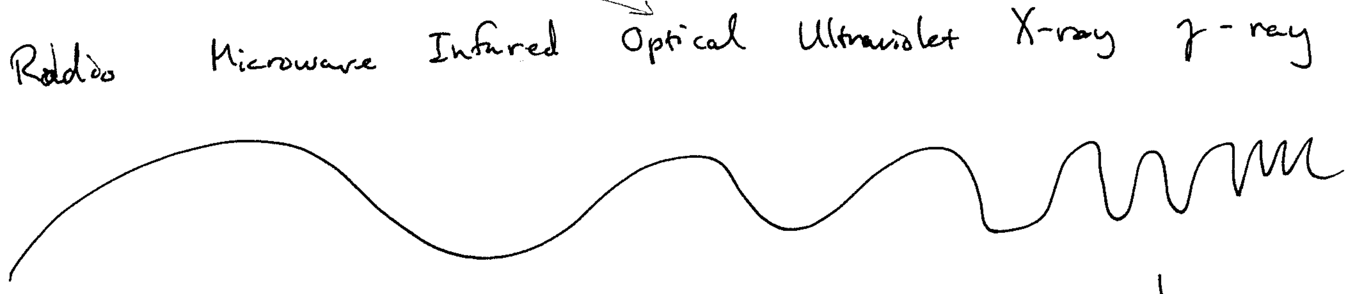
ASTR 201 EXAM II Review

Electromagnetic Radiation

Light is just one form



short wavelength
high frequency
high energy

λ Long wavelength
f low frequency
low energy

$$\lambda f = c$$

$$E = hf$$

h = Planck's constant

we see by scattered light

Hot objects emit light (thermal radiation, sometimes called "blackbody" radiation)

e.g., a
- hot stove top
- the sun

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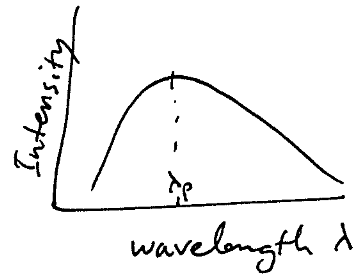
Physics of Light

Thermal radiation

Hot objects cool by emitting electromagnetic radiation over a broad spectrum.



The peak inetsity occurs at a wavelength λ_p that depends on Temperature through

- Wien's Law : $\lambda_p T = 2.9 \times 10^6 \text{ nm} \cdot \text{K}$
  - ↳ hotter object emit shorter wavelengths
- Stefan-Boltzmann Law $$\underset{\substack{\text{luminosity} \\ \text{(absolute} \\ \text{brightness)}}}{L} = \underbrace{4\pi R^2}_{\substack{\text{surface} \\ \text{area} \\ \text{of sphere}}} \underset{\text{constant}}{\sigma} \underset{\text{Temperature}}{T^4}$$
  - ↳ hotter objects emit more light

So hotter objects
- emit more energy
- are bluer

& bigger objects are brighter at a given Temperature

e.g., a star the same size as the sun but twice as hot will be $\left(\frac{T_*}{T_\odot}\right)^4 = 2^4 = 16$ times brighter than the sun

similarly for sizer:

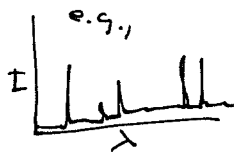
doubling the radius → $A \propto R^2 = 2^2 = 4$ times as brigh

Apparent brightness b is related to the luminosity by the inverse square law : $b = \frac{L}{4\pi d^2}$

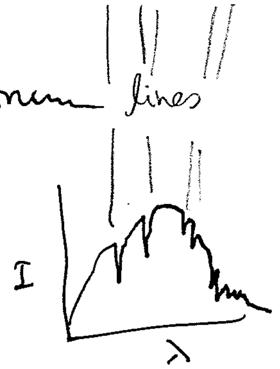
→ a star becomes fainter to our eyes as it gets farther away.

Kirchoff's Laws

- Hot, dense objects emit a continuous (thermal) spectrum
- Hot, diffuse gas emits an emission line spectrum



- Cool gas obscuring a background light source will result in an absorption line spectrum



Every element & molecule has its own specific set of emission/absorption lines, allowing them to be identified in the spectra of distant objects & their abundance measured.

Doppler effect

Motion causes a shift in wavelength : $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

The larger the velocity, the greater the shift

Approaching : blue shift

Receding : red shift

Telescopes : Bigger is Better : Light collecting are $\propto D^2$

The biggear the diameter D, Resolution $\propto D^{-1}$

Solar System

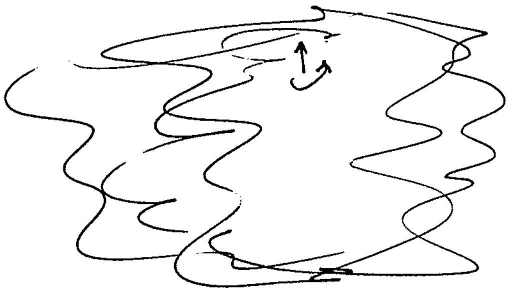
Know - contents & layout

names & order of major planets

location of Asteroid & Kuiper belts; Oort cloud

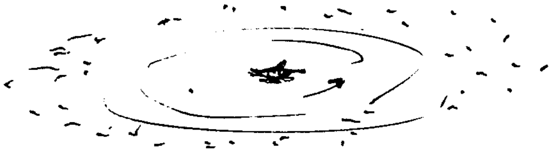
Distinctions between major planets, dwarf planets, moons, asteroids, & comets

Formation: solar nebular hypothesis

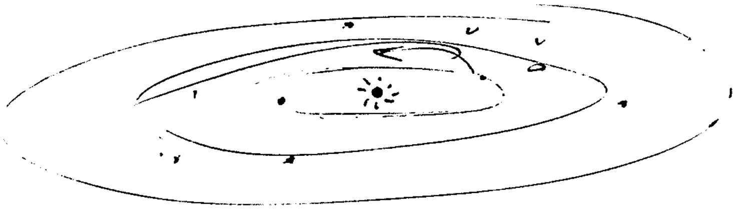


Initial cloud of interstellar gas

Collapse gravitationally into a preferred plane that spins up through the conservation of angular momentum



Sun starts to form in the center of the solar nebula. Solid particles condense out of gas with a composition that depends on the temperature



Solid particles agglomerate into planetesimals which collide until

Major planets have formed by sweeping up (or out) all

Condensation sequence

Nearest the young sun the solar nebular is hottest. Only the most refractory materials (mostly metals) can condense into solids. Hence the relatively large iron core of Mercury.

Moving outwards from the sun, the temperature steadily drops and progressively more materials can condense into solids. Hence the bulk composition of Venus, Earth, & Mars includes silicates and other rocky minerals in addition to their iron cores.

Still further out, one crosses the frost line (also called the ice line) around 3.5 AU. Here the temperature becomes cool enough for water (and other hydrogen compounds) to freeze into solid grains of ice.

Ice is effectively another mineral in the outer solar system, being an important part of the bulk of the moons of the gas giant planets and dwarf planets.

Terrestrial planets form by the agglomeration of rocky & metallic planetesimals

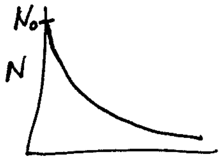
Jovian planets form as miniature solar systems within the solar nebula, perhaps seeded by large planetesimals. Accrete abundant hydrogen & helium gas to become massive while a system of moons

Asteroids & Comets are the rocky & icy (respectively) left overs of planet formation. There are relatively few left now – the sum of all asteroids is much less mass than any of the terrestrial planets. There were more in the past, especially in the distant past going back to the era of "late heavy bombardament" about 3.8 billion years ago (vs. the 4.5 billion year age of the solar system)

The conservation of angular momentum during the collapse of the solar nebula explains why the major planets all orbit prograde and also (mostly) spin prograde. Exception (like the extreme axial tilt of Uranus) can be attributed to the individuality of the last major collision during formation (such an event is thought to have formed the Earth's moon.)

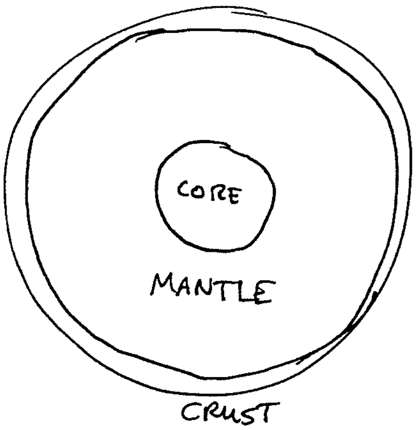
The isotopic composition of moon rocks & the Earth's mantle suggest a common origin. Ages can be dated through radioactive decay:

$$N = N_0 e^{-t/\tau}$$



Terrestrial Planets

Interior structure



CORE : high density,
metallic (iron, nickel)

MANTLE : mid-density,
rocky material

CRUST : lowest density rocks
Part of rigid lithosphere
floating on more plastic, hotter rocks of ~~the~~ mantle

In the case of the Earth, the core is further divided into a solid inner core and a liquid outer core. The other terrestrial planets probably had such a structure in the past, but they've cooled off & mostly solidified.

This CRUST – MANTLE — CORE structure is a natural consequence of differentiation during planet formation. The planets were initially molten from the heat of the many collisions that built them. Dense material (like iron) sank to the center to form the CORE while lighter materials floated on top.

Geological activity like volcanoes & earthquakes is driven by the escape of heat from the interior. Initially this is just the heat leftover from formation; later the major contributor to keeping the interior warm is the decay of long lived radioactive elements (like Uranium). In both cases, larger planets have and retain more heat for longer as the trapped heat scales as the volume (R^3) while the cooling only happens through the surface (R^2).

→ Small planets like Mercury have mostly cooled off and are now geologically dead.

→ Bigger planets like the Earth retain some interior heat, so remain geologically active.

Terrestrial Planet Surfaces Shaped By

- Impact Cratering – the dominant effect on most planets, but not Earth
- Volcanism – active everywhere; mostly in the past
- Plate Tectonics – mostly on the Earth
- Erosion
  - wind
  - water – rivers, rain, ice & glaciers

Old surfaces have lots of craters : the accumulated scars of time

Surfaces lacking many craters must be younger, getting re-paved

Individual Cases - every planet is unique in some way
by increasing size

- The Moon : geologically dead. Heavily cratered surface. Darker maria regions where lava filled in larger craters after the period of heavy bombardment but still in the ancient past (~ 3.5 billion years ago)

- Mercury : geologically dead. Heavily cratered, but also with smoother spots covered by ancient lava (like the moon). Additionally, Mercury shrank substantially in radius as it cooled, leaving huge, planet-spanning stretch-mark cliffs ("scarps").

- Mars : Many craters but also many other features: giant extinct volcanoes, enormous canyons, wind-blown sand dunes, erosion features that are apparently ancient river beds. We now have good evidence that water once flowed on the surface of Mars, and still seeps from crater rims on occassion.

- Venus : Fewer craters, mostly large. Volcanoes (mostly extinct but maybe not all) plus dome-like features not seen elsewhere. Some hints of fractures attributed to failed plate tectonics.

- Earth : Geologically active. Plate tectonics with mountain building and seabed spreading and plate subduction. Volcanoes at plate boundaries and also over hot spots (e.g. Hawaii). Very active erosion (wind,

Terrestrial Planet Atmospheres

The thin veil between a planet's solid surface and the hard vacuum of space

Atmospheric Pressure $P = NkT$

Temperature

Pressure

constant

Number density of air molecules

More gas means higher pressure

Higher Temperature means higher pressure

Pressure is a function of altitude, being greatest at the surface where the weight of the atmosphere above presses down, and decreasing to zero upwards as the atmosphere tapers into space.

Planet	Pressure (ATM)	Composition	Temperature
Mercury	—	—	797° F (day) -283° (night)
Venus	90	96% CO_2 3.5% N_2	878°F
Earth	1	78% N_2 21% O_2 + H_2O, CO_2, etc.	~59°F
Moon	—	—	257°F (day) -283° (night)
Mars	0.007	95% CO_2 2.7% N_2	-58°F

The "normal" atmospheric composition appears to be CO_2 & N_2. The Earth is unique in having washed most of its CO_2 out of the atmosphere and sequestering it in rocks. It is also unique

Climate

The temperature of a planet is a balance between

↑ heat input from sun

↓ heat lost to space

Sunlight warms the surface by day, which cools by night by radiating into space as a thermal radiator (with λ_p in the infrare

Heat input depends on
- distance from the sun
- albedo of surface

Heat loss to space depends on
- temperature reached during day
- heat trapping by atmosphere

Greenhouse Effect

Gases like CO_2, H_2O, CH_4 have strong absorption lines in the IR

Remember Kirchoff's laws: heat trying to escape into space as InfraRed radiation is partially absorbed and trapped by greenhouse gase

The final temperature is determined by the balence of heat input and heat outflow. The more trapping of heat by greenhouse gases, the higher the resultant temperature.

Hence Venus, with a thick CO_2 atmosphere, is very hot — hotter even than Mercury, despite its greater distance from the sun.

Factors Affecting Atmospheres

Sources of Atmospheric Gas:

- Outgassing by Volcanoes
- Evaporation/Sublimation of Liquid/Ice from surface
- Delivery from comets

Sinks of Atmospheric Gas:

- Thermal Escape to Space
- Condensation onto surface
- Chemical reactions combining with surface materials
- "Bombardment" - splitting of molecules by hard radiation with subsequent escape of lighter components to space.
- Atmospheric cratering - big impact events can eject material into space & take some atmosphere with it.

The Atmosphere of Mars appears to have evolved from one thick & warm enough in the ancient past to permit the presence of liquid water to the thin, cold place it is now through a gradual loss of gas both to space and to condensation on the surface.