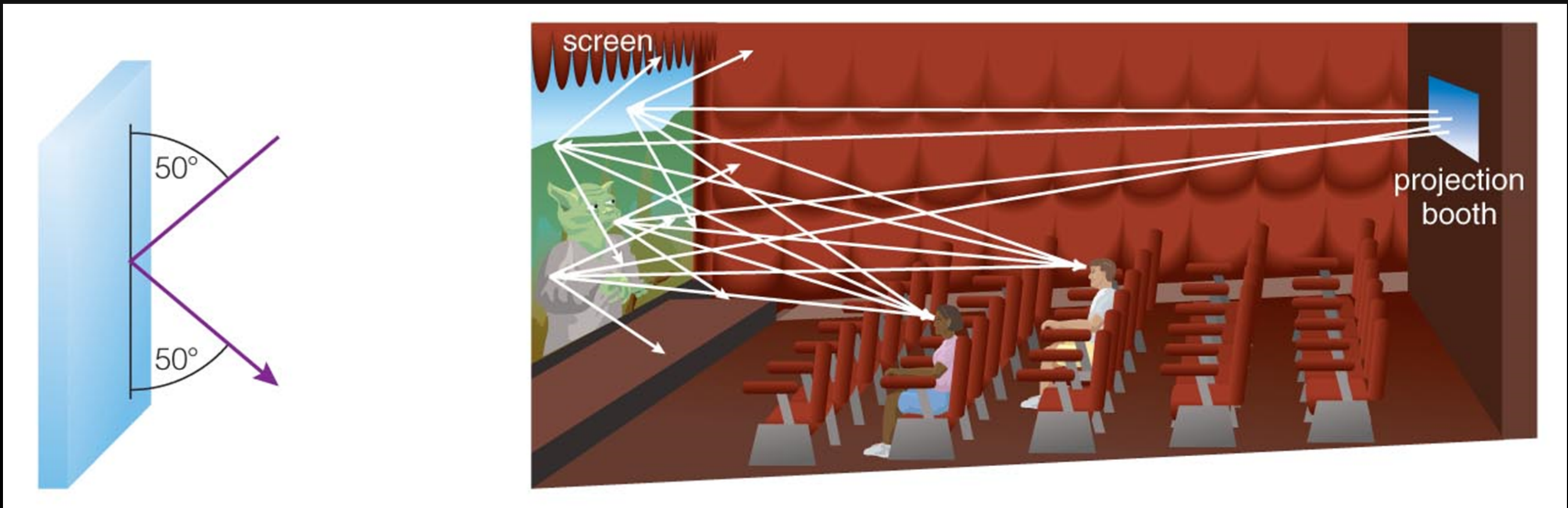
MATTER DOES THESE THINGS WITH LIGHT:

- Emission
- Absorption
- Transmission
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection or scattering

REFLECTION AND SCATTERING



Mirror reflects light in a particular direction.

Movie screen scatters light in all directions.

THIS IS HOW YOU SEE THINGS

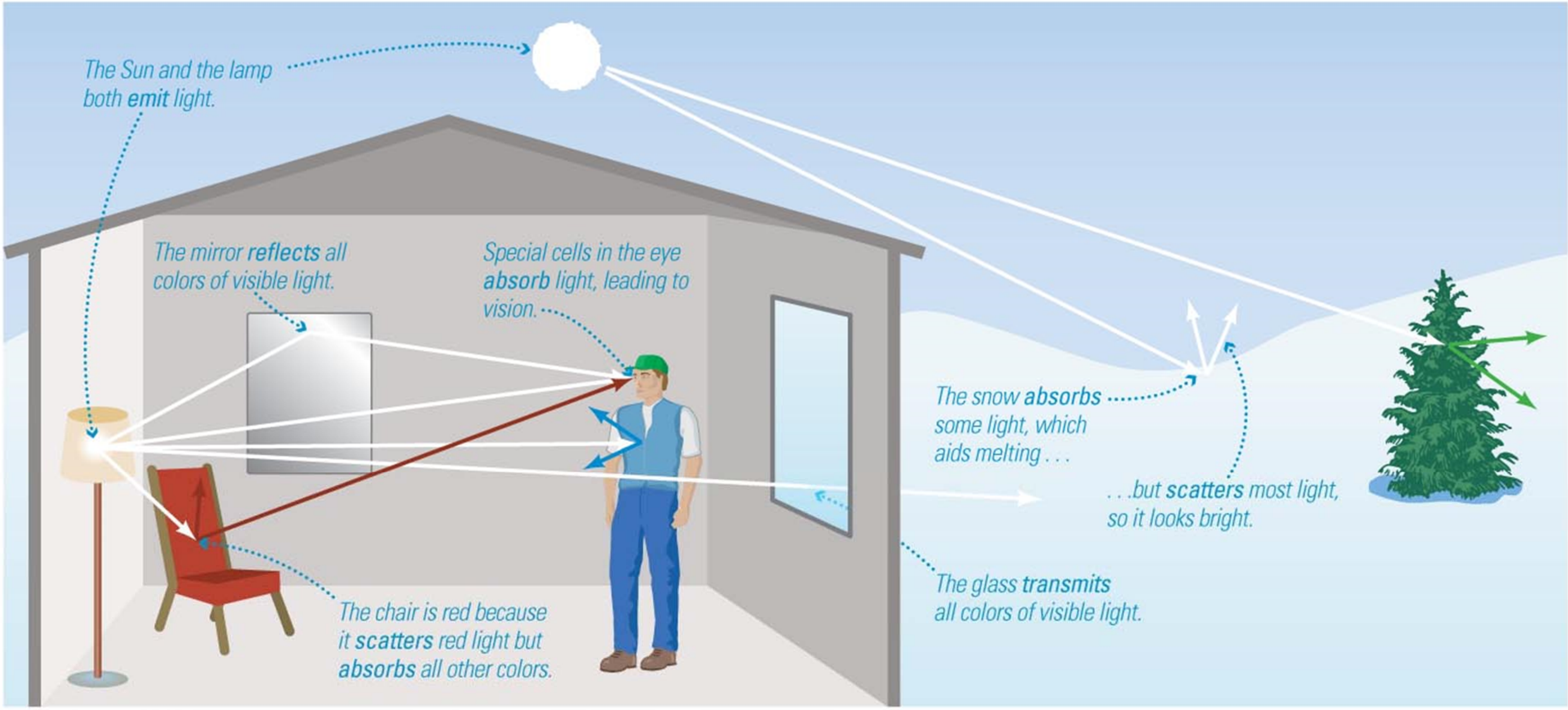


Fig.5.7

WHAT IS A SPECTRUM?

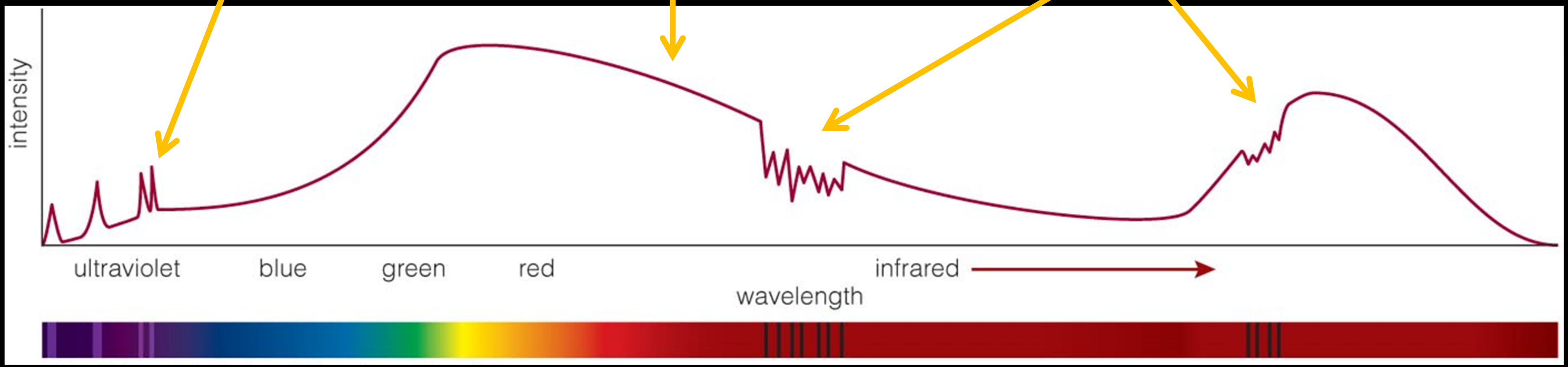
- Split light into its component colors
- Make a graph of how strong the different colors are

PLAY

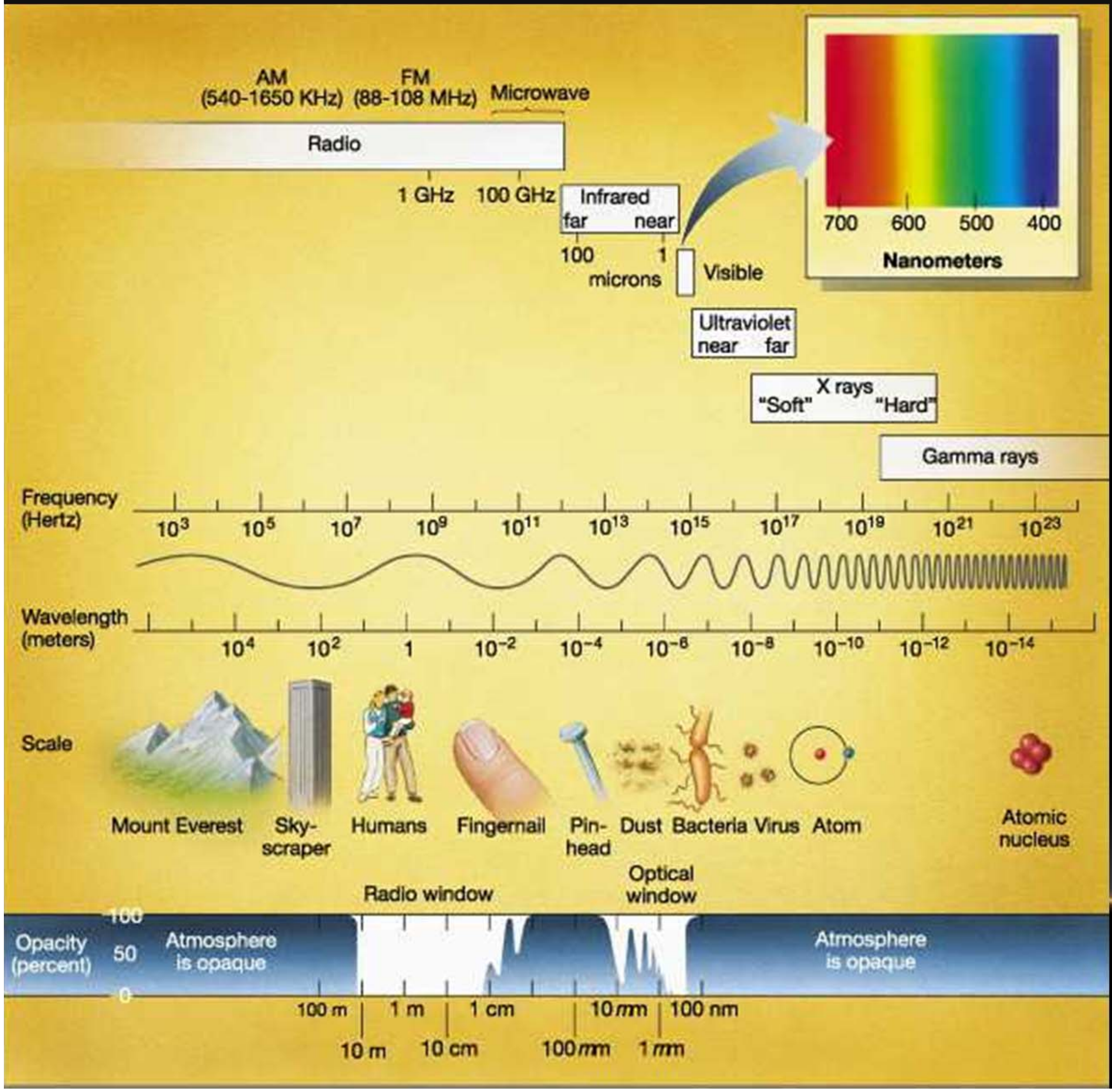
Continuous Spectrum

Emission Line Spectrum

Absorption Line Spectrum



THE ELECTROMAGNETIC SPECTRUM

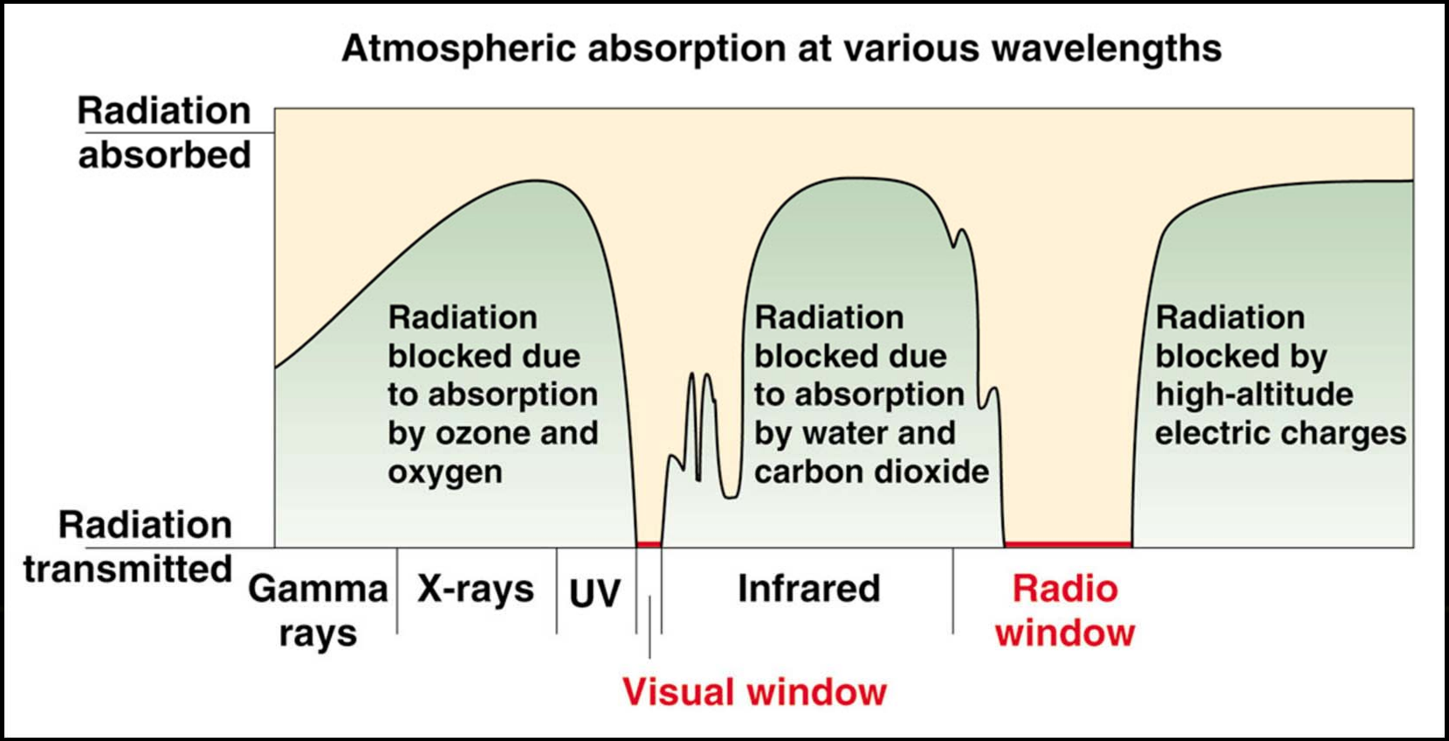


- At longer and shorter λ, we call EM waves by names other than light
- Units:
  - λ in nanometers (nm=10^{-9}m)
  - f in Hertz (Hz = 1/s)
- Visible Light:
  - λ = 400-700 nm

PLAY

EM WAVES MEET AIR

- The atmosphere is not transparent to most λ's
- Need to go to orbit to see them



LIGHT'S MEASURABLES

- What can you measure about some light you observe?
  - Direction – where it came from
  - Intensity – how much there is (brightness)
  - Wavelength (color)
- Put all together to get a picture
- Sometimes all from the same direction (a *point source*, *e.g.* a Star)

COLORS

- White light is a mixture of all the colors
- Colored light contains only a few colors
- Light might be *emitted* with a particular color:
  - A neon light creates red light
  - A iron in a forge creates orange light

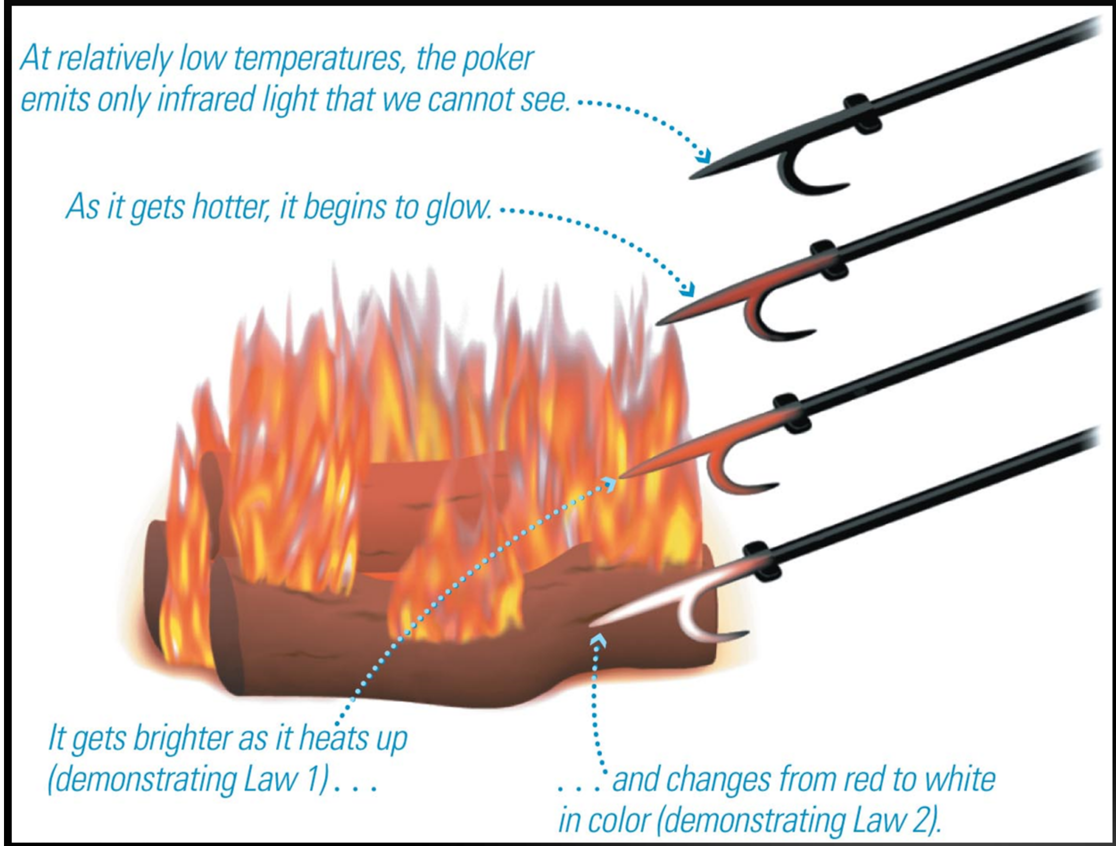
ABSORPTION AND TRANSMISSION

- If you look at light through rose-colored glasses:
  - The glasses are *absorbing* all colors except red
  - They *transmit* the red pretty well
- Absorption on reflection: light bouncing off a red apple
  - The apple is absorbing all but the red light, which we see after it *reflects* from the apple

THERMAL EMISSION

- As atoms rattle around, they emit EM radiation
  - A *thermal spectrum*
- Remember, temperature is a measure of how much the atoms and molecules in something are rattling about
  - Those moving charges make electromagnetic waves

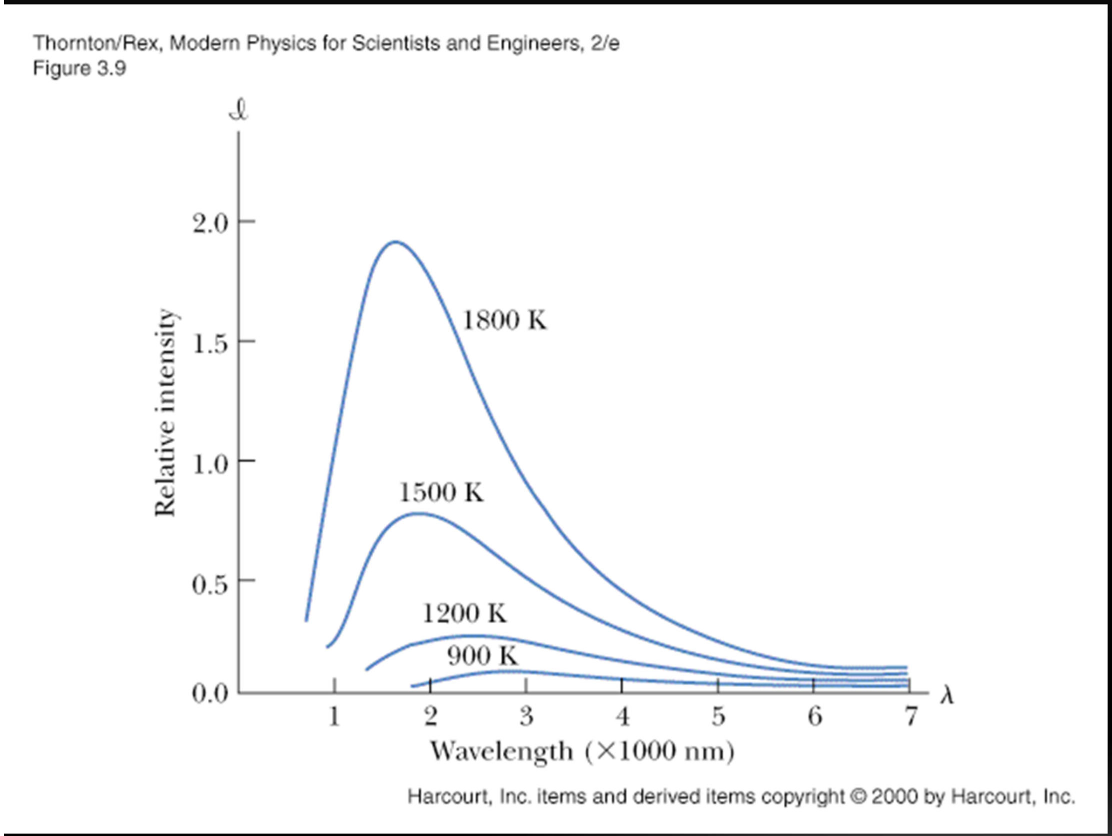
HEAT IT UP…



- Hotter makes shorter wavelengths
- Earth: IR
- Molten lava: red then orange then white hot
- Sun is “white hot”
  - So are incandescent light bulb filaments

Fig.5.12

BLACKBODIES



- Black things appear black because they absorb light well
- Correspondingly, they emit well when heated
  - Produce Blackbody Spectra
  - Hotter things peak at shorter λ
  - Hotter things emit more light in total

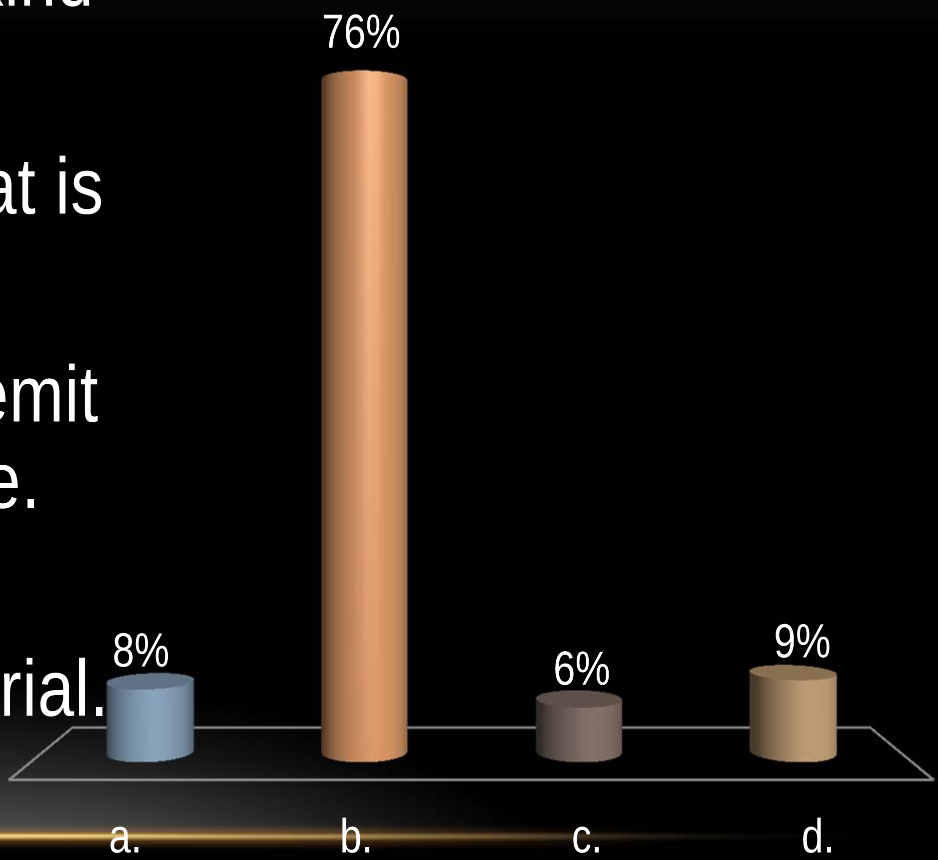
SO, WE'RE WARM, WHY DON'T WE GLOW IN THE DARK?

a. People do not emit any kind of light.

✓ b. People only emit light that is invisible to our eyes.

c. People are too small to emit enough light for us to see.

d. People do not contain enough radioactive material.



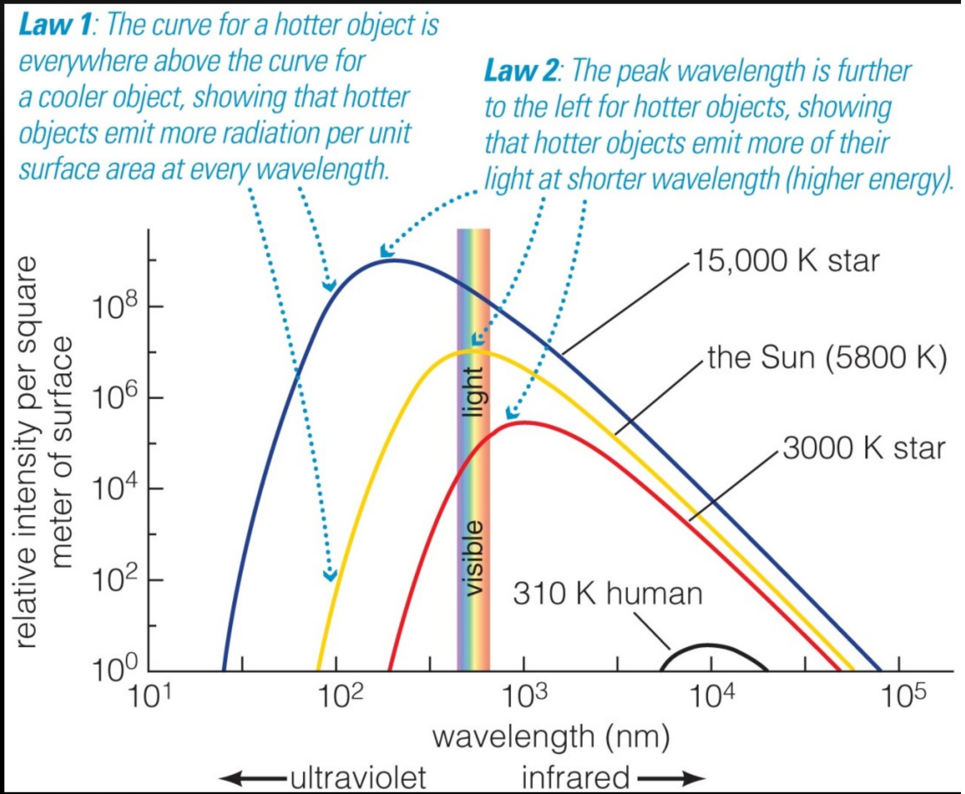
COLOR AND TEMPERATURE

Images from x20.org

- As atoms rattle around, they emit EM radiation
  - A *thermal spectrum*
- Body temperature is at longer λ, in the infra-red

QUANTITATIVELY

- Stefan-Boltzmann Law:
  - Energy radiated α T^4 (per unit area)
  - How bright is it?
- Wien's displacement Law:
  - λ_{max} α 1/T
  - Where is the peak of that curve?



- So, looking at the spectra, we can tell how hot it is, and how much power it is radiating!

PLAY

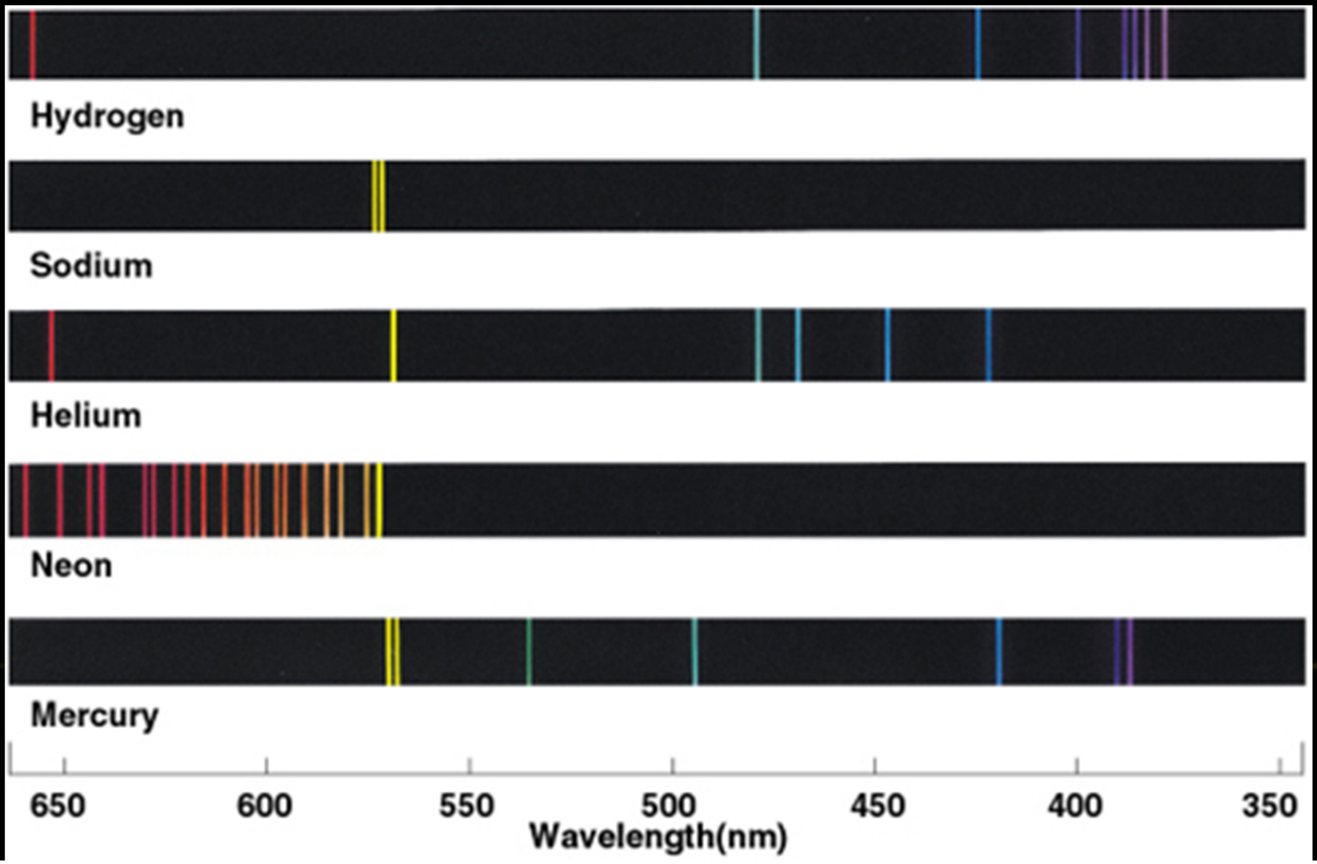
Fig.5.11

TYPES OF SPECTRA

- The blackbody curve was a *continuous* spectra
  - A little bit of many different colors
- There are also:
  - Emission spectra
    - Only a few colors created
    - *e.g.*, a neon light
  - Absorption spectra
    - A few colors missing

EMISSION SPECTRA

- Each element has its own fingerprint spectrum when excited as a gas



PLAY

ABSORPTION SPECTRA

- If a continuous spectrum is viewed from behind some gas, the gas will absorb light at the same wavelengths it would emit it if it was excited

KIRCHHOFF'S LAWS

- A hot, dense glowing object emits a *continuous* spectrum
- A hot, low-density gas emits light of only certain wavelengths – a bright line or *emission* spectrum
- When light having a continuous spectrum passes through a cool gas, dark lines appear – a dark line or absorption spectrum

PLAY

THE BOHR MODEL OF THE ATOM

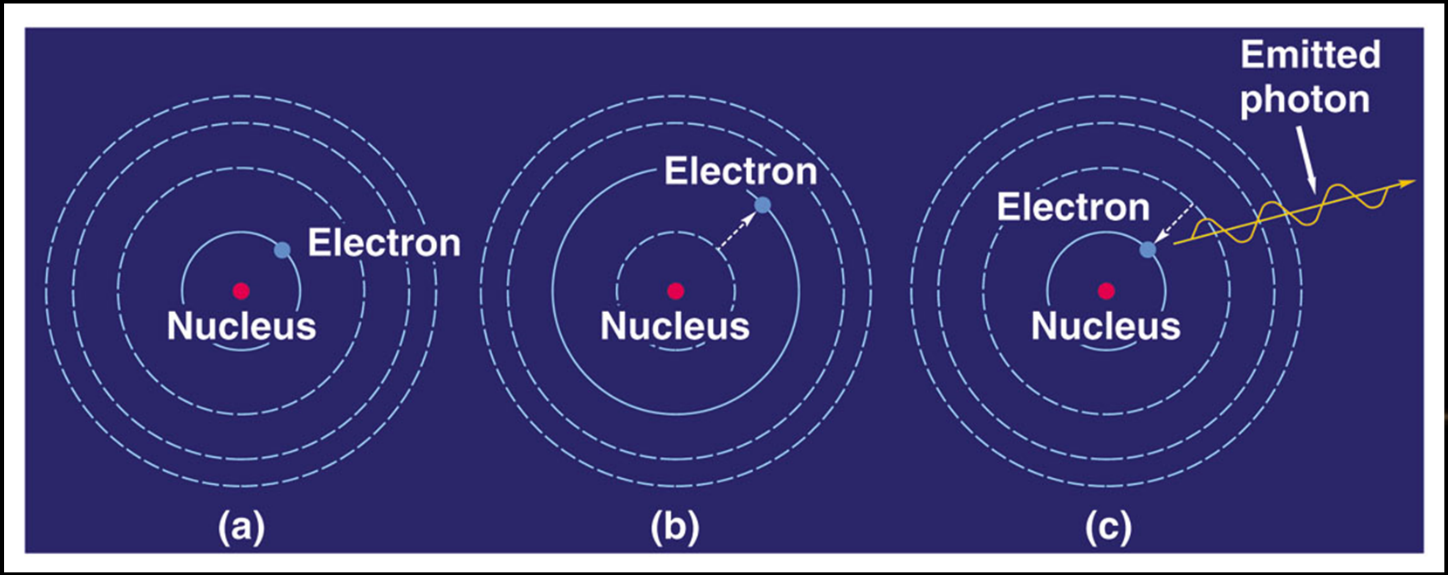
- Why do gasses emit and absorb only at specific wavelengths?
- Niels Bohr made a simple model of an atom:
  - Heavy, small nucleus (made of protons and neutrons)
  - Light electrons orbit this nucleus

BOHR'S POSTULATES

- The hypothesis Bohr proposed:
  - Electrons in orbit around a nucleus can only have certain specific energies
  - Electrons can change between these energy levels
  - The energy needed to do so is absorbed or emitted in chunks (photons) of energy $E=hf$ equal to the energy change of the electron
    - h is a constant called "Planck's Constant"

BOHR ATOM AND SPECTRA

- If a *photon* (smallest unit of light) comes along that has exactly the right energy to bump an electron to the next higher orbit, it is absorbed
- If the electron falls down to the next lower orbit, it emits a photon of exactly that energy



$E=hf=hc/\lambda$

Short λ means Higher E

EMISSION SPECTRA

- An electron is excited to a higher energy level
  - Physically (*temperature!*) or electrically rattled around, or by absorbing just the right λ light
- When the electron falls back to a lower energy level, it gives off a photon of light
  - Of exactly the energy difference between levels
- Gas needs to be at low density to have a chance to do this
  - Otherwise electrons can get knocked back down from a collision before they radiate

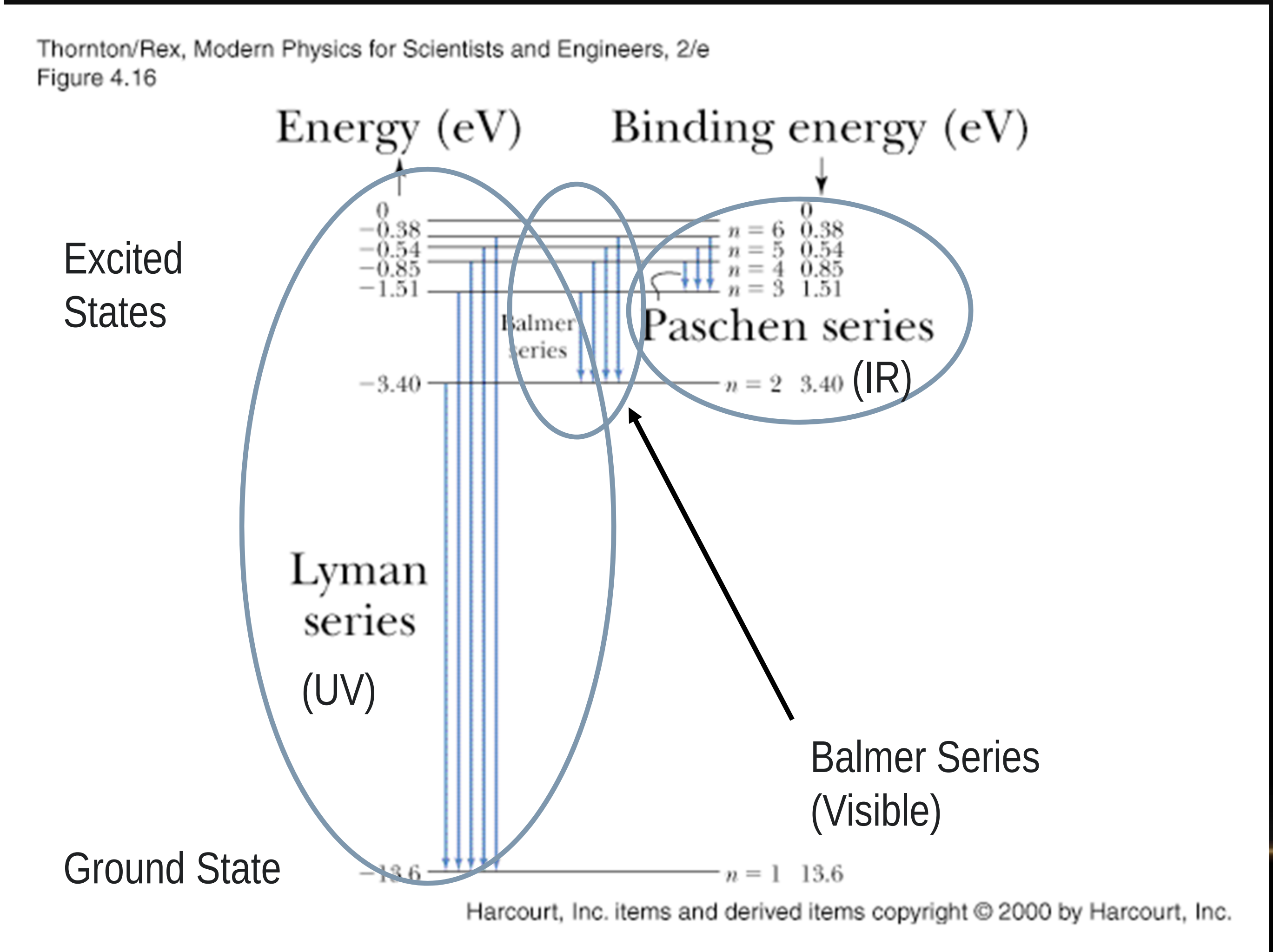
PLAY

ABSORPTION SPECTRA

- Light of just the right energy bumps electrons up to an excited state and is absorbed (making a dark line in a continuum)
- Later those excited electrons will de-excite and fall back down, giving off light of that specific energy
- Which specific energies are involved tell us what the atom's structure is – thus, what element is doing the absorbing and emitting?

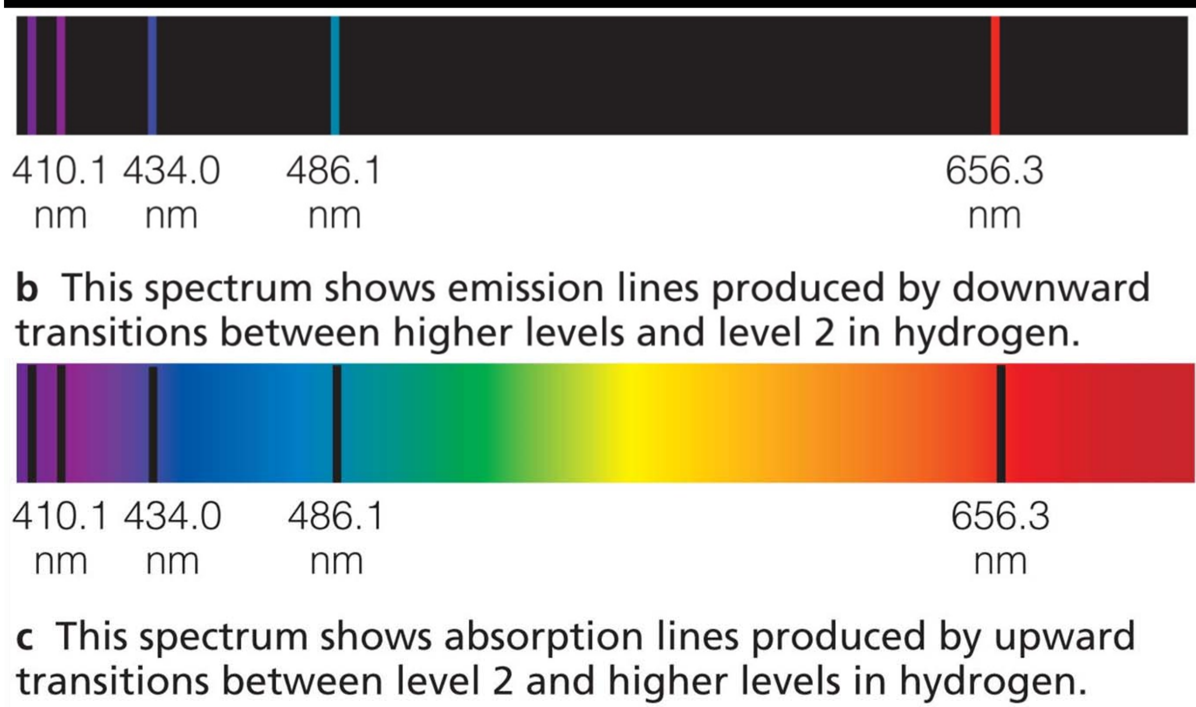
PLAY

HYDROGEN SPECTRA



- Hydrogen is simplest element
- Bohr model predicts energy levels and spectra very well

BALMER SEQUENCE



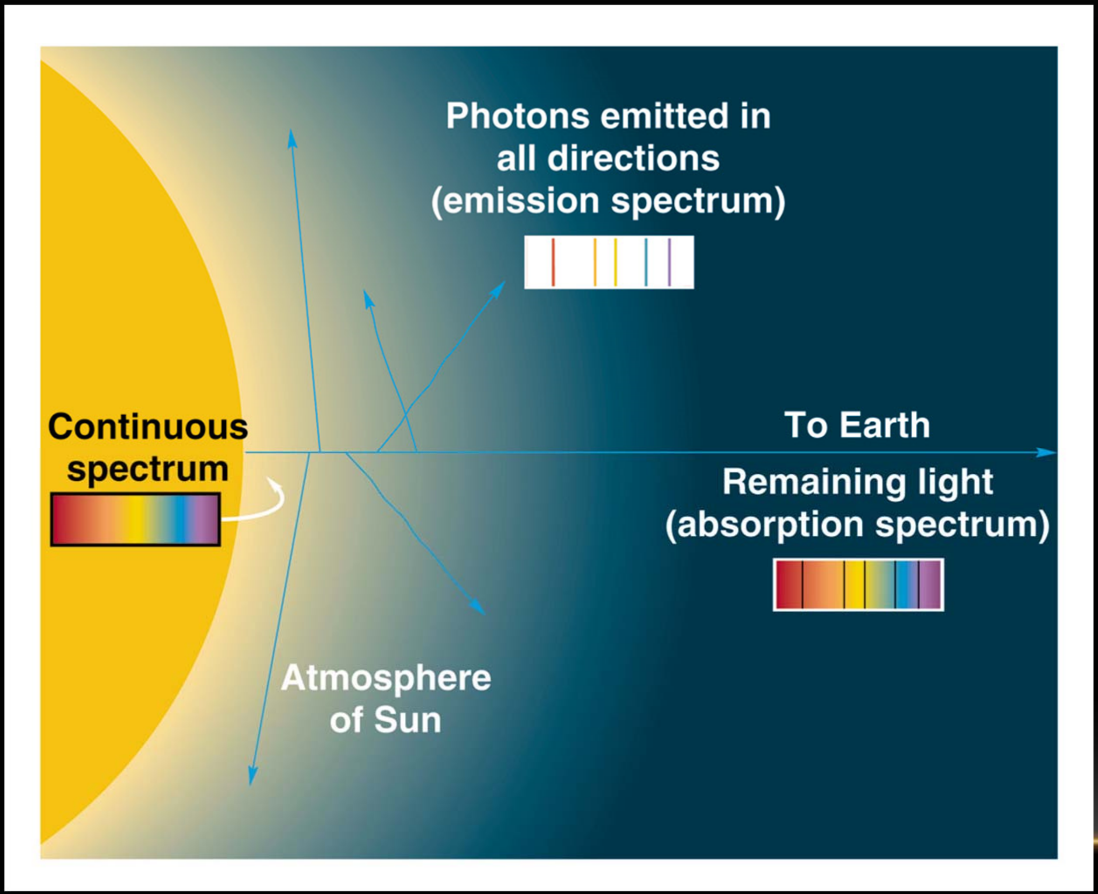
b This spectrum shows emission lines produced by downward transitions between higher levels and level 2 in hydrogen.

c This spectrum shows absorption lines produced by upward transitions between level 2 and higher levels in hydrogen.

Fig.5.10b,c

- Balmer series of Hydrogen lines mostly in visible
- From transitions to the second energy level
- Called H_α, H_β, etc.
- Hydrogen most common element in the universe
  - You will see these lines & colors everywhere!

ALL TOGETHER NOW

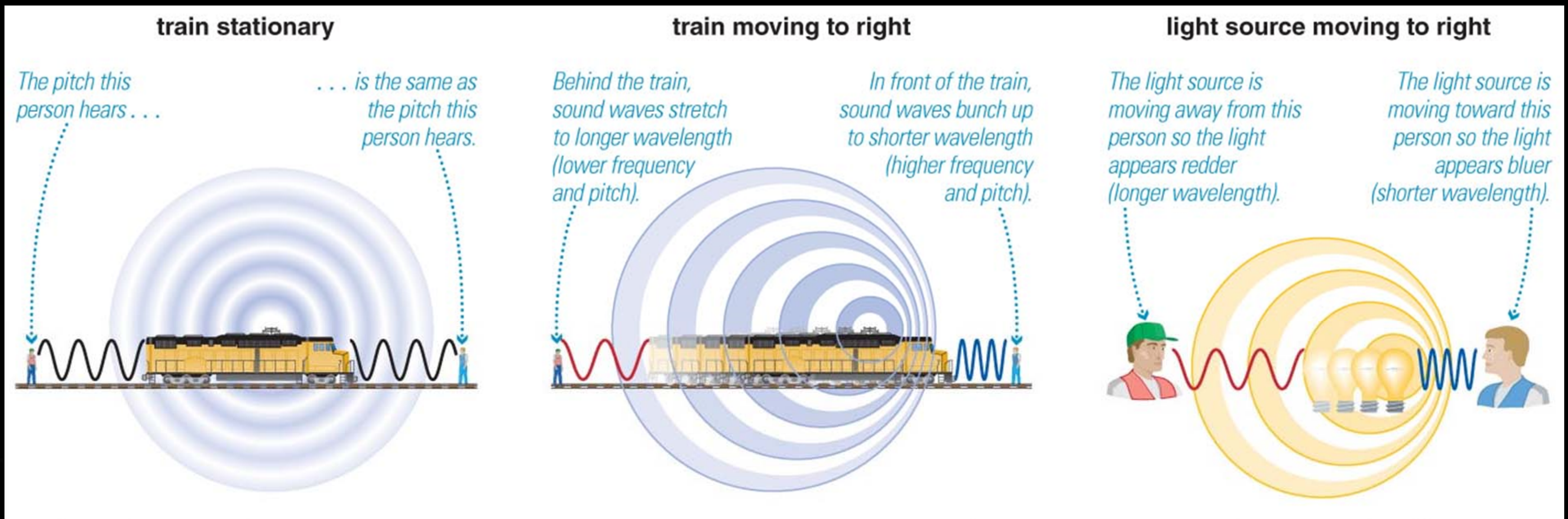


- The Sun is hot and dense – produces a continuous blackbody spectrum
- Less dense gas in the Sun's atmosphere absorbs some lines
- If you look at this from the side, you'll see the emission lines
  - Photons get re-emitted in all directions

THE DOPPLER EFFECT

- As an object moves, waves it emits are scrunched up ahead of it and stretched out behind it
- $\Delta\lambda/\lambda = v/c$
  - v is velocity towards or away from you
  - So measure the shift in λ, get the velocity!

Fig.5.13



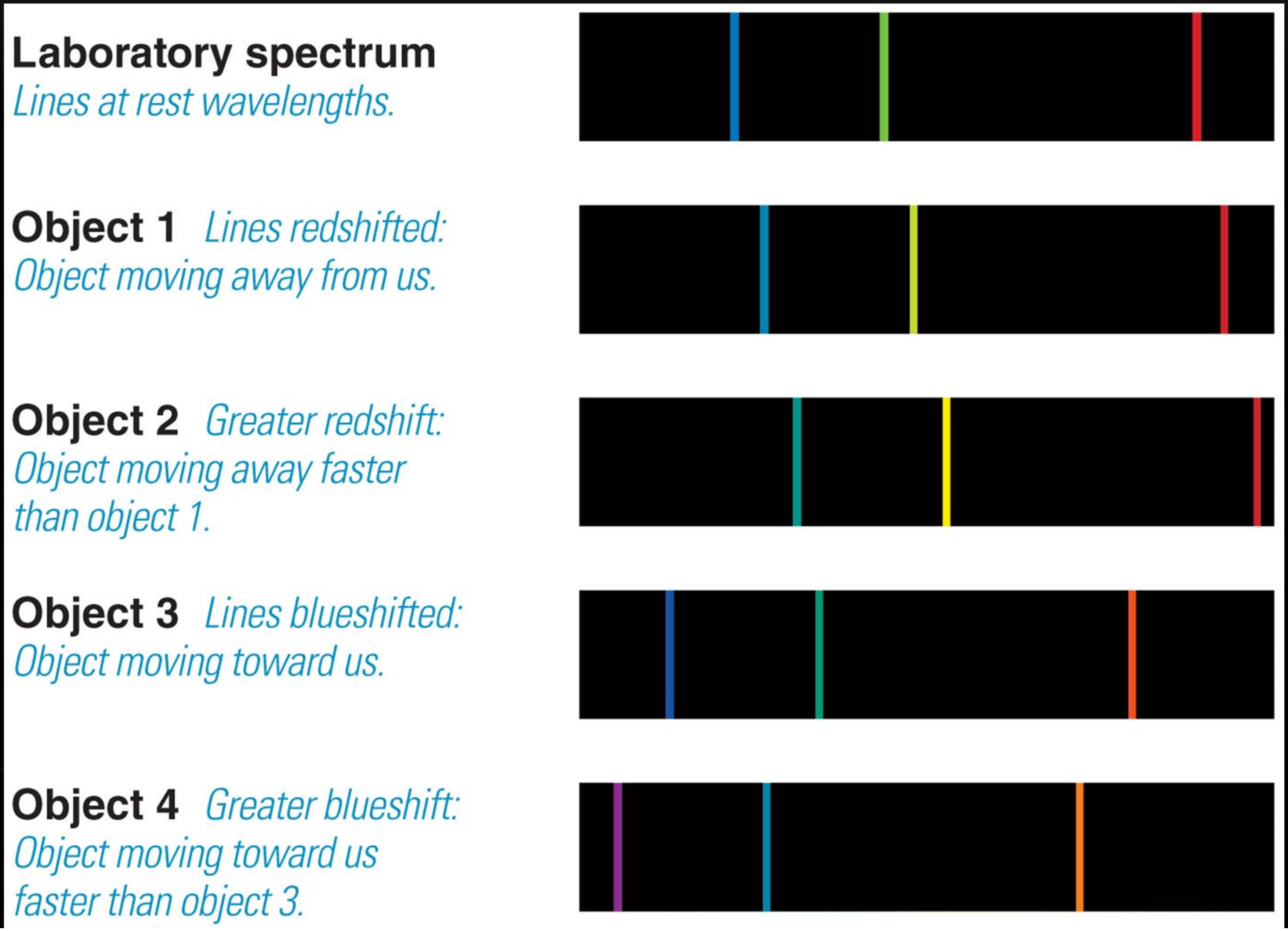
a The whistle sounds the same no matter where you stand near a stationary train.

b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

c We get the same basic effect from a moving light source (although the shifts are usually too small to notice with our eyes).

DOPPLER SHIFT APPLIED

Fig.5.14



ONLY RADIAL VELOCITY

- Doppler shift only tells us about motion towards or away, not to the side

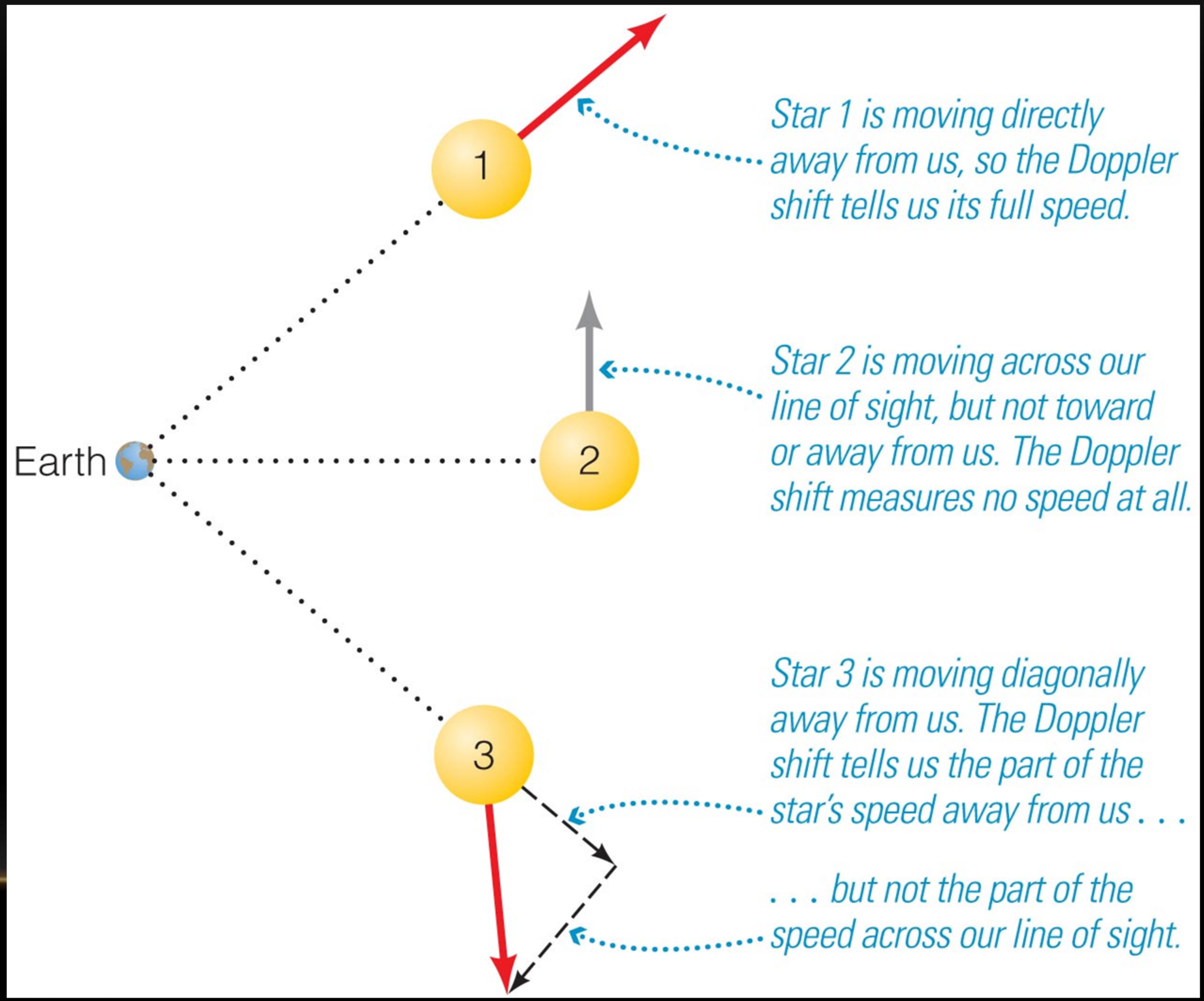


Fig.5.15

OTHER APPLICATIONS

- Rotation rates of Sun, Planets, etc:
  - Object spins
  - One side heads towards you, the other away – compare λ's from each side
  - For stars – can't see the sides separately, but a line will appear split!
- Binary Stars:
  - Stars orbit each other, move towards and away from us. We see lines get split, and can watch the stars move