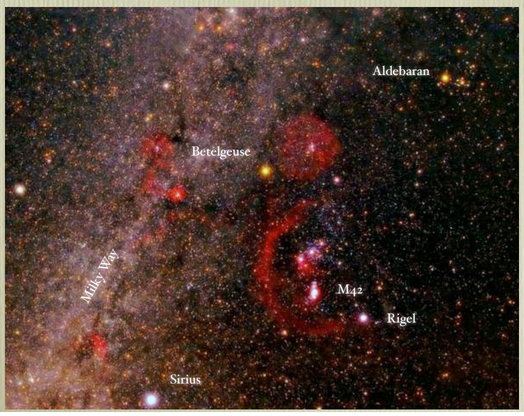
Radiation (again, again!)
And photons



Peter Watson

Ashar Shoaib

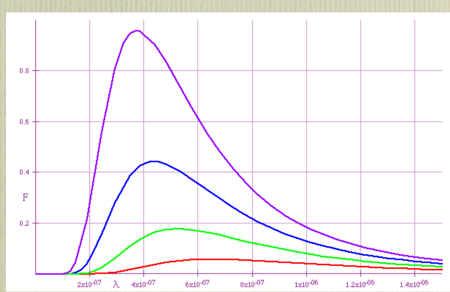
1. What is light?

2. Light exhibits both particle and wave properties and we like to believe we have some understanding of what light is and how it works. How can something show properties of two different things? Is light made of entirely of something different for which we have no name or understanding? Or does light go through a special phenomenon which allows it to switch between being a particle and wave. Or do we not fully understand the connection between a particle and a wave?

3.5. We might have few different theories and explanations for this question yet there is no consensus between scientists around the world.

Planck (1900)

- Was trying to understand black body curve



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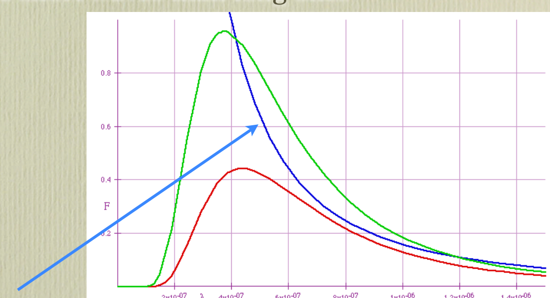
- If we take waves at random,no expectation that we would get any particular wavelength
- a lot more short waves than long ones



Get completely the wrong curve

Also: how can light have a temperature?

- Think of box of different atoms:
- velocities of each will be random,but will "average out" to give smooth curve.
- Energy is equally divided between different molecules on the average:
- also average energy increases with temperature.

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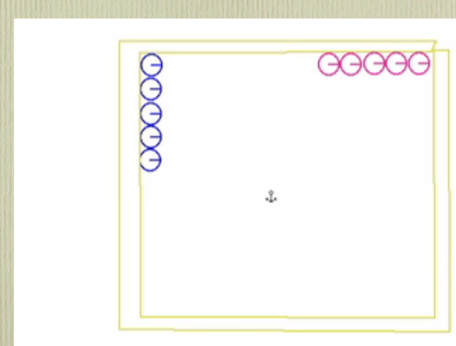
- Collisions redistribute the energy: heavy molecules move slower on average



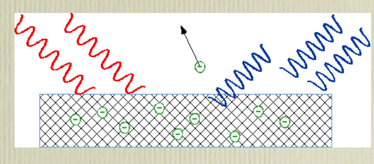
- But suppose light is a particle...
- Planck (1900) suggested that E.M. radiation is emitted in lumps of energy (quanta) which became known as "photons"

- First we need new unit of energy: Joule is much too large for atomic processes
- 1 electron-volt (eV) = 1.6×10^{-19} J
- 0.00000000000000000016 J
- most chemical processes involve energies of a few eV per molecule

- Energy of photon = Planck's constant x frequency
- E = hf
- Photons are also particles with a difference:
- Always travel at c (speed of light) and can easily be created and destroyed.
- At room temperature average photon has E ~1/40 eV (same as average energy of gas molecule)
- photon of yellow light has energy ~ 2 eV

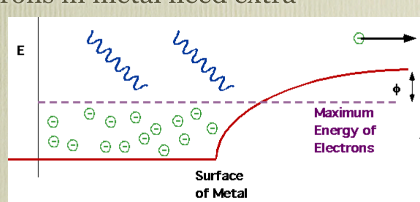
Photo-electric Effect

- Light shone on metal produces (small) electric current
- Electrons are kicked out of metal
- but current depends on colour of light & kind of metal
- blue (small λ, large f) gives high energy electrons
- red (large λ, small f) may not give any



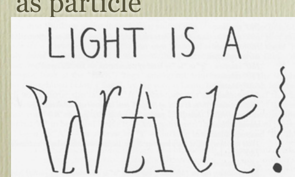
Einstein and the Photo-electric Effect

- Since particles have energy, photons must carry energy (obviously light has energy: that's how you get a sun tan!)
- Einstein (1903): light is absorbed in quanta (photons)
- most energetic electrons in metal need extra boost to escape:



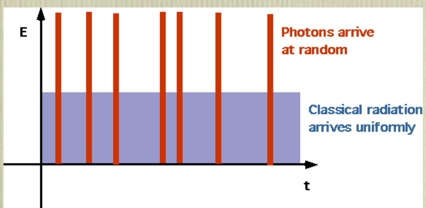
But you told me light was a wave............! What is light?

- Particle? Newton, Descartes
- Wave? Young, Huygens
- Yes? Planck, Einstein
- Light travels as wave, but arrives and departs as particle



Douglas R. Hofstadter

- So we have to take photons seriously!
- Electrons are ejected as soon as light strikes (no need for energy to accumulate), since photons arrive randomly



- Photons “average out” to give same total energy

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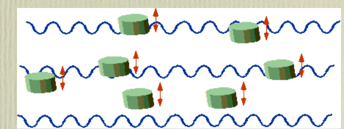
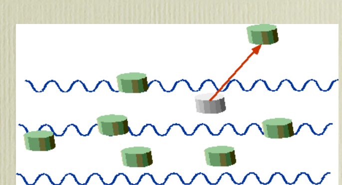
- The first of many paradoxes:
- How could we detect water-waves if we couldn't see water?
- "Classical" corks bob up and down



- "Quantum" corks are either stationary or ejected.



Why are we not aware of discrete arrival of photons?

- Frequency of orange light $4x10^{14}$ Hz
- Energy of photon 2eV

- A 60W bulb produces $2x10^{19}$ photons each second , so gap in time < 10^{-18} s
- Our eyes take 1/50 s to respond
- Note that the shorter the wavelength, the more like a particle, so X-rays are usually treated only as particles.

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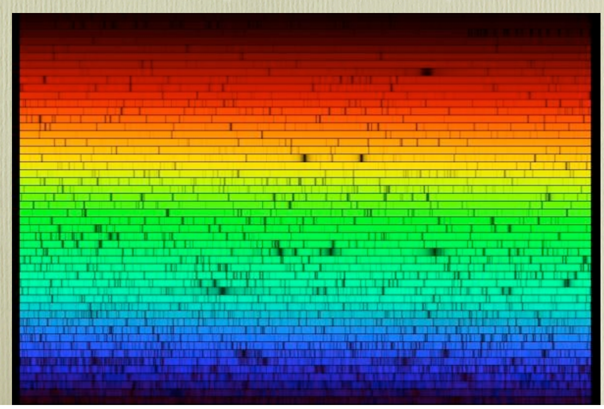
Fraunhofer (1817)

- Found black lines superimposed on sun's spectrum.
- This is the sun's spectrum "folded up"



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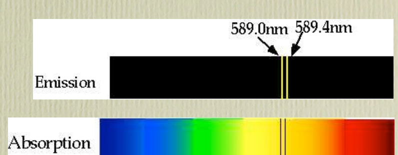
- Heated gases give characteristic wavelengths, e.g. Sodium
- Can match dark lines in solar spectrum to bright emission lines:



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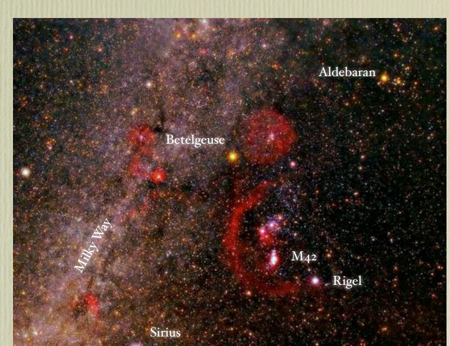
Orion

- Sirius; fairly dim star that is very close
- Rigel: blue supergiant: would be 1000 times brighter than Sirius if it were at the same distance
- Betelgeuse: cool red supergiant



- But what’s the red stuff?

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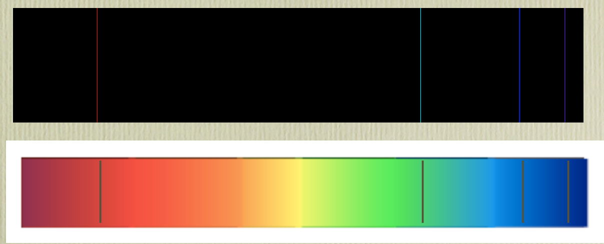
Hydrogen

- Simplest atom



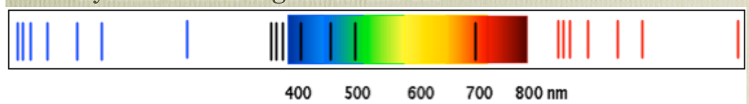
Emission

Absorption

Balmer found a very simple formula for this

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right), m = 132435465..6...., m > n$$

- Paschen discovered the spectrum goes to the UV
- Lyman found it goes to the IR



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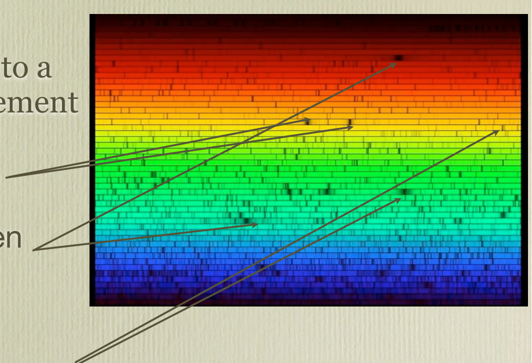
- We can look at the light from the sun
- Each line is corresponds to a particular element
- e.g sodium
- and hydrogen



- But these lines didn't correspond to anything

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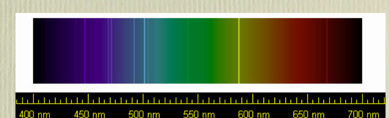
Until we discovered Helium

- Discovered in sun in 1868
- on earth in 1895



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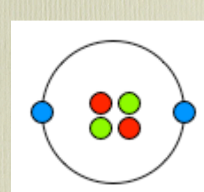

Problems

1. What gives the formulae?
2. Why do atoms only emit certain wavelengths?
3. How are absorption and emission related?

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Anya Besharah

I am curious about why it is sound when moving towards you is at a higher pitch than when it is moving away from you? I saw some place that this information was used to track which way galaxies rotate and I find that fascinating. It made me wonder about other physical properties of sound waves and how they are used in physics. It is a very broad question but I think worth exploring.

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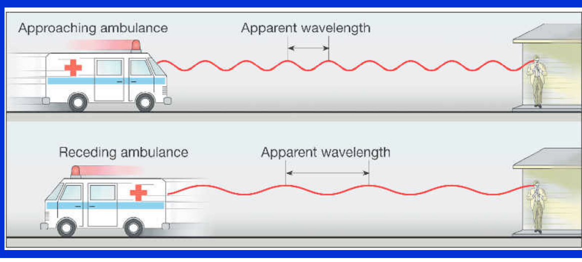
Doppler shift

1. Universal for all waves, including sound
2. Wave gets “stretched out” by motion
3. Can measure how fast something is moving by looking at the light



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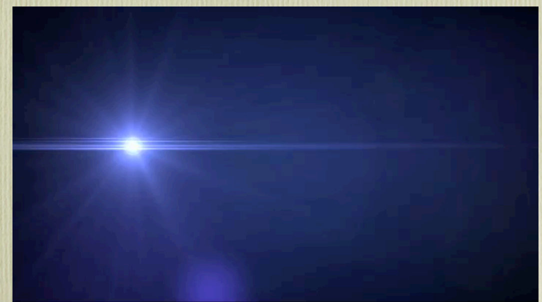
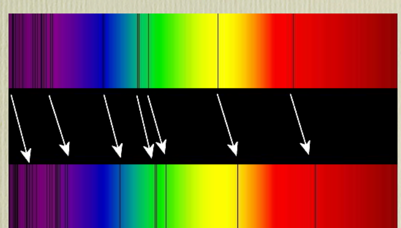
- Blue shift: something moving towards us (and appears hotter)
- Red shift: something moving away from us (and appears cooler)



NASA

Note: can’t use just the colour of stars

- How would we know if it’s just a blue star or a star moving towards us
- Can use these spectral lines since they **all** get shifted by the same amount



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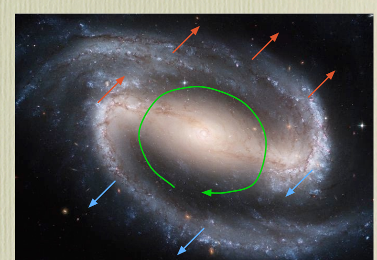
Galaxies are collections of (10 billion) stars like the sun

- Spiral galaxies are rotating
- Not fast enough to see, but
- We can measure speed of stars moving towards or away from us



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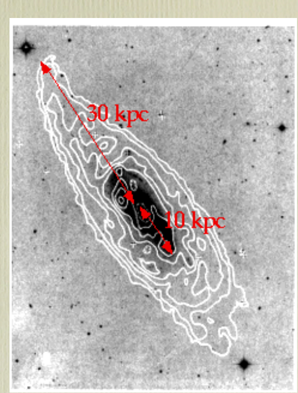
- Typical Spiral (NGC3198)
- outer parts are just seen as Hydrogen gas



- Galaxies rotate **much** too fast
- Can fix this by saying that galaxy has halo of dark matter around it.
- Halo + core add together to give correct curve

But the halo has to have **40** times the mass of the visible galaxy....!

i.e. the stars we see represent a tiny amount of the mass in a galaxy. What is the rest?

We Don’t Know

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