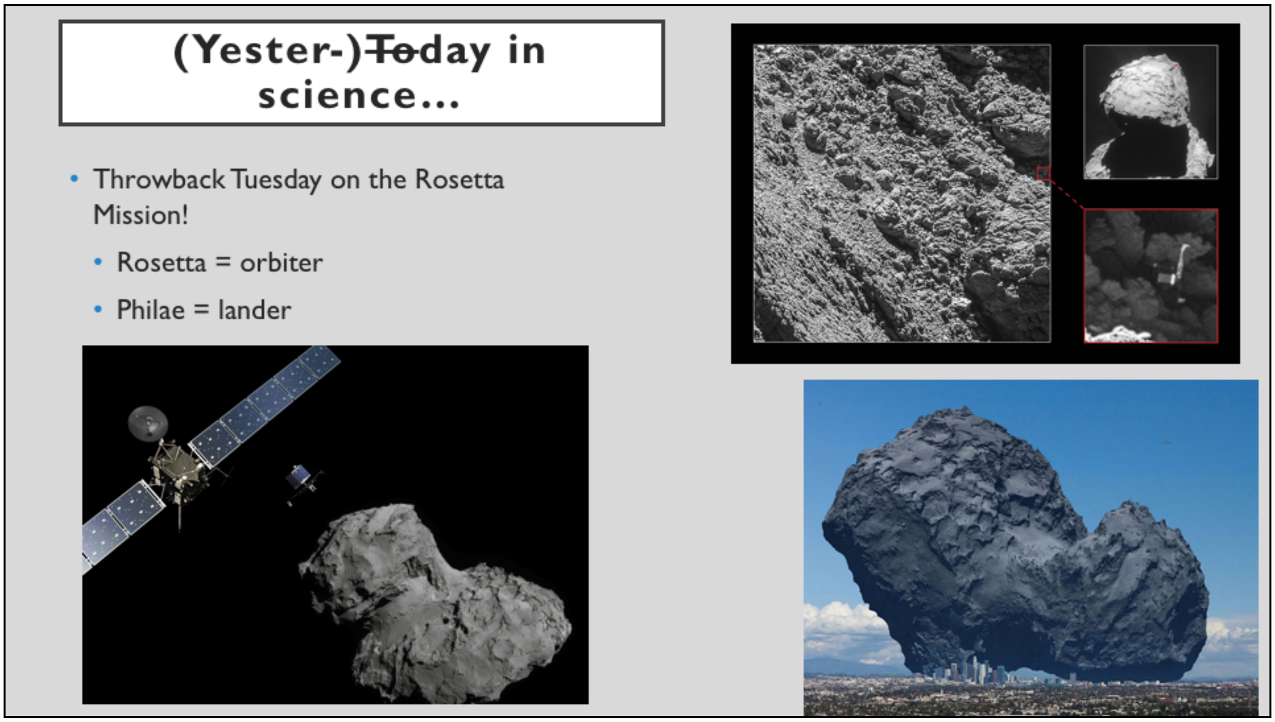
Today in science…

- Kind of..
- "We've been conditioned… to focus on our talents, and to let them define us. These descriptors might limit us, but they also comfort us... they do not readily leave room for attempting something new—and sucking at it"
- Consider your positionality sitting in this classroom.
  - Stereotype threat
  - Growth mindset

This is what I read this weekend, I think it applies to learning physics as well as anything else new

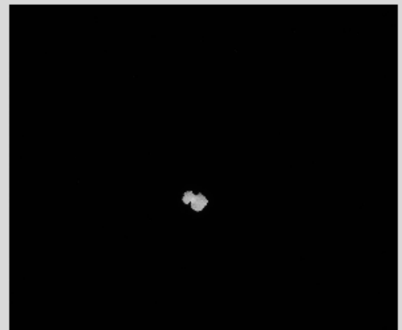


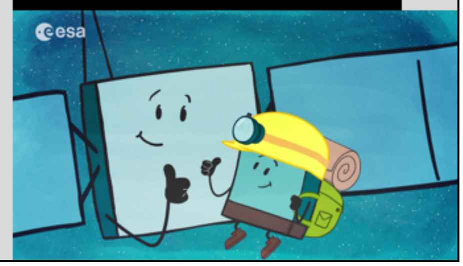
67P compared to Denver, I'm pretty sure
https://twitter.com/AntonioParis/status/1039274847719829504

67P/Churyumov-Gerasimenko is the full name of the comet

Why did Philae bounce?

- F_g!
- A little math… what is acceleration due to gravity on the comet, and how does that compare to Earth?
  - $Fg = \frac{G M_{comet} M_{Philae}}{R_{comet}^2} = M_{Philae} * a$
  - $\frac{6.67 \times 10^{-11} m^3 kg^{-1} s^{-2} * 10^{13} kg}{(4000 m)^2} = a_{comet}$
  - $4.17 \times 10^{-5} m/s^2 = a_{comet}$ (compare to $9.8 m/s^2$ on Earth!)



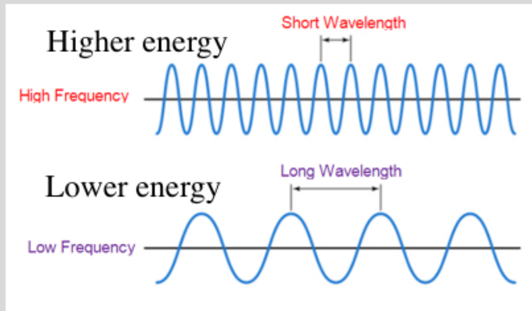


http://sci.esa.int/rosetta/14615-comet-67p/

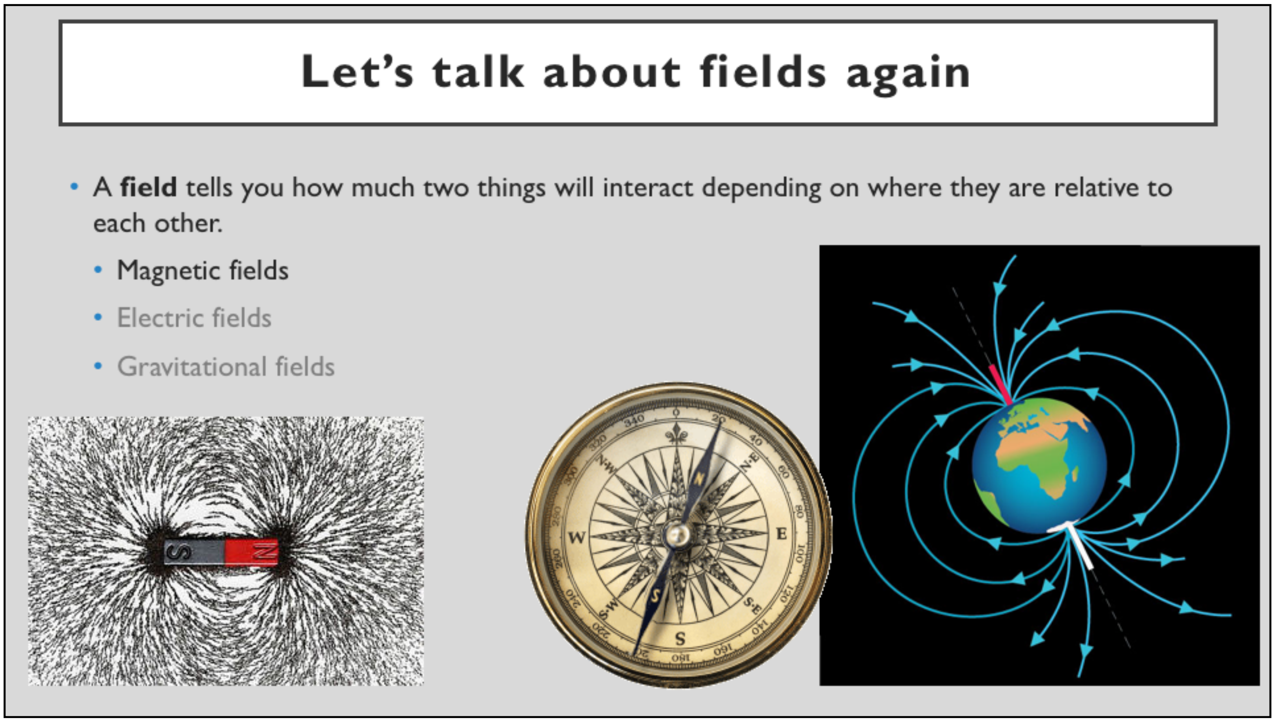

Properties of light
The Cosmic Perspective, Chapter 5, 5.1-5.2

Recap of last time

- Last time, we talked about the behavior of light
  - Light is emitted
  - It can be absorbed, transmitted, reflected, diffracted, scattered, and it can interfere
    - Scattering depends on size of scatterer (molecules in atmosphere, clouds) and the wavelength of the light
    - Blue efficiently scattered in atmosphere, red not



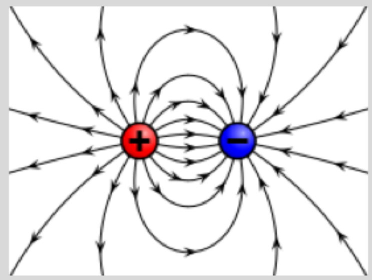
Light can have



I'm afraid that last time I went too fast and might have given you the idea that light is a stream of charged particles.. It is not.

Let’s talk about fields again

- A **field** tells you how much two things will interact depending on where they are relative to each other.
  - Magnetic fields
  - Electric fields
  - Gravitational fields



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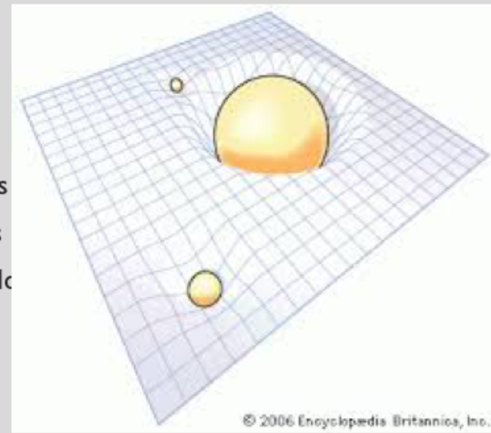
Let’s talk about fields again

- A **field** tells you how much two things will interact depending on where they are relative to each other.
  - Magnetic fields
  - Electric fields
  - Gravitational fields
- Every day, we are surrounded by, and move through, fields
  - Charged particles interact with magnetic, electric fields
  - Light and massive objects interact with gravitational fiel



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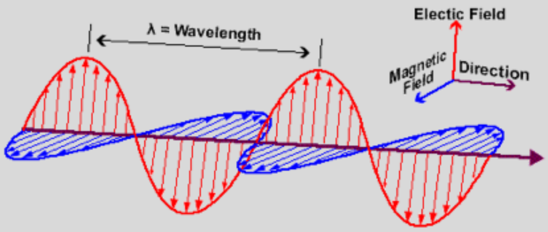
Light as an electromagnetic wave

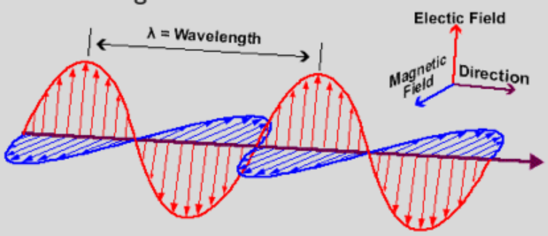
- The nature of light was experimentally determined
  - Light was seen to behave as a particle, and
  - As a wave. It was observed to have electric and
  - Magnetic properties; thus, defined as an electromagnetic wave.

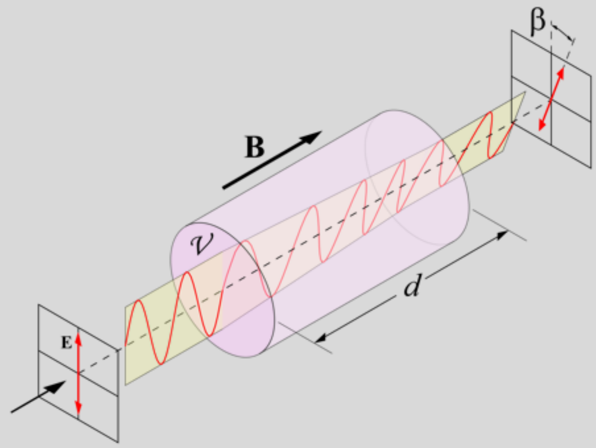


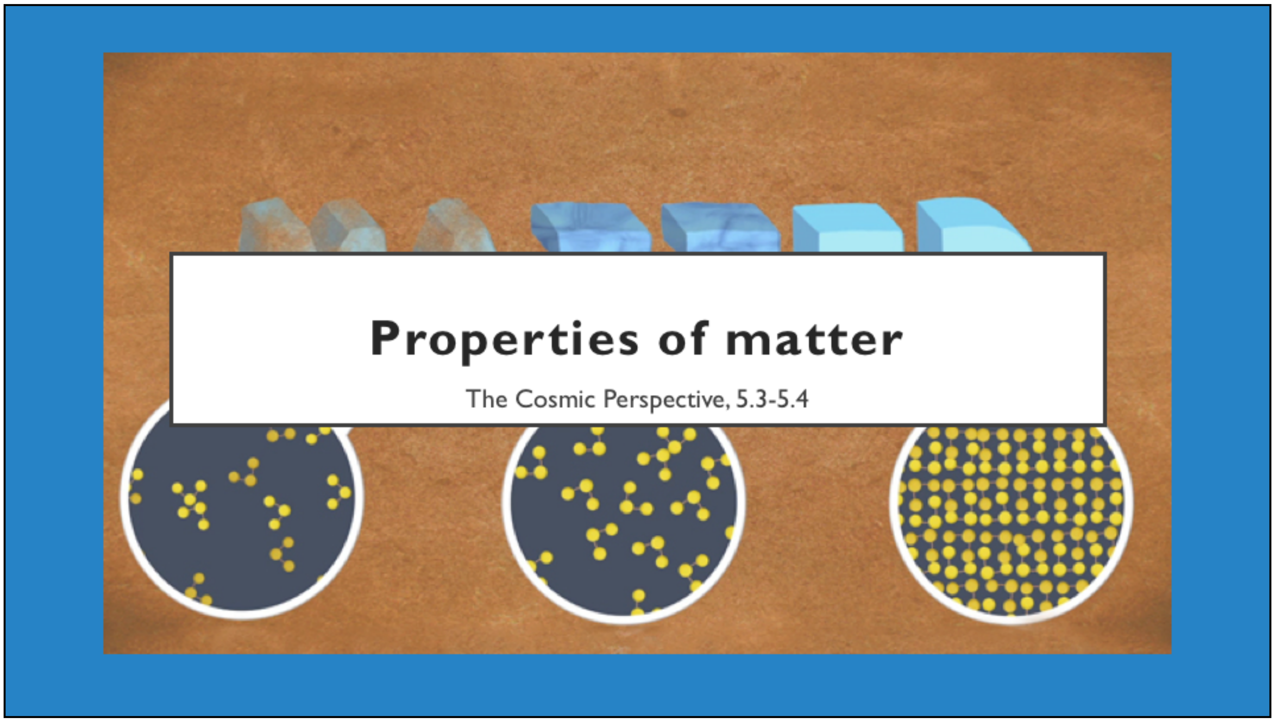
https://commons.wikimedia.org/wiki/File:Faraday-effect.svg

The Faraday effect

- Light can be *polarized*
  - Polarization is the orientation of the electric field in the electromagnetic wave
- Faraday found that light's polarization changes depending on the magnetic field it travels through



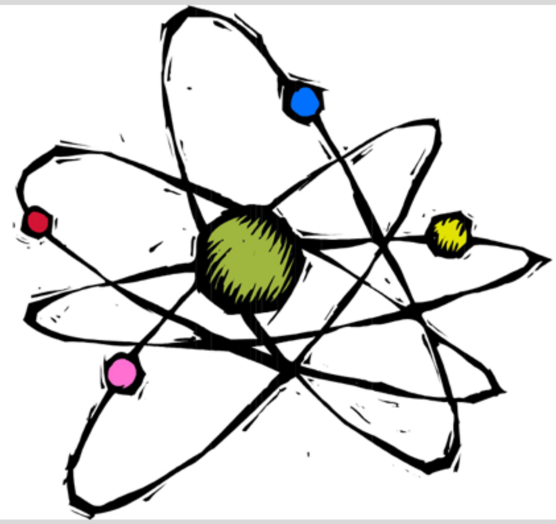



Properties of matter
The Cosmic Perspective, 5.3-5.4

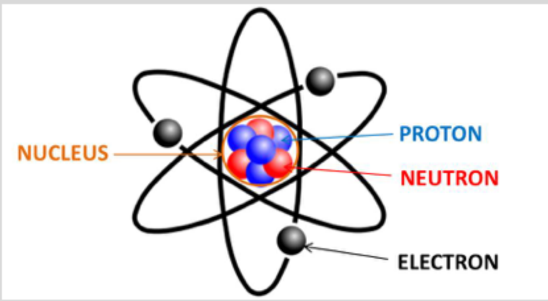
Atoms!

from Greek *atomos:*

'indivisible,' based on *a-* 'not' + *temnein* 'to cut.'



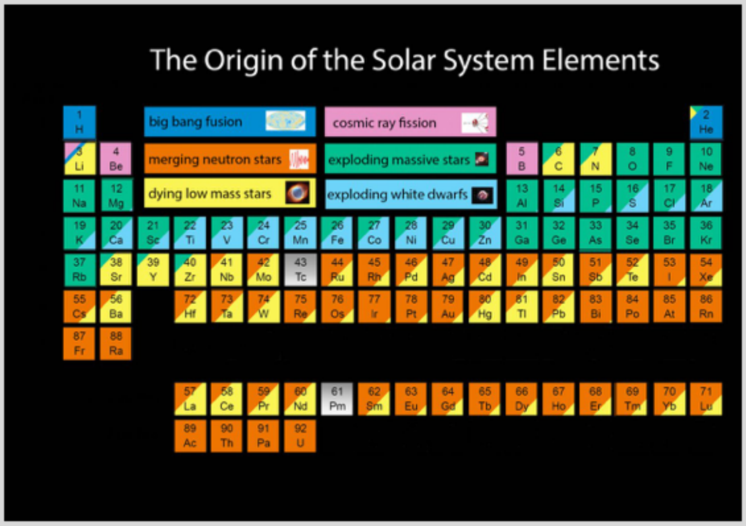
Atomic structure



- Proton: +1 charge
- Electron: -1 charge
- Neutron: 0 charge

- *Incredibly* small– 10^{-10}m across
- Proton, neutron, each ~2000x more massive than electron

Atomic structure

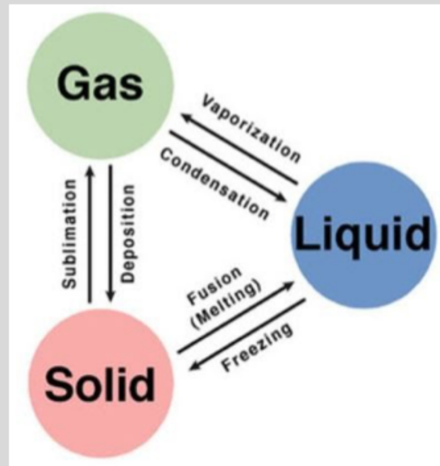


- Atomic number: how many protons in the nucleus
- Atomic mass number: combined number of protons and neutrons (recall: mass of electron is tiny tiny!)
- Atoms can combine to form molecules

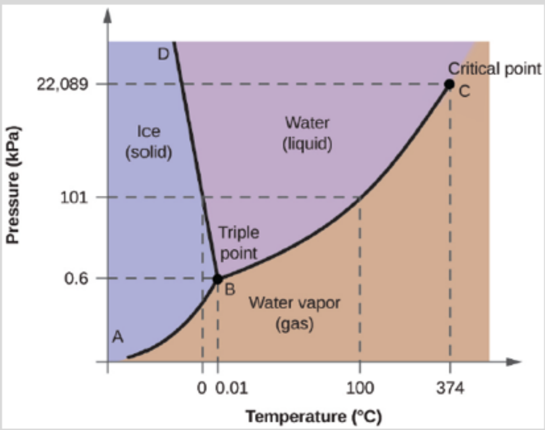
https://twitter.com/jajohnson51/status/816827622369935362

Phases of matter

- Depends on the *phase* of matter
  - Solid
  - Liquid
  - Gas
- Phase of matter depends on
  - composition
  - temperature
  - pressure

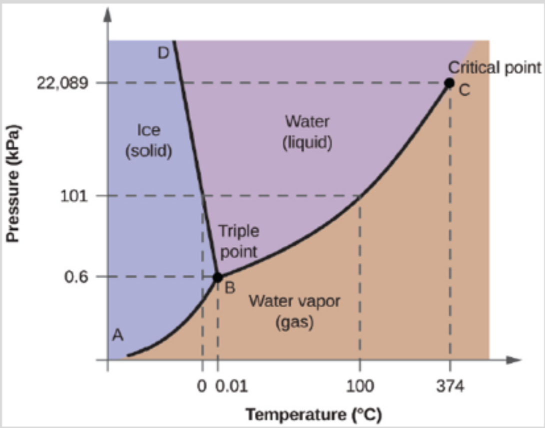


Phases of matter: Water



- At low temperature…
  - Low kinetic energy of molecules
  - Molecules bound to 4 other molecules
  - Tightly packed, solid
- Increase the temperature…
  - Kinetic energy increases,
  - Molecules bond to ~3 other molecules
  - Loss of rigidity, can now flow: liquid
- Increase the temperature even more…
  - Molecules begin to move freely
  - Gas phase

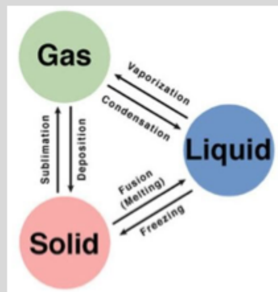
Phases of matter: Water

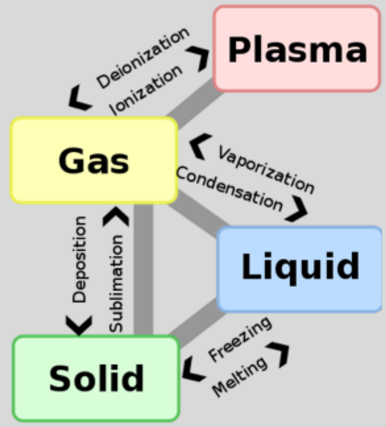


- From solid to liquid: melting
- From liquid to gas: evaporation
- From solid to gas: sublimation

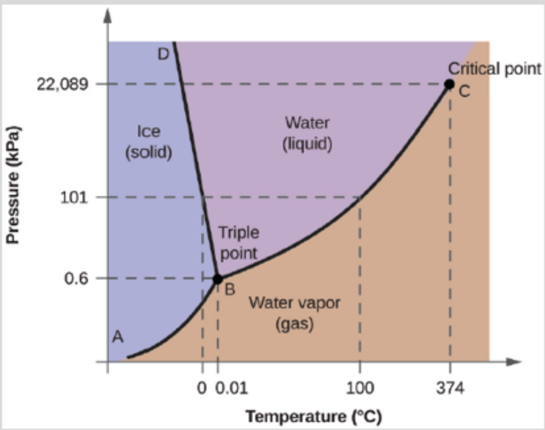
Phases of matter

- Beyond the boiling point?
  - Can break up molecules: molecular dissociation
  - Adding even more energy can free electrons from atoms: ionization
    - Ion: an atom with some net charge (either positive or negative)





Phases of matter: the effect of pressure



- ***Pressure*** is force per unit area
- High pressure can keep water in liquid form despite temperature changes
- In Earth's core, it's hot enough for iron to be molten, but high pressure keeps it a solid

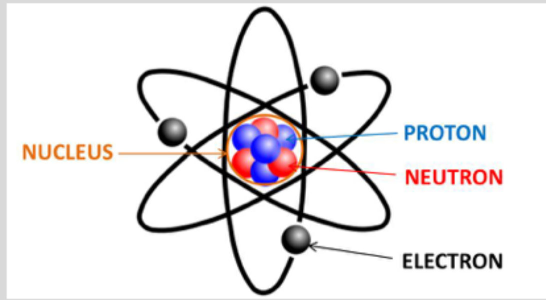
High pressure keeps water from going into a gas phase or a solid phase.

Increasing pressure makes it harder for molecules to escape water into a gas phase: the energy required to escape gets higher, the boiling point rises.

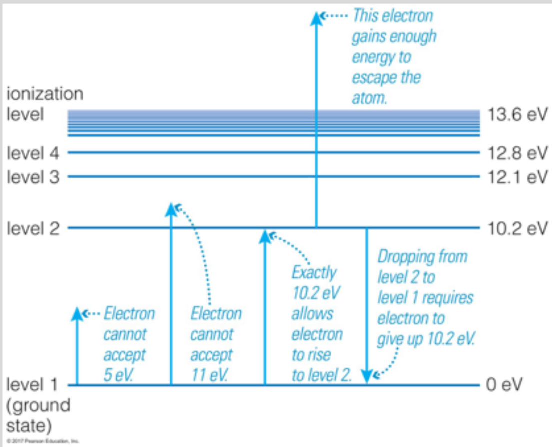
In the Earth, the pressure doesn't allow the iron in earth's core to move freely, so despite the heat and energy of the iron atoms, they stay tightly bound to their neighbors.

Back to atoms…

- Electrons have energy
  - Discrete **energy levels** possible
  - Can gain or lose energy, but only in specific amounts



Atomic energy levels

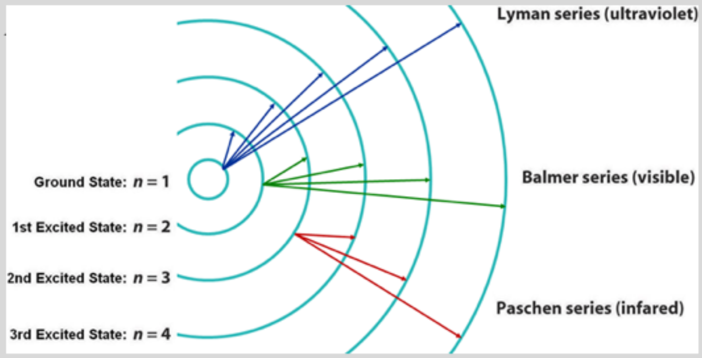


- These discrete energy level jumps possible are *quantized*; called *quanta*
  - Origin of *quantum mechanics*
- We use units of energy, eV, electron-volts (where 1 eV ~ 10^{-19} Joules; 1 Joule = 1 $g*m^2/s^2$)

Energy level transitions

- Lowest possible energy level is called 0
- Other levels are defined relative to that level
- When electrons gain energy, they move to higher energy levels
- When electrons lose energy, they move to lower levels

- How do electrons gain or lose energy?
  - Gain: absorbing energy from light
  - Lose: emit light!

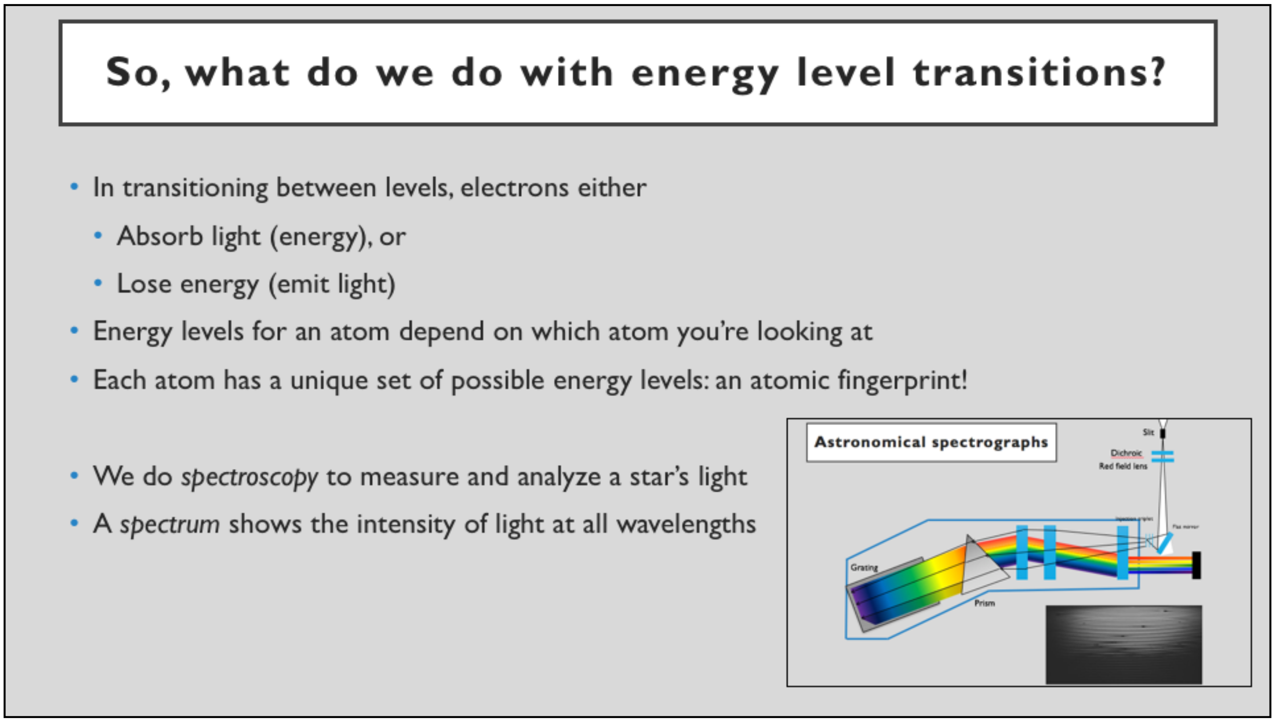


Quantized, quantum what now?

- Quantum mechanics is weird.
  - Einstein was unconvinced: "I, in any case, am convinced He does not play dice with the Universe."
  - Feynman acknowledged its abstraction: "If you think you understand quantum mechanics, you don't understand quantum mechanics."

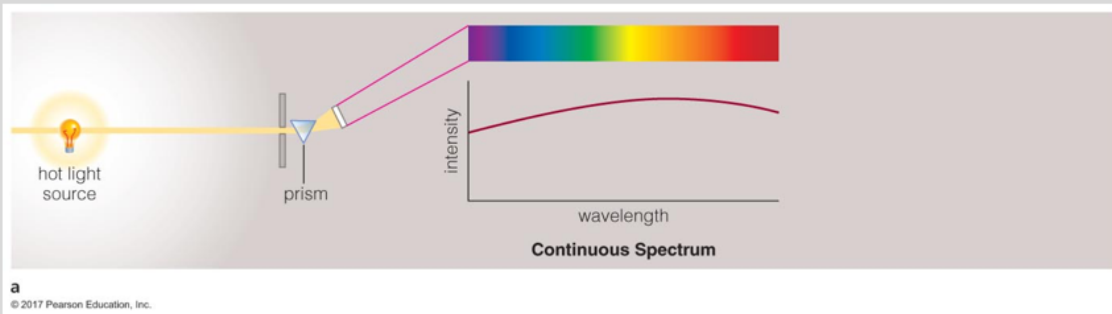
- tl;dr version of quantum mechanics: a way of describing how atoms, and subatomic particles, behave. It's based in probability and statistics, and accepts there are some measurements you cannot make at the same time. Moved our thoughts on physics from equals signs to inequalities.

https://en.wikipedia.org/wiki/Bohr–Einstein_debates

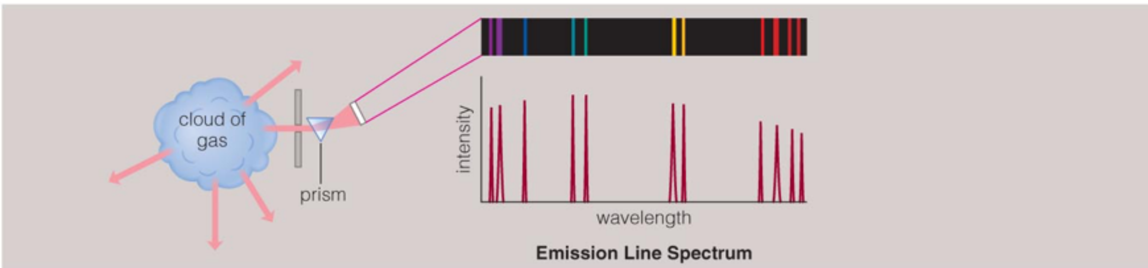


Inset from lecture 8 slides

Continuous sources

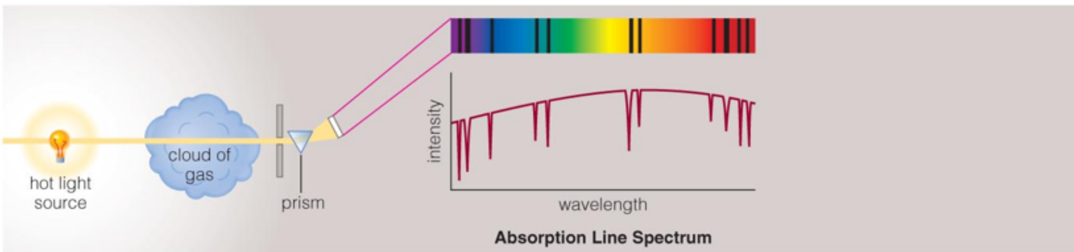


Emission line spectrum

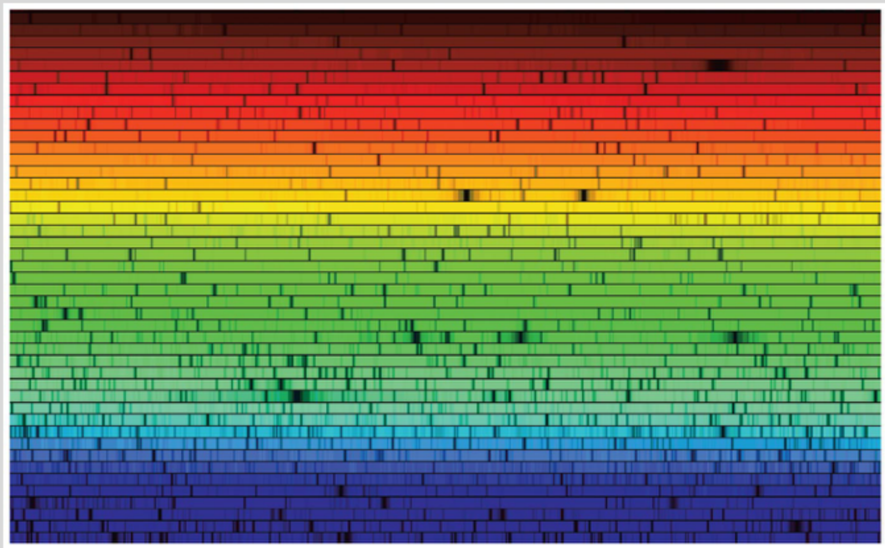


b

Absorption line spectrum

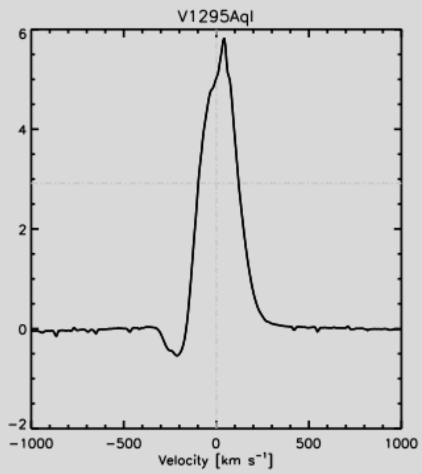


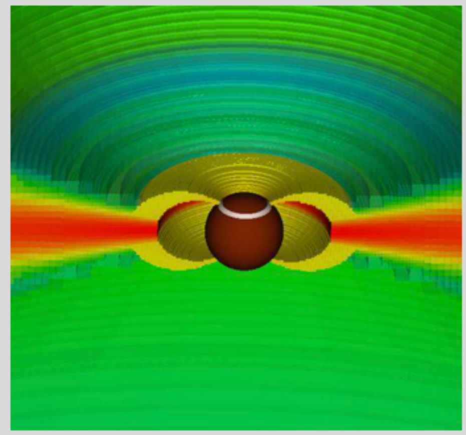
The Sun



The spectrum of the sun. you see continuum emission (rainbow colors) and absorption (black lines of various broadness)

Stellar spectrum: emission, absorption, *and* continuum

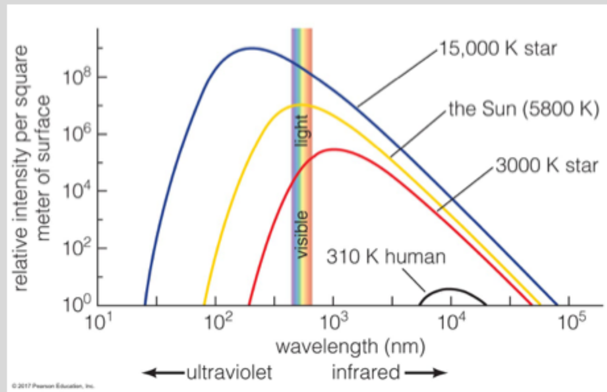




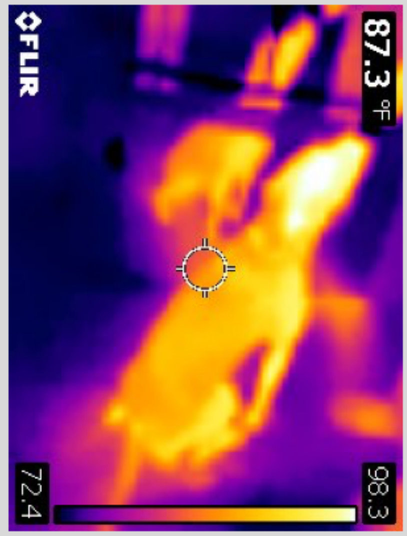
On the left, the Hydrogen alpha line of a young star. The x-axis is showing the doppler shift in velocity from the center of the line at 6563A. On the right, a model setup of this star, interacting with a circumstellar disk, via magnetic field.

Thermal radiation

- On the sun and stars, we see a combination of absorption, emission, and continuum. Where does the continuum come from?
  - "Blackbody radiation," which is thermal emission
  - Depends on an object's temperature



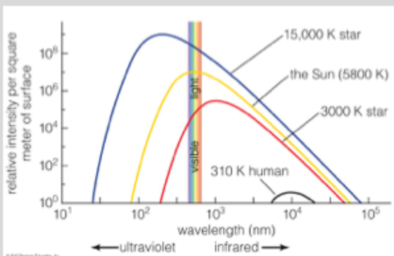
Thermal radiation



My dog’s thermal emission, viewed in the infrared. Infrared light also reflects, like off of the stainless fridge!

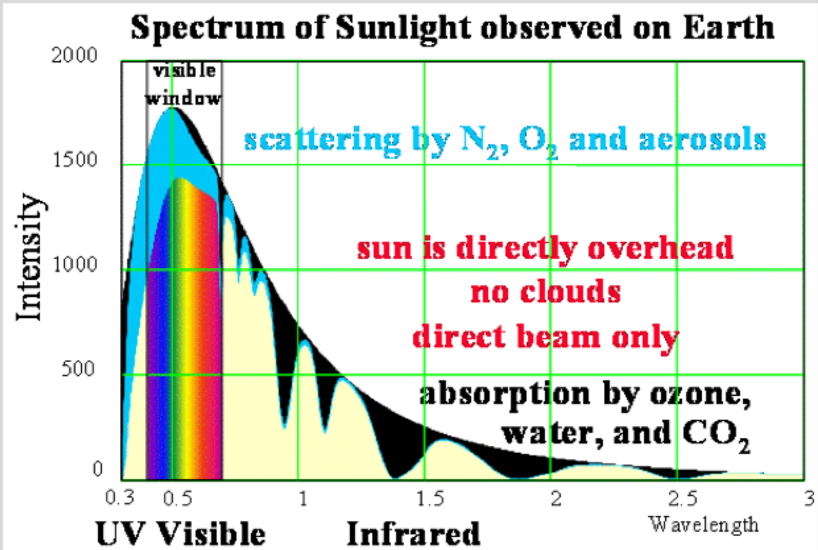
Two laws of thermal radiation

- Stefan-Boltzmann law
  - When you look at the same size piece of thermally emitting objects, the hotter object always emits more light at all wavelengths
    - Can see this in curves below



- Wien's law
  - Hotter objects emit photons with higher average energy
    - The peak of the intensity curves move bluer as objects are hotter
    - Affects color of an object. Example: the Sun peaks around green wavelengths

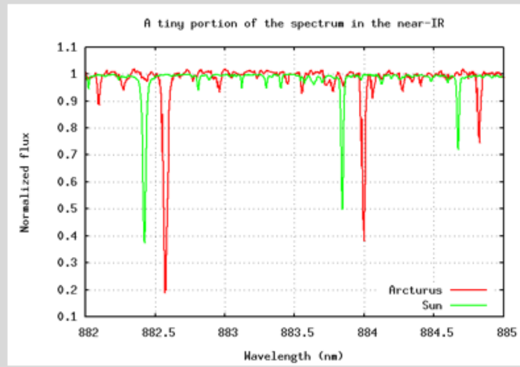
The Sun, again



https://web.calpoly.edu/~rfield/Thermalstructure.htm

Doppler effect

- As something is moving toward or away from us, the position of the source of a wave is moving, so the observed wavelength *appears* to shift
  - Imagine an ambulance going by. You hear the tone of the siren changing as it goes by.
  - Imagine driving the ambulance. You hear the same tone of the siren no matter where you're going or how fast.



http://spiff.rit.edu/classes/phys301/lectures/doppler/doppler.html

Stellar motions

- Stars are moving relative to us in the galaxy: we can measure their speeds toward or away from us using the Doppler effect
- (We can also measure motions of galaxies toward and away from us)

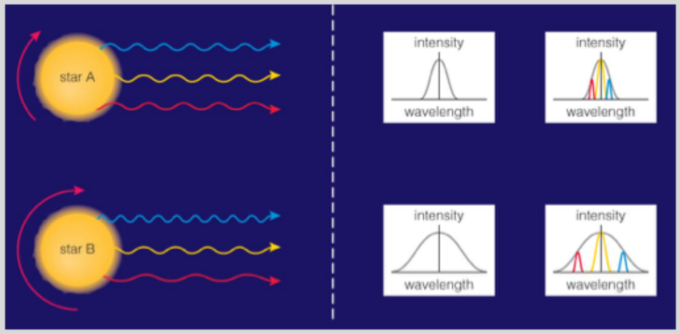
Click the blue box… it goes to https://www.classzone.com/books/earth_science/terc/content/visualizations/es2802/es2802page01.cfm?chapter_no=visualization

What's wrong with this visualization? It's cool but there's definitely something wrong with it…

Some typical radial velocities measured for nearby stars: ~2km/s. Doesn't sound like much, but it's about 4500mph!

Stellar rotation

- As stars rotate, plasma on one side is moving towards us coming into view while plasma on the opposite side is moving out of view, away from us
- Rotation of the star has an observable Doppler shift!
  - Signature is greater the faster a star is rotating



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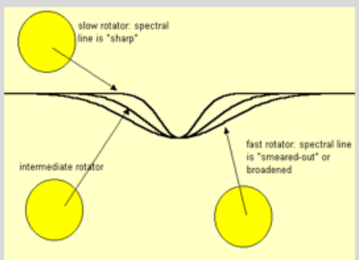
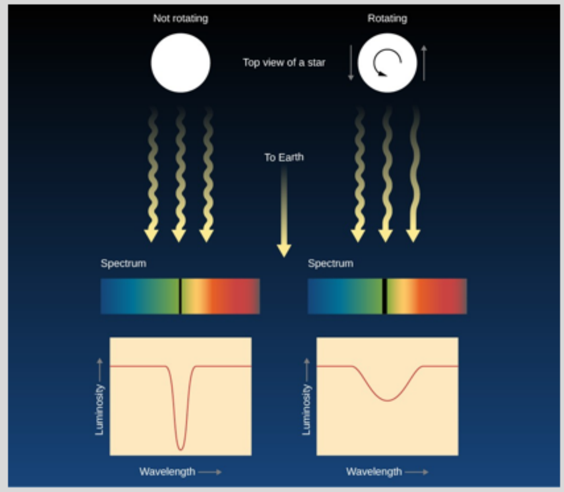


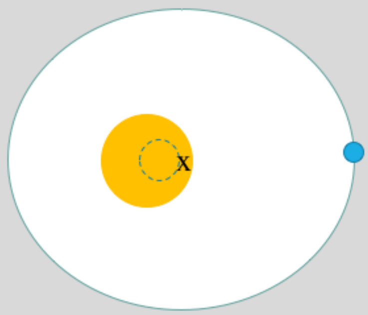


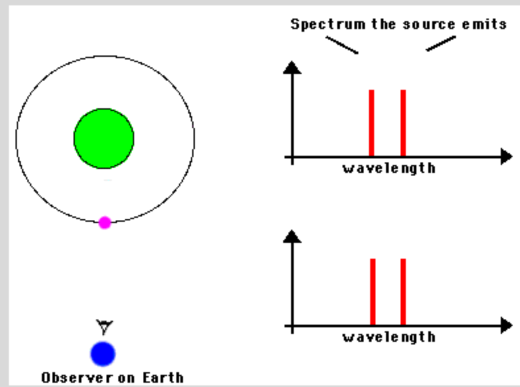
http://www.kcvs.ca/martin/astro/course/lectures/fall/a200l10g.htm

https://courses.lumenlearning.com/astronomy/chapter/using-spectra-to-measure-stellar-radius-composition-and-motion/

Stellar motion due to planets

- We use Doppler shift to detect planets around other stars!
- As the planet orbits, it 'tugs' on the star (both orbit a common center of mass)
- The star's 'small orbit' is detectable in its spectrum





Remember when I forgot to tell you about detecting exoplanets? This is how!
http://www.faculty.virginia.edu/ASTR5110/lectures/spectroscopy/spec.html

Recap for today

- Today, we talked about
  - Atoms and their structure
  - Phases of matter
  - Atomic energy levels
  - Energy level transitions in atoms
  - Types of spectra
  - Thermal radiation
  - Fingerprints of chemistry, temperature, and motion on spectra

https://www.redbubble.com/people/startorialist/works/22175215-one-sun
(not an advertisement)