4$
- as r increases, F_g decreases by $\sqrt{r}$
- when dealing with a spherical object, mass acts as if it was centered

- F on Earth vs. Moon

$$F_\oplus = \frac{G M_\oplus M_p}{R^2} \quad / \quad F_{\text{moon}} = \frac{G M_{\text{moon}} M_p}{R^2}$$

$$F_\oplus = M_\oplus / R^2$$

$$F_{\text{moon}} = M_{\text{moon}} / R^2$$

$$M_\oplus / R_\oplus^2 \cdot \frac{R_m^2}{M_m}$$

$$\frac{F_\oplus}{F_m} = 81 \cdot \left(\frac{1}{3.7}\right)^2 = 6$$

* Newton's Revision of Kepler's Law

- $p^2 = a^3$ - original equation
- works for all objects orbit our sun in our solar system
- Newton Revised the law to work for anything in universe
- $(M_1 + M_2) \cdot p^2 = a^3$
- mass has to be in solar mass
- solar mass = 2×10^{30} kg (mass of sun)
- within our solar system, the equation can be reduced back
- used to find mass of astronomical objects by measuring their gravitational pull

* Mass of Saturn

- Titan is the largest moon of Saturn
- its period is 15.945 days
- $a = 1,200,000 \text{ km}$
- converted to years = 0.04365 years
- converted to AU = 0.00816 AU
- $M_1 + M_2 = \frac{a^3}{P^2}$
- $M_1 + M_2 = \frac{0.00816^3}{0.04365^2} \text{ solar mass}$
- $M_1 + M_2 = \frac{1}{3500} \text{ solar mass}$
- since Titan would not affect, drop it
- mass of Saturn = $\frac{1}{3500}$ of sun's mass
- works for everyone but Venus & Mercury because they don't have moons

Quiz 3

* Newton's Law

- first law - inertia
- second law - $F = ma$
- third law - $F_1 = F_2$
- fourth law - $F = G \frac{m_1 m_2}{R^2}$

* Orbital Motion

- earth changes direction, therefore accelerates
- gravity acts over a distance and can travel through vacuum
- gravity is continuous and doesn't stop acting
- if object's trajectory equals curvature of earth, it goes into orbit
- orbital motion is falling motion, but it has enough inertia to never reach Earth because it misses
- In orbit, objects always accelerate toward center

* Weightlessness

- 0g or weightless
- terms are not correct
- they feel gravity of Earth and so does space station
- both are in motion and move at same rate (accelerate down)
- a scale would read 0 because the person and scale are moving at same rate, so no force is applied to scale
- no net acceleration between them
- a better term is freefall, both fall at same rate
- they appear weightless relative to their surroundings

* Escape Velocity

- $V^2 = G \frac{M}{R}$
- V is orbital circle
- M is mass
- R is radius from center
- escape velocity is the minimum velocity you can have it escape into orbit
- for surface of Earth is $11.2 \frac{\text{km}}{\text{s}}$ or $25,000 \frac{\text{mi}}{\text{h}}$
(neglect air resistance)

- $V_{esc}^2 = 2 \frac{GM}{R}$ or $V_{esc} = \sqrt{2} V_{circular\ orbit}$
- this equation is for how to escape orbit
- a larger planet is easier to escape from (larger with respect to radius)
- escape velocity determines how fast an atmosphere of planet leaks into space
- more massive planets hold atmosphere better
- of two planets, one with smaller radius will hold more atmosphere if mass was same
- a colder atmosphere is retained better
- temperature of gas measures how fast molecules move
- hotter gases have faster velocities
- if it is between the two, you get an elliptical orbit

* Units of Energy

- velocity - m/s , $\frac{km}{h}$, mi/h
- acceleration - m/s^2 , km/s^2 , $mi/h/s$
- mass - kg , g , slug, solar mass,
- force - newtons, pounds
- energy - joules, calorie, Calorie
- Calorie = 1000 calories
- calorie = amount of energy needed to heat 1 g of water at STP $1^\circ C$
- joule = $\frac{1}{4}$ calorie
- power - watt (rate that energy is produced) $power = \frac{energy}{time}$
- watt = $\frac{joule}{second}$
- on electric bill, it shows kilowatt-hours
- energy = power $\cdot$ time
- kWh = energy produced a 1000-watt lightbulb in hour
- kWh = 900 Calories
- units are important!

* Units of Energy

- joule, kilocalorie, calorie, Calorie, kilowatt-hour

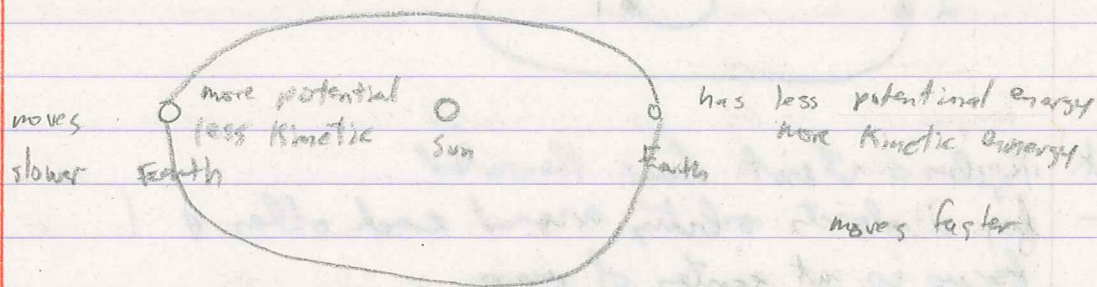
* Temperature Scales

- Temperature is how fast particles move around
- measures energy of substance (of motion)
- temperature not proportional to energy
- Kelvin, Fahrenheit, Celsius or Centigrade
- Fahrenheit - boiling is 212° freezing 32°
- Celsius - 100° 0°
- Kelvin - 373 K 273 K
- to convert Fahrenheit to Celsius - subtract 32 & times by $\frac{5}{9}$
- $^{\circ}\text{C} = \frac{5}{9} (F^{\circ} - 32)$
- $\text{K} = ^{\circ}\text{C} + 273$
- 0 K is absolute zero, -273°C or -459°F
- absolute zero mean all molecules stop moving entirely
- no negative temperatures on Kelvin
- Kelvin is used commonly in science

* Types of Energy (Three)

- energy of motion - kinetic
- potential energy - stored energy that could be converted to kinetic
- gravitational potential energy - objects high in gravity, has grav. potential energy
- chemical potential energy - energy stored in chemical bonds
- radiative energy - energy carried by light
- all can be converted from one type to another
- energy cannot be created or destroyed
- Conservation of Energy
- if no friction, rock would go back to the top
- the energy of friction turns into heat
- heat is kinetic energy

* Kepler's 2nd Law Revised



- his law is the consequence of energy conservation
- it happens because of $\uparrow$

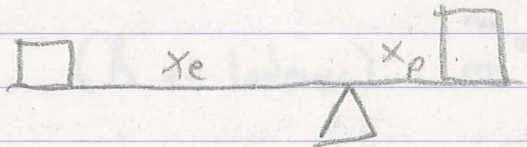
* Kepler's 3rd Law Revised

- $p^2 = a^3$ for objects orbiting our sun
- more general $(M_1 + M_2) p^2 = a^3$
- if can't where masses are near, don't leave out

- to get both masses, use center of mass

* Center of Mass

- where the mass acts, the balance point of system
- set like a seesaw
- pivot point is closer to object with more mass
- if Peter was 3x mass of Ellie:

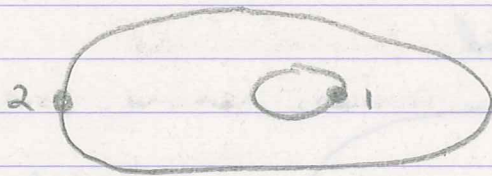


- $X_e = 3(X_p)$
- $M_1 X_1 = M_2 X_2$
- X is distance to center of mass



$$M_1 > M_2$$





* Kepler's First Law Revisited

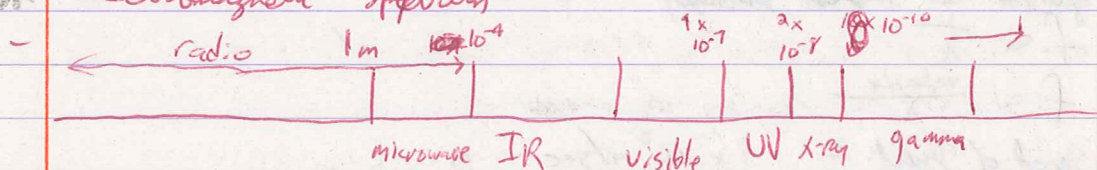
- for 2 objects orbiting around each other & 1 focus is at center of mass
- when $M_1 \gg M_2$, then sun is very close to both foci

* Chapter 3 - Light

- electromagnetic radiation
- light carries alot of info
- ordinary white light can be broken down
- ROY G BIV
- sequence of wavelengths
- light is a wave
- wavelength = distance between crests
- λ is wavelength
- red = 7×10^{-7} m
- blue = 4×10^{-7} m
- violet = 3.8×10^{-7} m
- an Angstrom = 10^{-10} m (symbol is Å)
- red is 7000 Å
- blue is 4000 Å
- light is a wave that can travel through vacuum
- sound needs a medium, cannot go through vacuum
- light is electric and magnetic
- light can carry energy & can act like a particle
- photon - light particle
- called wave-particle duality of light
- has 0 mass
- photon is a package of energy
- particle with wavelength associated

- visible light is only one type of light
- ultraviolet, infrared, radio, gamma, x-ray, microwaves
- all light with different λ

* Electromagnetic Spectrum



- William Herschel detected IR with a thermometer
- UV was discovered in 1801 by Johann Ritter by using silver chloride with a prism
- microwaves are radio waves
- Percy Lebaron Spencer - 1945 - microwave ovens
- he was working on radar
- amount of energy carried light increases when λ decreases
- UV can kill bacteria
- radio has lowest energy
- cell phones can't hurt you
- in theory, spectrum goes on forever
- AM + FM
- AM - 180m to 300m λ
- FM - 2.5m to 3.5m λ

* Frequency of light

- how many waves pass per amount of time
- smaller wavelength larger frequency
- $c = \lambda \nu$
- $f \propto \frac{1}{\lambda}$

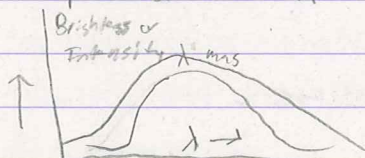
Quiz 3

* Light

- electromagnetic radiation
- radio has long wavelength
- gamma rays have shortest wavelength
- gamma has highest energy
- $f \propto \frac{1}{\lambda}$
- $f = \frac{\text{velocity}}{\lambda}$
- Speed of light = $3 \times 10^8 \text{ m/sec}$ or c
- Blue light $\lambda = 4 \times 10^{-7} \text{ m}$ or $4000 \text{ \AA}$
- $1 \text{ \AA} = 10^{-10} \text{ m}$
- frequency is measured in hertz (hz)
- 89.5 FM - MHz
- $8.95 \times 10^7 \text{ hz}$
- $\lambda = \frac{3 \times 10^8 \text{ m/s}}{9 \times 10^7 \text{ Hz}}$ $\lambda = \frac{1}{3} \times 10$ $\lambda = 3.3 \text{ m}$

* Thermal Radiation

- any object not at absolute zero radiates light
- hot solid, dense gas $\rightarrow$ thermal radiation (blackbody radiation)
- The hotter the object, the shorter the λ of light we see
- temperature $\propto \frac{1}{\lambda}$

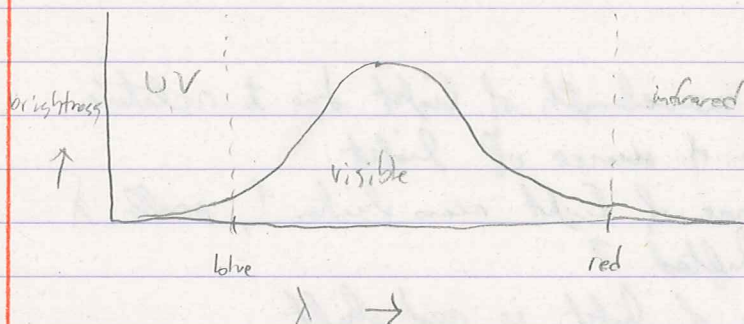


not symmetric
moves $\uparrow$ with more brightness

- thermal spectrum $\uparrow$
- temperature $\propto \lambda_{\text{max}}$

* Wien's Law

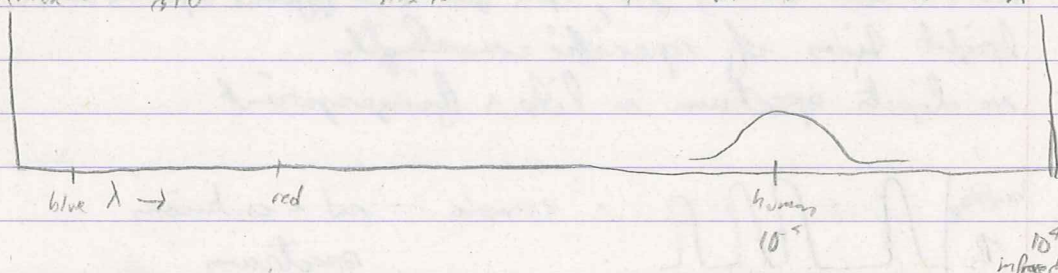
- $\lambda_{\text{max}} = 0.0029 / \text{temperature}$
- T is in Kelvin
- 0.0029 is constant
- λ_{max} is in meters
- sun - 5800 K. for surface or photosphere
- $\lambda_{\text{max}} = \frac{0.0029}{5800} = \frac{2.9 \times 10^{-3}}{5.8 \times 10^3} = 0.5 \times 10^{-6} \text{ m}$ or $5 \times 10^{-7} \text{ m}$
- that is a greenish-yellow



- a red star would be colder than our sun because it is red

- human - 98.6 F is 37°C & 310K

$$\lambda_{\text{max}} = \frac{0.0029}{310} = \frac{2.9 \times 10^{-3}}{3.1 \times 10^2} \approx 10^{-5} \text{ m or } 100 \times 10^{-7} \text{ m}$$



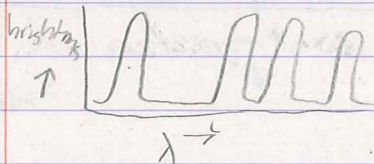
- long wavelength infrared
- total luminosity increases as temperature goes up
- luminosity - amount of energy per second or rate of energy production
- joules / second
- total amount emitted from all directions
- $L \propto T^4$
- small change in temperature means big luminosity change
- Stefan's law & Stefan-Boltzmann law
- luminosity $\neq$ brightness
- brightness is what we see, depends upon distance & distance of observer to object
- luminosity is all directions
- $B \propto \frac{L}{\text{distance}^2}$
- surface area of sphere = $4\pi r^2$

* Doppler Shift

- shift in observed wavelength of light due to relative motion of observer & source of light
- moving towards source of light means higher f , smaller λ
- called blue shifted λ
- moving away from source of light is red shift
- looking perpendicularly to star's velocity means no Doppler shift
- only measures radial motion, not transverse motion

* Low Density Gas - Emission Line Spectrum

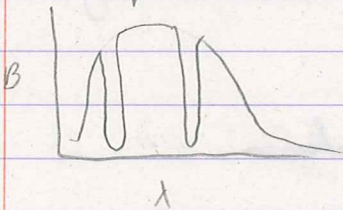
- with a low density gas, you get a different spectrum
- bright lines of specific wavelengths
- an object's spectrum is like a fingerprint



example - not a continuous spectrum

* Absorption Line Spectrum

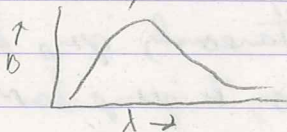
- a star produces this



light has been absorbed by atmosphere

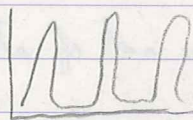
* Spectra (Kirchhoff's Laws)

- solid, hot dense gas



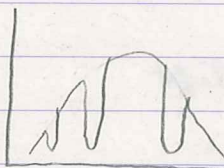
continuous

- low dense gas



emission line spectrum (bright-line)

- source of continuous light with low density gas in front



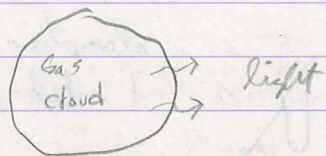
absorption line spectrum (dark-line spectrum)

- these are called Kirchhoff's Law
- empirical laws - what happens, but don't explain why

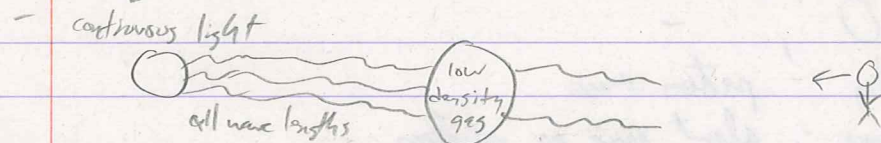
* Atoms

- proton, neutron, electrons
- $+$ 0 $-$
- 1.67×10^{-27} kg - proton mass
- neutron mass - about same as proton
- electron mass = $\frac{1}{2000}$ proton mass
- protons & neutrons in nucleus with electrons orbiting around
- atom is held by electromagnetic forces, not gravity
- electron can only orbit in certain specific orbits
- each orbit corresponds to different energies
- as you further away, energy goes up
- energy of electron of atom quantized only in certain specific values
- electrons can jump between energy levels
- electron gains energy from a photon (absorbing light) or if atoms collide together
- excitation - process of electron moving up in energy levels

- excited atom - atom with electron has moved up
- electron will spontaneously jump down to lower level
- to get rid of energy to jump down, electrons emit a photon of light
- sometimes it can jump out of atom's orbit if enough energy
- ionization $\rightarrow$
- an ion is an atom which has lost electrons



- an electron can only absorb a photon with enough energy to move up the level, not in between
- the spectral of the atom is shown by the fact that the electron can only emit a photon of a certain energy

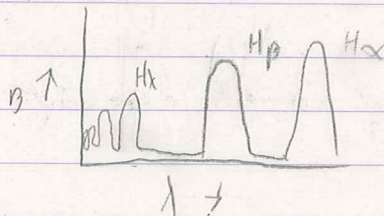


- only certain wavelengths are absorbed, this makes the dark line spectrum
- if you were looking at a 90° angle, you would see bright line spectrum of low density gas
- wavelength absorbed is wavelength emitted, but in a random direction, or could be a divisible (could be broken up into different but equal wavelengths)
- kinetic energy of motion could be converted into radiative energy
- different elements have different wavelengths they will absorb
- * Isotopes
- # of protons determines which chemical element
- 1 proton - hydrogen, 2 - helium

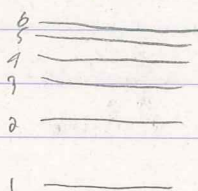
- periodic table shows elements in order by # of protons
- two atoms with same # of protons but different number of neutrons is called an isotope
- $6p$ $6n$ - carbon common form (Carbon-12)
- ^{12}C - 12 is atomic mass - number of protons + neutrons
- ^{14}C - $6p$ $8n$
- spectra of two isotopes are slightly different because of the difference of atomic mass
- an ion has a different spectrum of a neutral atom
- ionized atom - C^+ lost 1 electron
- C^{++} or C^{2+} doubly-ionized
- in astronomy - $\text{C}^0 = \text{CI}$
- $\text{C}^+ = \text{CII}$
- $\text{C}^{2+} = \text{CIII}$
- $\text{C}^{3+} = \text{CIV}$

* Hydrogen

- H^0 or H^+
- HI or HII
- red cloud of Horse Eye Nebula is Hydrogen
- hot stars emit UV rays & ionize the hydrogen
- the red light is when electrons come back to atoms
- this type of cloud is called HII region
- H common - $1p$ $0n$
- HII has $1p$ $1n$ - deuterium, or deuterion, or heavy hydrogen
- ^2H has twice mass of ^1H
- HIII has $1p$ $2n$ - tritium
- red line is H alpha
- blue line is H beta
- violet line is H gamma
- energy level



as you go up in energy for hydrogen, levels get closer



- $H\alpha$ is $3 \rightarrow 2$
- $H\beta$ is $4 \rightarrow 2$
- $H\gamma$ is $5 \rightarrow 2$
- $H\delta$ is $6 \rightarrow 2$
- this is called Balmer Series
- from $2 \rightarrow 1$, you get UV photon
- from $3 \rightarrow 1$, UV with more energy
- any level $\rightarrow 1$, UV
- $4 \rightarrow 3$, infrared because not alot of energy
- any high level $\rightarrow 3$, infrared
- $100 \rightarrow 99$, radio

* Refraction

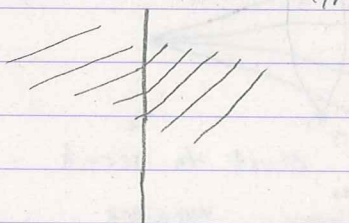
- process of bending light
- happens when light moves from a different medium & hits at an angle
- could be used to focus or separate light

* Atoms - Uncertainty Principle

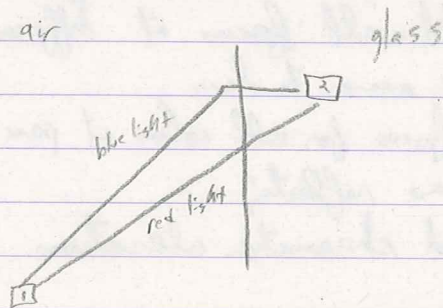
- atom as we know is called the Bohr Model
- incorporate Heisenberg uncertainty principle, which says you can never measure position & velocity of particle at same time; built in uncertainty
- energy levels have thickness, which means it could be a range of λ emitted
- the doppler shift also broadens the lines

* Refraction

- bending of light when it moves from one medium to another & it hits boundary at an angle
- different colors of light bend at different angles
- shorter λ bend more, longer λ bend less
- light always travels same speed in vacuum
- light slows down when traveling through medium

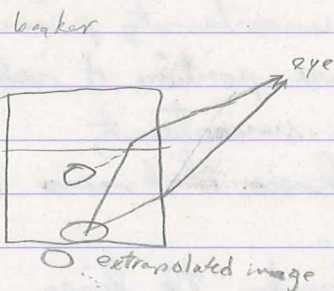


- shorter λ light interacts more with other molecules & slows the velocity
- bigger the lag, bigger angle of refraction
- light traveling from one point to another will take path of least resistance and time

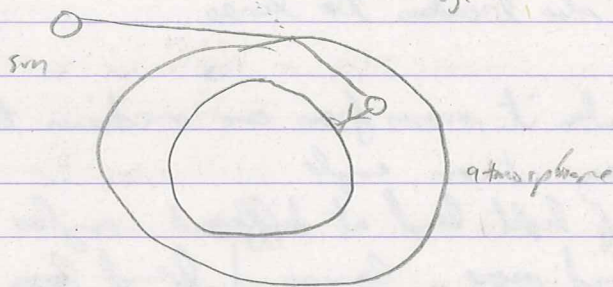


* Mirages

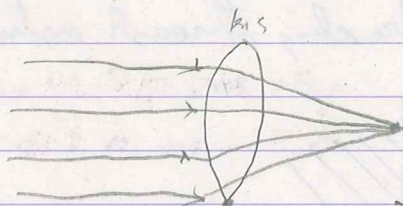
- refraction is responsible



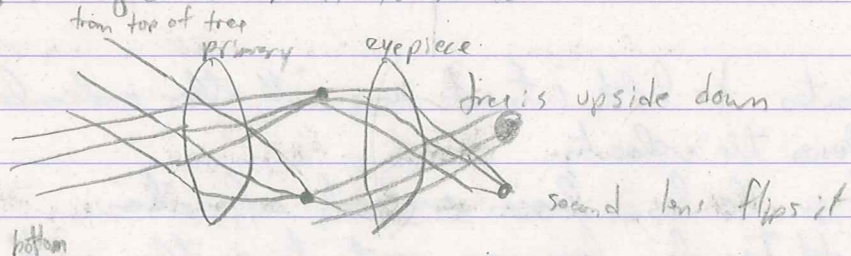
makes it seem as if two pennies are present



* Refracting Telescopes



- focal length - from 1st point to second



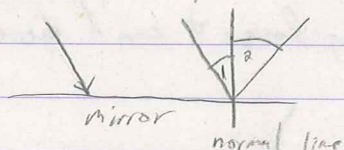
- refracting telescope
- different colors of light will focus at different points
- focus for blue would be nearer to lens
- telescope cannot be in focus for all colors at same time
- most modern telescopes are reflecting
- that process is called chromatic aberration

* Reasons for Telescope Use

- most are reflecting because of chromatic aberration
- cost is a factor
- easier to support a large mirror than a lens; a lens could only be supported by rim
- on refracting, glass will absorb some light, which means it is less sensitive

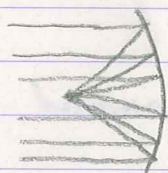
* Laws of Reflection

- when light hits mirror, incident angle = reflected angle



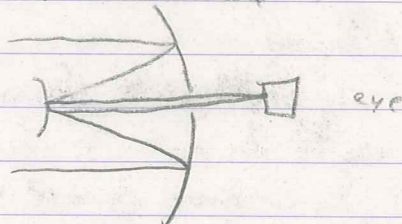
1. incident angle
2. reflected angle

- two different types of mirrors - concave + convex
- concave curve inward + convex curve out



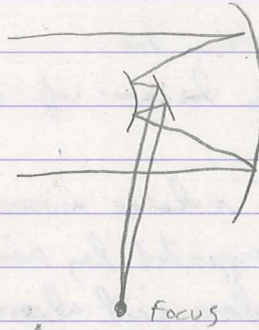
also parallel beams of light come to focus

- image would be upside down
- since focus is in front of mirror, that is an inherent problem
- called Newtonian Focus Telescope
- use flat second mirror to move light another place
- top-sided, since eyepiece is on one side
- to get around this,

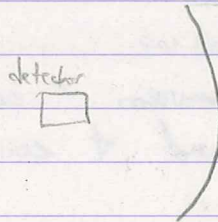


- called Cassegrain Focus
- could use electronic camera

- three mirror model



- advantage is that you could always focus in same location
- called Coudé Focus
- used for spectrometers (very large & can't move)
- Primary Focus



- only works if mirror is very big compared to size of detector
- common in radio astronomy
- also called Prime Focus
- advantage is you don't lose light because of extra mirrors

Quiz 4

* Reflection

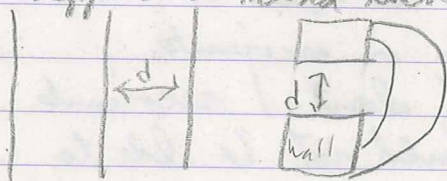
- concave mirror brings light to a focus

* Refraction

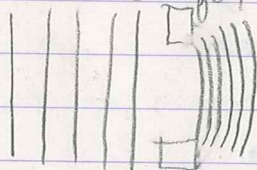
- bends light when traveling through medium to another

* Diffraction

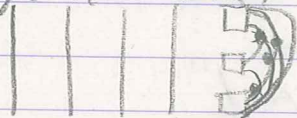
- bending of light around corners or bending of waves in general
- this happens when light goes through a medium
- also happens to sound waves



- $\lambda \approx D$ then lots of bending
- remember d for "door"



- only bends a little and doesn't reach all the way
- sound waves are big enough to bend
- A note has f of 440 Hz
- speed of sound = $345 \frac{m}{s}$ at STP or about $770 \frac{mi}{h}$
- $v = \lambda f$ $\lambda = \frac{v}{f}$ $\lambda = \frac{345 \frac{m}{s}}{440 \text{ Hz}}$ $\lambda = 0.75 \text{ m}$ or 75 cm
- visible light has range of $4 \times 10^{-7} \text{ m}$ and $7 \times 10^{-7} \text{ m}$ (won't bend much)
- to get it to bend, you would need a tiny door



- the waves will interfere with each other
- constructive interference happens because waves add together
- destructive interference happens when the waves cancel each other out

- if λ is shorter, more interference happens
- locations of interference depend upon the λ
- so, λ decreases, the interference points get closer
- diffraction gratings are used to find spectrum
- diffraction determines resolution

* Resolution

- the sharpness of an image, or amount of fuzziness
- resolution is the minimum separation of two objects where we can still distinguish two objects
- measured in usually, arcseconds or arcminutes
- human eye has resolution of about 1 arcminute
- if stars were closer, we would not be able to separate them out
- diffraction causes fuzziness of image
- smaller, the better resolution for the image
- resolution of telescope $\propto$ diameter of mirror
- resolution $\propto$ wavelength
- bigger resolution means fuzzier picture
- Res $\propto \frac{1}{D}$
- radio telescope is going to have a fuzzier picture
- big telescope makes up for big λ
- Earth's atmosphere also makes images "fuzzy"

* Seeing

- can vary night to night depending on atmosphere
- resolution & seeing determine fuzziness
- limits a normal telescope to about 1"
- adaptive optics - the telescope mirror is adjusted with time to give a sharper image
- view from space and out of atmosphere
- both of these get rid of seeing

* Light Gathering Power

- bigger the scope, the more light it can get
- number of photons collected per second
- $A = \pi r^2$
- power depends on radius
- light gathering power $\propto r^2$
- can see more distant objects + fainter objects
-

* Telescopes

- 14" telescope refers to diameter of mirror
- small telescopes at observatory are Cassegrain
- the telescope in Arizona is 0.9 meters
- we put telescopes on mountains to get above atmosphere
- Arizona Telescope is operated by internet
- SARA Consortium
- National Optical Astronomical Observatory - runs Kitt Peak
- funded by National Science Foundation
- Gemini 8 meter telescope operated by NOAO in Mauna Kea, Hawaii (around 14,000 feet high)
- W. mirrors have to be smoother than radio mirrors to get a sharp image
- if size of ball is about the size of bump, then scattering happens
- the shorter the λ , the rougher the mirror can be and get a clear picture
- resolution $\propto \lambda/D$
- big resolution is bad resolution, means you have a fuzzy image
- 100 m radio telescope in Green Bank WV
- run by National Radio Astronomical Observatory
- funded by NSF
- 300 m radio telescope in Arecibo, Puerto Rico
- not steerable
- has big light gathering power
- light gathering power $\propto \text{diameter}^2$
- combine telescopes to get sharper image
- interferometer - many telescopes acting as one
- it is a telescope array
- Very Large Array - VLA, 27 telescopes, each is 25m

- VLA is in New Mexico
- spread over 20 miles
- they get a resolution of a diameter of 21 miles
- light gathering power is not the same, it is smaller than a normal
- we can do radio astronomy when it is cloudy or during the day
- VLA is on tracks
- * Telescopes at other λ
 - put a satellite to view small wavelengths
 - send an observer to International Space Station
 - balloons or rockets or aircraft
 - Kuiper Airborne Observatory was a plane used by NASA to observe long λ infrared
 - SOFIA - stratosphere observatory for infrared astronomy
 - SOFIA is replacing KAO
 - SOFIA is 2 m telescope
 - NASA + DLR (German NASA)
 - it is a passenger plane, not cargo like
 - can land at any airport that can handle a 747
 - Spenser Infrared Telescope - above atmosphere
 - launched in 2003
 - telescope can draw out light of objects trying to be observed
 - cool telescope down when making long λ infrared
 - the detectors have to be near absolute zero
 - we use liquid nitrogen or liquid helium
 - its lifetime is limited to how much nitrogen or helium it has
 - SIT is in orbit around us and is slowly moving away from Earth
 - Hubble is 24 m

- Hubble gets very sharp images because it is above atmosphere
- also has "just beyond visible" infrared detectors
- used to do UV observation
- UV instrument died
- should be replaced soon
- Solar Explorer Mission or GALEX - UV
- Far UV spectroscopic Explorer or FUSE
- measures far UV
- X-rays are hard to focus
- they don't like to be reflected
- they only will reflect at steep angle
- Chandra X-ray Telescope
- the tube is 10m long
- largest spacecraft and barely fit in cargo bay
- normal stars don't produce x-rays
- material on event horizon emit x-rays
- very hot interstellar gas
- gamma rays won't reflect
- hard to measure direction with gamma rays
- Compton Gamma Ray Observatory
- launched in 1991, destroyed in 2000
- Swift Observatory
- BeppoSAX } gamma + xray
- gamma ray bursts - come from distant galaxies & are massive, more luminous than supernovas
- most energetic in universe

* Inventory of Solar System

- $D_{\odot} = 13,000 \text{ km}$ or $8,000 \text{ mi}$
- $D_{\odot} = 109 D_{\oplus}$
- $D_{\text{VENUS}} = 0.95 D_{\oplus}$
- $D_{\text{MARS}} = 0.53 D_{\oplus}$
- $D_{\text{MERCURY}} = 0.38 D_{\oplus}$
- $D_{\text{JUPITER}} = 11 D_{\oplus}$ or $0.10 D_{\odot}$
- $M_{\text{JUPITER}} = 0.001 M_{\odot}$
- $M_{\oplus} = \frac{1}{330,000} M_{\odot}$
- $D_{\text{SATURN}} \approx 9 D_{\oplus}$
- $D_{\text{URANUS}} \approx 3.97 D_{\oplus}$
- $D_{\text{NEPTUNE}} \approx 3.85 D_{\oplus}$
- $D_{\text{PLUTO}} \approx 0.18 D_{\oplus}$
- in August, IAU demoted Pluto from planet status
- IAU = International Astronomical Union
- they voted on definition of planet
- they came up with dwarf planet
- planet
 1. orbits around a star
 2. large enough to be spherical
 3. has to clear its orbit, must be dominant in its part of solar system
- dwarf planet
 1. orbits a star
 2. $\approx$ spherical
 3. does not dominate its orbit
 4. not a satellite
- ETSU - 3 to 1 say Pluto should be a planet
- Clyde Tombaugh discovered Pluto in 1930
- Alan Stern is lead scientist for New Horizons to Pluto
- more than 100 planets have been found orbiting other stars
- extrasolar planets?
- Kuiper Belt objects are large objects on edge of solar system
- 3 objects have been labeled dwarf planets

- Pluto - 2300 km
- Ceres - asteroid belt, 1000 km diameter, $a = 2.7 \text{ AU}$ ^{2.5}_{2.9}
- Eris - Kuiper Belt object, slightly larger than Pluto
2400 km
- semimajor axis - $a = 68 \text{ AU}$ 37 AU - 100 AU
- Pluto $a = 39 \text{ AU}$ 29 - 49 AU
- Eris is not in ecliptic
- Pluto is 17° out of ecliptic 2,300 km
- Ceres is about 11°
- Eris is 99° out of ecliptic
- its orbit is more like a comet than a planet
- comets come in at an angle
- objects in Kuiper Belt are out of ecliptic
- Charon may be classified as a dwarf planet
- Charon is Pluto's moon
- is this a double dwarf planet or dwarf planet and moon
- Charon diameter, 1,200 km
- $M_{\text{Charon}} = \frac{1}{6} M_{\text{Pluto}}$
- Pluto & Charon orbit around center of mass
- there are other large Kuiper belt objects, but we don't know much about them
- Pallas, Vesta, Hygiea - asteroid belt - may be spherical
- Eris has a moon
- all of this is about terminology
- there are 7 moons in our solar system bigger than Pluto
- 169 moons so far are in our solar system
- moon - orbiting around a planet
- Mercury has no moons
- Venus - 0
- Earth - 1
- Mars - 2 Phobos & Deimos $\approx 20 \text{ km}$, not spherical
- Jupiter - 62 known
- Saturn - 56 known

- Uranus - 27
- Neptune - 13
- Pluto - 3 Charon, Nix, Hydra
- 7 moons less than Pluto
Europa, Io, Ganymede, Callisto - Jupiter

our moon

- Titan - Saturn
- Triton - Neptune
- Ganymede - 5,200 km, largest moon in solar system
- Titan - 5,200 km, second (atmosphere makes it look bigger)
- Mercury - 4,880 km in diameter
- 3. Callisto - 4,800 km
- 4. Io - 3,600 km
- 5. our moon, 3,500 km
- 6. Europa - 3,100 km
- 7. Triton - 2,780 km

* Asteroids

- most are in asteroid belt, some orbit other places
- Kuiper Belt
- comets
- interplanetary dust & gas (lies mostly along ecliptic)
- rings - Saturn, Jupiter, Neptune, Uranus
- Mercury is 0.4 AU from Sun
- Venus - 0.7 AU
- Mars - 1.5 AU
- Jupiter - 5.2 AU
- Saturn - 9.5 AU
- Uranus - 19 AU
- Neptune - 30 AU
- Pluto - 39 AU (from 29 - 49 AU)
- most objects spin counter-clockwise and orbit (most)
- Venus spins backward, Uranus spins on its side (112°)
- Earth is 23.5°

- Mars - 24°
- Mercury - 28°
- Jupiter - 27°
- Saturn - 30°
- Venus - 3°
- Neptune - 29°
- Pluto - 118°
- sidereal day on Earth - 23 hours 56 mins
- Mars sidereal day - 24 hours 37 mins
- Venus - 243 days - spin slowly
- Mercury - 58 days - $\frac{2}{3}$ of sidereal year of Mercury
- Jupiter - 10 hours
- Saturn - 10 hours
- Uranus - 17 hours
- Neptune - 16 hours
- sun $\approx$ 22 days

* Planet

- Terrestrial planets - inner planets $4 - 5.5 \frac{g}{cm^3}$
- Jovian planets - outer planets
- water = $1 \frac{g}{cm^3}$
- rock = $2-3 \frac{g}{cm^3}$
- moon = $3.3 \frac{g}{cm^3}$
- terrestrial planets are rock & metal
- moon has lower proportion of metals
- density = mass / volume
- get mass by measuring gravity effect on moon or effect on comet, asteroid, or satellite
- Jovian - Jupiter-like (gas giants)
- mostly made of liquid with small rocky, metal core
- Jovian - $0.7 - 1.6 \frac{g}{cm^3}$
- Pluto - $1.7 \frac{g}{cm^3}$, probably could be rock & ice
- not terrestrial or jovian

- $3.59 \frac{g}{cm^3}$ - Io + Europa, about same as Jupiter
- mostly rock
- rest of moons w/ known densities - $1-2 \frac{g}{cm^3}$
- combination of ice + rock
- Kuiper Belt objects - $1-2 \frac{g}{cm^3}$

- Uranus
- 1 only
- Voyager 2 - flew by in 1986
- Neptune
- 1 only
- Voyager 2 - flew by in 1989
- Voyager 1 veered out of ecliptic to look at Titan in 1980
- both still operate, about 100 AU away
- trying to measure solar wind at heliopause
- heliopause - end of sphere of influence for our sun
- Pluto

- 0 visited
- New Horizons is on its way, launched spring 2006
- fly by in 2016 or 2017
- fly by Jupiter in 2007
- eventually study objects in Kuiper Belt

* Properties of Solar System

- almost everything orbits the sun in the same plane, except comets & Kuiper Belt Objects
- Eris is largest Kuiper Belt object
- almost everything orbits & spins the same direction, except Venus, which spins backwards, & Uranus on its side
- Triton orbits around Neptune reversely in a retrograde orbit
- terrestrial & Jovian planets
- asteroids are rocky, the moon
- moons in outer part of solar system are ice & rock, like Pluto
- 2 inner most Galilean moons are rocky, Io & Europa
- comets are ice & rock about 1 light year away in the Oort Cloud
- could be about a billion comets
- the nucleus of comet is ice & rock
- tails appear when it gets in inner solar system
- some are big & some are small

* Standard Model for Solar System Formation

1. - huge clouds of interstellar gas & dust about one light year part
 - about 99% gas & 1% dust
 - most of it is hydrogen - 73% by mass
 - 25% helium, 2% all other elements
 - universe is mostly hydrogen & helium
 - in equilibrium state, cloud is held by gravity & gas pressure is pushing outward and is in balance
2. - external force acts on cloud & compresses it
 - collides with another cloud, a supernova goes off, nearby stars' solar wind
 - cloud compresses & shrinks
3. - as cloud shrinks, it spins faster because of conservation of angular momentum
 - angular momentum is measure of spin & orbital motion of an object
 - $AM \propto \text{mass} \times \text{spin velocity} \times \text{size}$
 - mass is fixed, size decreases, so velocity must increase
4. - flattens to a disk along spin axis
5. - gas and dust starts to clump up
 - dust is made of heavier elements
 - dust stick together & gas condenses on dust



- cloud at time could be 10-100 K
 - particles start to clump bigger
 - clumps grow - "growing snowballs"
- o o o
o o o
o o o
- planetesimal or baby planet

- in center of disk, more material builds up
- core starts to get hot (gravitational potential energy to kinetic energy)
- it starts to glow - thermal radiation
- about 2000 K - proto sun - long λ infrared
- the light evaporate ices or clumps of material in inner parts of disk
- inner planets do not have much ice because of this
- the clumps become protoplanets
- planetimals make craters on protoplanets
- Venus is going backwards maybe because it was hit in right direction
- our moon was probably caused by a collision
- protosun gets hot enough for nuclear reactions to start, and becomes a star

* Formation of Solar System

- formed out of gas & dust
- mostly made of hydrogen
- more than 1 lightyears
- could have collided with another cloud or a supernova was near or solar wind
- its spin rate became faster as it shrank
- it flattened to a disk
- things orbit in same plane because of flattened disk except comets
- comets formed with a spherical distribution
- most comets are in Oort cloud outside of Kuiper Belt, about 1 light yr.
- Kuiper Belt objects are not in plane of solar system
- Eris is biggest Kuiper Belt Object (49° to ecliptic)
- the disk clumped up & formed bigger clumps
- clumps are called planetesimals
- 4.6 billion years old - solar system
- can determine by radioactive dating of rocks (meteorites)
- planetesimals eventually made planets
- core gets hot and radiates heat
- it evaporated the ices in the rocks
- this is why inner & outer planets differ
- inner planets are small because there was no alot of dust
- Jovian planets and its moons form like mini solar systems
- moons orbit in about the speed & direction
- protoplanet got hot & produced light
- Io & Europa are two innermost moons of Jupiter
- terrestrial planets also got hot
- so hot, they were semi molten
- they underwent differentiation

* Differentiation

dense material sinks, light material rises due to gravity

- this is why Earth has an iron core
- we know its iron because we have magnetic field & we know our density (5.5 g/cm^3)
- hydrogen $\rightarrow$ helium - now is a star
- when born, it is unstable & blows off wind
- the wind cleans out most of the system
- it still has a wind, but it is still weaker
- Kuiper Belt objects could have been deflected out of orbit
- Triton was gravitationally captured by Neptune
- plutooids - never formed into a planet because of Neptune
- Mars would have been too big to be captured
- Mercury - too close off
- Earth's crust on Earth eroded; geological activity
- more than 100 planets have been found so far
- exoplanets planet $\uparrow$
- we can detect them indirectly by measuring the gravitational effect on star
- we can measure Doppler shift of the star moving
- if star is moving, there is something there to make it move
- can get period of star & mass
- can't measure Doppler shift if motion is in line of sight
- the velocity we see may not be the full velocity, and Doppler shift may be off, so mass will be incorrect
- we can however get a lower limit of mass
- this might not be a planet, could be low mass star or brown dwarves
- brown dwarf is in between a star & planet - a failed star cause it can't make nuclear reactions
- a mass less than 8% of sun

- mass of brown dwarf > 13 Jupiter
- mass of Jupiter $\approx \frac{1}{1000} M_{\odot}$
- brown dwarf could have deuterium fusion
- ^2H will form He
- ^1H will not go to He
- deuterium does not produce a lot of energy
- brown dwarf emits infrared light (or extremely planets)
- all extrasolar planets found so far have masses larger than Earth
- they just have less of an effect (they = low mass planets) that we can find them
- most extrasolar planets are less than an AU from star
- we have a selection effect on how we find our planets; it is a bias at how we collect data
- most ES planets have elongated orbits, unlike our planets
- planetary migration; may be spiraling into center & planet will fall into sun
- Jupiter's orbital year is 11.8 years
- the mass we would get for velocity is not an upper limit, it would be the correct one

* Atmospheres of Planet & Moons

- Earth - 78% N_2 , 21% O_2 , Ar , CO_2 , traces
- Venus - 96% CO_2 , 4% N_2 , traces H_2SO_4
atmosphere = 90 times of Earth
- Mars - 95% CO_2 , 3% N_2 , traces of others
atmosphere = $\frac{1}{10,000}$ Earth
- Mercury - 10^{-15} atmosphere of Earth, H , He , Na , K
- Jovian - 95% H , 4% He , traces of others
- similar to universe as a whole
- Pluto sometimes has an atmosphere; when it is closest to sun, some of the ices sublimates
- 10^{-5} atmosphere of Earth
- when it moves away from sun, some escapes & some condenses

Quiz 5

* Atmosphere of Planets & Moons

	Composition	Atmospheric Pressure (compared to Earth)
- Mercury	H, H ₂ , Na, K	10^{-15}
- Venus	96% CO ₂ , 4% N ₂	90x
- Earth	78% N ₂ , 21% O ₂	1x
- Mars	95% CO ₂ , 3% N ₂	10^{-4}
- Jovian planets	H, He	very high
- Pluto	CH ₄	only during summer, 10^{-5}

* Factors that determine atmosphere

- how fast atmosphere leaks into space
- mass & size & temperature of atmosphere

* Escape Velocity

	EV (in km/sec)	Why?
- Mercury	4.3	solar wind hitting surface
- Venus	10.5	
- Earth	11.2	photoevaporation, sublimation, & escape
- Mars	5.0	condensation $\rightarrow$
- Jovian	60 (for Jupiter)	came when it was formed
- Pluto		sublimation of ices

- accretion from disk in early solar system for Jovian planets
- H₂ will escape more easily because of its low mass
- Volcanoes, outgassing for all terrestrial planets
- Volcanoes, CH₄, NH₃, N₂, CO₂, H₂, SO₂ $\rightarrow$ chemical reactions
- H₂ escapes and N₂ & CO₂ will be mostly there
- the solar wind is mostly H & He (ionized)

* Moon's Atmosphere

- 7 moons are bigger than Pluto

Moons	Elements	At. Pressure	Why?
- Ganymede	O_2	10^{-11}	solar wind
- Titan	90% N_2 , CH_4	1.5	outgassing, outbursts, evaporation
- Io	SO_2	low	very volcanic
- Europa	O_2	10^{-11}	solar wind hits H_2O ice, H_2 escapes
- Triton	N_2 , CH_4	10^{-5}	outgassing, sublimation
- Callisto	CO_2	trace	outgassing
- The moon	Na , K , H , He	10^{-15}	solar wind

- there could be liquid of hydrocarbons on Titan
- Enceladus - Saturn's moon - traces of H_2O vapor due to geysers

* Why is the sky blue?

- because our atmosphere scatters light
- the shorter the λ , the more likely it will be scattered

* Relative Distance of Solar System Object

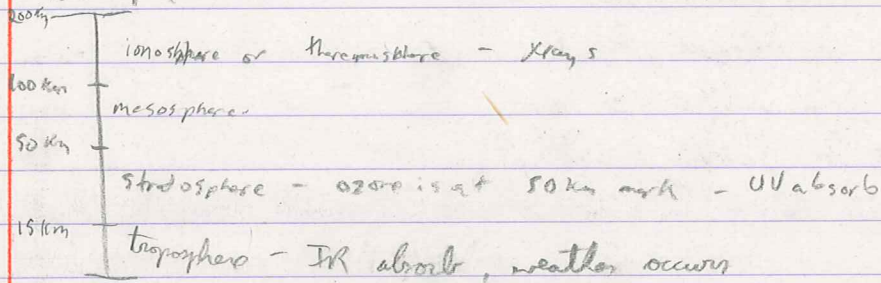
- 1 AU = 100 D_0

Planets	Distance in AU	Distance Scaled
- Mercury	0.4	8 m
- Venus	0.7	14 m
- Earth	1	20 m
+ Mars	1.5	30 m
- Jupiter	5.2	100 m
- Saturn	9.5	200 m
- Uranus	19	400 m
- Neptune	30	600 m

* The Greenhouse Effect

- Earth produces infrared radiation & is absorbed by atmosphere
- the infrared comes from the sunlight that hits Earth
- CO_2 , SO_2 , H_2O , CH_4 - greenhouse gases
- the molecules randomly emit the energy
- the energy is trapped by the lower atmosphere
- the greenhouse effect is good, if it was not here, it would be about -9°F
- it increases the temperature by about 90°C
- but we don't want too much; just enough to be stable
- Venus has the most of the GH effect of terrestrial planets
- Venus' atmosphere is mostly CO_2 & a lot of it
- average temp on Venus is about 750 K or 900°F
- it is about 500 K higher if there was none at all
- there is a very small GH effect on Mars
- Mars has CO_2 , but not a lot of it
- temperature on Mars is 203 K or -58°F
- it is about 5 K higher if there was no GH effect
- not really a GH effect on Mercury or the moon
- distance is closer to the sun than we are (0.7 AU for Venus)
- Venus is a little bit warmer
- if there was water, it evaporated into atmosphere
- H_2O is GH gas, & increased temp of Venus
- the rocks start to bake, & start emitting CO_2 , & temp $\uparrow$
- this is called the runaway GH effect
- we are far enough away that our water remained liquid
- ice caps reflect light & help prevent some heating of Earth
- water absorbed some of the heat
- O_2 in atmosphere tends to get dissolved into water
- some of it even produces rocks
- photosynthesis helps to pull CO_2 out also
- N_2 & O_2 are not GH gases

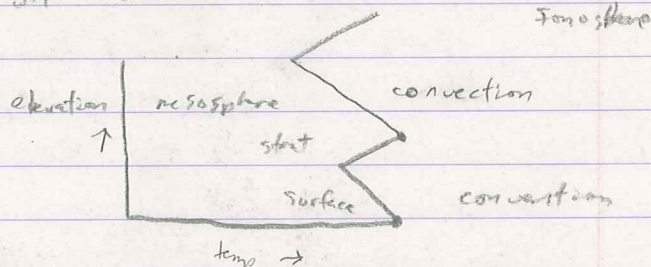
- deforestation is bad because trees take the CO_2
- * Ozone Layer
- UV is absorbed by ozone, O_3
- atmosphere is about 200 km total, while D_2 is 13,000 km
- 99% of air is within 30 km of surface
- atmosphere



- Mt. Everest is 8 km, eye plane at 20 km
- the ionosphere is mostly ionized
- long radio waves is reflected off ionosphere (longer than 100 m)
- AM radio waves can bounce off of ionosphere, but FM goes through
- AM can be heard at large distance

* Temperature Vs. Elevation on Earth

- surface - 60°F
- stratosphere -



- when hot gas rises & and cold gas sinks, convection occurs
- within a gravity field $\uparrow$
- weather is due to convection & rotation of Earth
- convection is caused by heating of sun
- more direct sunlight near bottom part of Earth
- hot gas rises more equator, & sinks near poles
- that is called a convective cell

* The Coriolis Effect

- swirling motion due to rotation & inertia

* Convective Cells

- 3 in north + 3 in south
- Jupiter has cells around it because it moves fast
- the stripes on Jupiter are caused by Coriolis Effect
- all gas planets have stripes

* Interiors of Planets

- figure out mass + density
- shake it + listen
- we can study seismic waves from earthquakes
- three kinds of waves, P, S, L
- primary waves - P - or pressure waves, compression waves
- P waves can travel through solid + liquid
- sound is a form of P
- S is secondary or shear waves - transverse waves
- S waves need a rigid material to travel through, cannot go through liquid
- L is for love waves, after person who discovered them
- L travels on surface of planet, not helpful for studying interiors
- in center, the core is mostly iron + nickel about 20% radius of Earth
- a liquid outer core is about 35% radius of Earth, with iron + nickel
- the mantle is about 45% radius
- the crust is 0.5% radius, or about 30 km thick
- 6,400 km = radius of Earth
- person on other side of Earth during quake only sees P waves, while person near, sees both P + S
- refraction also happens to seismic waves
- speed varies depending on what material they travel through
- by timing + mapping, you can make a map of interiors of the earth
- Earth's core is about 12 g/cm^3
- surface of Earth - 300 K
- inner core - 5000 K
- interior of Earth is warm because heat left over from formation
- conversion of grav. PE to KE

- radioactive decay provides heat when isotopes decay
- in the sun, fusion happens - Hydrogen combines to make Helium
- the bigger the planet, the more likely it will have a liquid layer
- the total amount of heat a planet in lifetime is $\propto$ mass
- mass $\propto$ volume $\propto \frac{4}{3}\pi r^3 \propto r^3$
- the rate of heat that is lost is the amount of heat lost per time
- cooling rate depends on surface area of planet
- $SA = 4\pi r^2 \propto r^2$
- amount of time it takes planet to lose all heat =
total amount of heat / rate of heat loss,
 $\propto \frac{r^3}{r^2} \propto r$
- the bigger the planet, the longer it retains the heat
- Venus probably also has a liquid core
- The moon is probably solid all the way through
- The Apollo mission left seismic equipment on the moon & detected moon quakes of about Richter scale 2
- There was one possible detection of a quake on Mars in 1976 by Viking II of about 2.5
- Mars is probably solid too because of its small size

* Magnetic Fields

- Earth has strong fields
- Earth's field extends to about $10 D_{\oplus}$
- Earth is not a solid bar magnet, but the field is created by moving charged particles
- a charged particle that is moving creates a magnetic field
- electrons running through wire is an electromagnetic
- in the liquid metal, the electrons are not closely confined to an atom
- the Earth's spin makes current, which creates the field

- Mars doesn't have a big magnetic field, less than $\frac{1}{1000}$ that of Earth's
- Mars doesn't have liquid interior, but does have fast spin
- Venus doesn't either because it spins slowly
- Venus is less than two Earth's
- The moon does not have a strong field, less than $\frac{1}{1000}$ of Earth's, plus its sidereal day is 29.5 days
- Mercury does have a magnetic field, but is about $\frac{1}{100}$ of Earth's, even though it is small + spins slowly
- Messenger will study magnetic field
- The process of the charged particles moving is called magnetic dynamo
- magnetic field protects planet from solar wind
- ionized particles at high speeds can damage DNA
- if a moving charged particle encounters a magnetic field, it is deflected by it
- the particle spirals around the field
- that area is called the van Allen belts
- the solar wind shape the magnetic field lines
- the opposing part is extended out 30-70 D₀
- life on moon, Mars, or others need shielding from solar wind
- the moon + Mars may have had life there in the past, but not now

* Earth

- aurora borealis - northern hemisphere (northern lights)
- there is a semi liquid up near the upper mantle
- upper part cause earthquakes, plate motion, volcanoes
- continental drift = plate tectonics
- asthenosphere - upper part of mantle
- P & S waves travel through asthenosphere, so it is somewhat rigid, but moves around a little
- core of earth = 5000 K
- the hot layers can push through crust and make volcanoes
- plates are pulled along by the cells by a few centimeters/yr

* Continental Drift

- first suggested in 1800s by mapmakers
- popularized in 1910 by Alfred Wegener, but not taken seriously by scientists
- by 1960s, continental drift was well accepted
- the mid-Atlantic ridge, where two plates are pulling apart, and making new sea floor
- this process is called sea floor spreading
- MAR discovered during WWII by Harry Hess
- he was captain of a naval vessel; his ship had Radar
- fossil studies indicated that far away lands had similar fossils
- radioactive dating can be used on rocks, rocks near MAR are young
- we can measure drift using GPS satellites
- only about 3 cm/yr
- scientists found magnetic stripes on ocean floor
- the Earth's magnetic field has reversed in the past
- could be between 1000 to 100,000 years
- due to combination of rotation & convection
- about 150 to 200 million years ago, all continents were together

- this was called Pangea, time of dinosaurs
- what is pulled underneath is called a subduction zone
- Andes are created by the plate pushing up
- another example is the Himalayan mountains last
- both plates are pushing up
- when they did part each other, it could cause an earthquake
- hot spot volcanism - one spot in mid-ocean, etc
- lava, smoke, etc
- hot spot seen 1 more

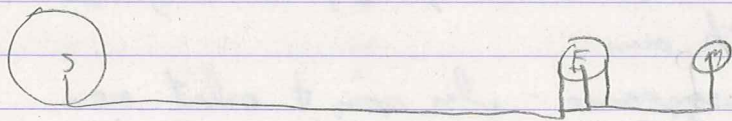
* Radioactive Dating

- The nuclei of some isotopes will change
- ^{12}C will stay, but ^{14}C will decay
- ^{14}C will change into ^{14}N + emits
- $^{14}\text{C} \rightarrow ^{14}\text{N} + e + \text{anti neutrino}$
- $n \rightarrow p + e + \text{anti neutrino}$
- $^{40}\text{K} \rightarrow ^{40}\text{Ar} + \text{positron} + \text{neutrino}$ (a proton turned into neutron)
 $19p, 21n \quad 18p, 22n$
- $p \rightarrow n + \text{anti electron (positron)}$
- all this happens spontaneously
- Rate of decay depends on element - half life
- half life - time it takes a sample to half decay
- ^{14}C - 5,730 years
- ^{40}K - 1.3 billion years
- it is an exponential decay, but it is statistical decay
- ^{40}K is good for dating rocks because Argon is a noble gas
- they remain gases till very low temperatures.
- if it is molten, the argon escapes, after time, ^{40}K turns to ^{40}Ar and it gets trapped
- by melting the rock + capturing the gas, measure the relative amount of gases, & figure out age of rocks
- if 3x as much Ar as K, then 2 half lives
- if 7x as much, then 3 half lives

- rocks on Earth have been found to be 1,000,000 - few hundred million years old
- oldest rocks found were 3.9 billion year old
- the ages we get is the age when the rock hardened first
- the Earth is 4.6 billion years old
- there is a recycling of the surface of the Earth
- the crust gets melted when pulled underneath
- new rocks formed by sea floor spreading
- rocks on moon - 3.2 - 4.4 billion years old
- meteorites have been dated to 4.6 billion years
-

* Tidal Forces

- gravitational forces
- due to difference in gravitational field in two locations
- $F_{\text{grav}} \propto \frac{1}{D^2}$
- moon has a different effect on different parts of earth
- it causes a tidal bulge near & opposite sides of Earth
- moon pulls on center of Earth more than far side
- high tide comes 2 times a day, every twelve hours apart
- tidal bulge means high tide
- moon has bigger effect than sun does on tides because it is closer



- during full moon, the tidal forces of moon & sun add up and the bulge is bigger
- during new moon, this also happens
- this is called a spring tide, when tide is highest
- a spring tide happens twice a month, nothing to do with seasons
- during a neap tide, the moon pulls one way, and sun pulls direction perpendicular
- happens during 1st & 3rd quarter moon
- the tidal bulge caused by moon is offset slightly
- bulge is a little ahead of the moon
- it happens because of rotation of Earth
- this slows down the spin rate of the Earth
- days are getting longer, about 1.5 milliseconds per 100 years
- angular momentum $\propto$ mass $\cdot$ velocity $\cdot$ size
- velocity is decreasing, and so is A_M
- angular momentum is conserved, though, but the moon changes it's angular momentum
- it is the total spin & orbital A_M that stays the same

- orbit $M = \text{mass} \cdot \text{velocity} \cdot \text{size of orbit}$
- size of orbit is getting bigger of the moon
- it moves away about 4 cm a year
- we will eventually be tidally locked to moon
- in past, the moon spun, but no more
- no planets are tidally locked to sun
- Mercury has biggest tidal force from sun
- Mercury's sidereal day = $\frac{2}{3}$ sidereal year
- Mercury's SD = 59 days 54 = 88 days
- it spins $1\frac{1}{2}$ times for each orbit around sun
- when Mercury is at its closest point, the long axis is aligned with sun
- spin-orbit resonance - when spin & orbit are related by tidal forces (by small numbers)

* Surface of the Moon

- there is a tiny bit of erosion from the solar wind & small meteorites
- the maria (pl.) - latin for seas - dark spots on moon
- the lighter region is called the highlands
- highlands are cratered, Maria are not, highlands are older
- Maria rocks have ages from 3.2 - 3.9 billion years
- Highlands rocks are ages from 4.4 to 4.0 billion years
- large impacts broke crust, lava flowed up, & made Maria
- no evidence for large scale plate tectonics on moon
- there is no Maria on the far side of the moon
- the moon is lopsided
- rocks in Maria have higher density material than highlands
- the streaks around the craters are called rays
- caused by material thrown by impact
- mountains on moon were caused by impacts
- very few volcanic moons on moon
- rilles on moon are rived into due to streams of lava in the past

- there were 6 landings between 1969 + 1972
- Apollo 13 did not make it
- we were able to study rocks, dating & composition & magnetic field
- we did seismic studies & geology of surface

Quiz 6

* Formation of The Moon

- four ways that moon could have formed

1. broke from Earth - fission
 2. captured by gravity
 3. formed like a double planet
 4. something collided with Earth
- last one best fits the data

* Observations

- density of moon < density of Earth
- moon = 3.3 g/cm^3 Earth = 5.5 g/cm^3
- density difference inconsistent with double planet theory, & has less volatile elements, (light elements with low escape)
- if 3 were true, it would have same composition.
- both Moon & Earth have same isotope ratios
- $^{18}\text{O} / ^{16}\text{O}$ - same on Earth & Moon
- usually the ratio changes
- the fact that it is the same tells it formed at same distance from sun,
- wrong against capture theory
- our moon could not have slowed by itself (energy conservation)
- moon is far away from earth
- $AM = \text{mass} \times \text{velocity} \times \text{distance}$
- if Earth broke a piece off, how would the moon gain AM to get so far away?

* Collision

- an object about $\frac{1}{10}$ of Earth (size of Mars)
- came from about same distance, so same isotopes
- it hit edge of Earth & add AM
- it vaporized the object & outer part of Earth
- the material settled into a disk around Earth
- vaporization helped remove volatile elements
- iron core sank to center
- moon formed from the smaller objects

* Surface of Mercury

- no Moon on Mercury
- surface of Mercury is older than moon
- we're only seeing one side though
- Mercury's craters have shorter rays than the moon's
- scarps - giant cliffs on Mercury
- the surface wrinkled up causing this
- Caloris Basin - 1000 km impact basin (600 mi.)
- caloris - Latin for "plain of heat"
- it sits above sun when Mercury is closest to sun

* Surface of Venus

- Maxwell mountains - taken by radio telescope, about 7 miles high
- it is a folded mountain range, like Appalachian
- surface of Venus is about 0.5 billion years old
- older than Earth, but younger than moon
- the corona - unique to Venus, circular cracks, volcanic in origin
- lava pushed its way up & made a dome, and dome collapsed, leaving cracks
- Magellan - 1990-1994, resolution of about 200 m
- the stripes are called tesserae - wrinkles, volcanic
- molten lava moving under surface
- there is controversy about whether Venus is geologically active
- pancake domes - lava was very viscous, spread slowly, and made domes
- no evidence for large scale plate tectonics in the past or now
- nothing similar to the trench off of South America
- volcanoes, but not plate movement
- Venus has no moon; this may drive activity
- Venus Express - European spacecraft in orbit
- study atmosphere & look for geological activity

8 Surface of Mars

- until 1965, people believed there was life on Mars
- dark features change with time, the seasons of Mars
- Mars is very barren & cratered
- there is a big crack called Valles Marineris
- the surface is red because of oxidation of iron
- it has alot of iron in its outer layers compared to Earth
- but density of Mars is less than Earth
- it's not differentiated as Earth
- it didn't get as hot or cooled off quickly
- diameter of Mars = $\frac{1}{2}$ Do
- Valles Marineris is 5000 miles long, as long as US
- Valles is thought to be Martin equivalent of Mid Atlantic Ridge
- > Mars is geologically dead
- Olympus Mons is biggest mountain on Mars & entire solar system
- it is 17 miles high, 3x higher than Mt. Everest
- mountain is thought to be caused by hot spot volcanism
- could be because of its small size
- there are some hills on Mars (Tharsis)
- there is frost on Mars, depending on season
- frost is water ice & dry ice
- ice caps contain water & CO₂ ice
- Mars average distance - 1.52 AU
- 1.37 AU - 1.67 AU
- Tilted by 24°
- closest to sun during summer of Southern Hemisphere
- in summer, caps evaporate & creates wind
- makes dust storms, can cover entire surface
- this is why it appears to change appearance during seasons
- Spirit & Opportunity, Global Surveyor, Mars Express,

* Phobos & Deimos

- 30 km - Phobos

* Mars

- NASA lost contact with Mars Global Surveyor
- got there in 1997
- Mars Express, (Spirit & Opportunity)
- 2001 Mars Odyssey
- Mars Reconnaissance Orbiter

* Mars' Surface

- lines can be caused by dust devils up to five miles high
- sand dunes
- Valles Marineris - crack across surface about 3000 miles

* Spirit & Opportunity

- longer lived than Sojourner
- goals
- look for evidence of precipitation
- look for minerals formed in water
- learn about geology

* Jovian Planets

- the stripes are called belts & zones
- belts are dark & zones are light
- Coriolis effect causes stripes due to convection & rotation
- all 4 Jovian have belts & zones
- belts & zones have different color depending on elevation

* Chemical Composition by Number

	Jupiter	Saturn	Uranus	Neptune
H ₂	86%	92%	84%	84%
He	13%	7%	14%	14%
NH ₃	0.03%	0.03%	—	—
CH ₄	0.2%	0.2%	2%	3%

- Saturn has not alot of helium because it may possibly rain

- Uranus & Neptune have no NH_3 because it precipitates out
- they have more methane because it is colder & objects have more methane ices
- that is why they both are blue
- CH_4 absorbs red light & scatters blue light
- we don't know why Jupiter & Saturn are their colors
- clouds on Jupiter & Saturn are made up of NH_3 , H_2O , NH_4SH
- they have NH_3 than NH_4SH , and H_2O
- clouds should be white though
- could be sulfur or phosphorus compounds
- we don't know for sure
- chemistry is complicated & we don't understand it well on these planets

* Jupiter

- Great Red Spot - storm in atmosphere of Jupiter
- Galileo first saw it, been around for 100s of years
- not sure when it is red

* Clouds

- Jupiter - 7.5 km thick
- Saturn - 380 km thick
- more haze on Saturn
- Uranus is almost uniform, but Neptune has belts
- more haze in Uranus, & difference of temperatures
- we can study interior with computer models by balancing inward force of gravity with pressure of air
- we know mass, gravity, at surface, surface temp, & composition
- we know that it is mostly liquid, only about 0.2% is gas on Jupiter
- 30% liquid H_2 also

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- plains - Latin for "plain of heat"
- it sits above our equator, Mercury is closest to sun

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- liquid metallic H_2 is about 55% of radius
- H_2 under extreme pressure
- it acts like a metal and is solid
- conducts electricity
- because of this, it has a magnetic field
- Jupiter's mag field is about 10,000 Earth's mag field
- Saturn has metallic H_2 also
- Jupiter has solid core, about 15% of radius
- Saturn's liquid H_2 is 50%
- metallic H_2 is 10%
- solid core 20%
- Saturn has 1,000 Earth magnetic field
- Uranus & Neptune don't have liquid metallic H_2
- they have 15% atmosphere of planet
- 50% is liquid and ices
- 25% is inner rocky core
- they both have fields 100 times that of Earth
- rotation axis is offset from magnetic field north

* Saturn

- all 4 Jovian planets have rings, Saturn's is distinct
- rings are not solid, made up of small particles like ice & rock and vary in size between microscopic or house sized
- very reflective
- the gap is called Cassini's division (less particles)
- ringlets have different colors
- the gap is caused by Mimas using gravity
- particles in the gap are in orbital resonance with Mimas
- a particle in that gap has an orbital period half of Mimas' orbital period
- there are gaps in asteroid belt called Kirkwood's gaps
- caused by Jupiter's gravity
- the spots change with time
- the rings continuously change because of collisions and other gravitational forces
- the rings could be material left over from moon formation
- could be moons or asteroids ripped apart by tidal forces and became ring particles
- the Roche limit is the distance a moon can be to close to a planet without being pulled apart
- the smaller the moon, the closer it can be
- the F ring is a thin outer ring & caused by Pandora & Prometheus
- both are shepherd moons and act like sheep dogs
- they don't allow particles to stray out of rings by using gravity

- ring particles usually have circular orbits
- when the particle is slowed, it has an elliptical orbit
- eventually, it becomes circularized

* Rings

- Jupiter's rings were discovered by Voyager I
- Jupiter's rings go down to the planet's surface
- happens on Saturn as well
- more ring particles are being created though
- Uranus rings were discovered in 1977 by Kuiper Airborne Observatory
- Neptune's rings are clumpy, which is evidence that new ring particles are changing

* Moons of Jupiter

- Io, Callisto, Europa, Ganymede
- Io is closest to Jupiter, Europa, Ganymede, then Callisto
- Is Everyone Doing Europa?
- Io has strongest tidal force from Jupiter
- Io is most geologically active object in solar system
- Callisto has most craters (not active)
- Europa has a few craters, but not many
- Io is 3.5 g/cm^3 , the most dense - mostly rock with some iron
- Europa is 3 g/cm^3 - rock, maybe ice
- Ganymede & Callisto are 1.9 g/cm^3 - water, ices & rock
- heat from Jupiter evaporated ice & put dense moons
- instead of mountains for volcanoes on Io, there is only a depression
- no craters because lava changes it
- only in polar regions can a mountain be
- Europa is an icy moon & is shiny & reflective
- sometimes called marble moon
- cracks are caused by tidal forces from Io & Jupiter
- some think that under the ice, there is liquid water
- heated by volcanic activity

- very few craters on surface
- geological activity refreshes the surface
- Callisto is very cratered
- Valhalla is a large impact basin that is 600 km, width is 5000 miles
- largest impact basin in entire solar system
- Callisto is geologically dead
- nothing has happened since the early solar system
- parts of Ganymede look like Callisto and other parts look like Europa
- the grooved terrain of Ganymede is in the lighter regions and is fairly young
- Jupiter has 63 moons, Amalthea - 5TH largest moon of Jupiter
- about 250 km along long axis

- * Moons of Saturn
- Cassini launched 1997, reached Saturn in 2004
- Saturn has 93 moons
- Mr. Educated Teacher Doesn't Read the Hawaiian Island Paper - Saturn moons
- Mimas, Enceladus, Tethys
- Titan is second largest moon in solar system
- Mimas is the deathstar moon
- Enceladus is icy, not many craters, rocks on surface
- Tropic region is in south pole of it
- no water there
- warm compared to rest of moon
- heat leaks through cracks
- has atmosphere of water vapor around south polar region
- is geologically active
- Tethys has a crack 600 miles long called Ithaca Chasma
- Odysseus crater is a big crater that may have produced cracks
- geologically dead
- Dione has cracks in surface
- Rhea has cracks also
- also has an impact crater with caps of fresh ice
- Titan has thick atmosphere with mainly N_2
- methane is second biggest
- triple point - Temp & pressure are such that an element or compound can exist in all three physical states
- Titan has a methane triple point
- Hyperion is elongated, not tidally locked to planet
- looks like Mars
- Iapetus - one side is dark & one side is light
- Phoebe - probably captured from Kuiper Belt

* Uranus' moons

- AUTO

- Ariel, Umbriel, Titania, Oberon

- closest → farthest

- Titania has swamps

- Oberon has craters

- Miranda is called Humpty Dumpty moon

- pictures taken by Voyager 2

* Asteroids

- Kirkwood gaps are caused by gravity

- 100,000 in asteroid belt

-

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