# Nature of Light and Atomic Spectra

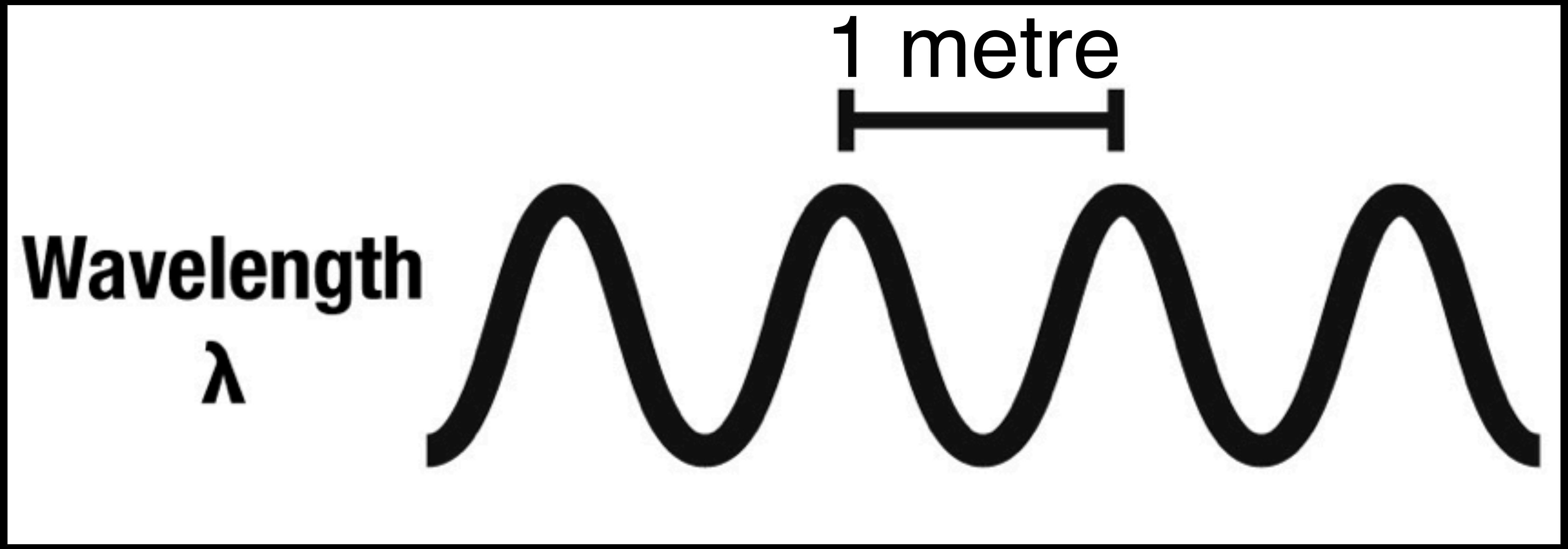
Astronomy 101: Exploring the Night Sky

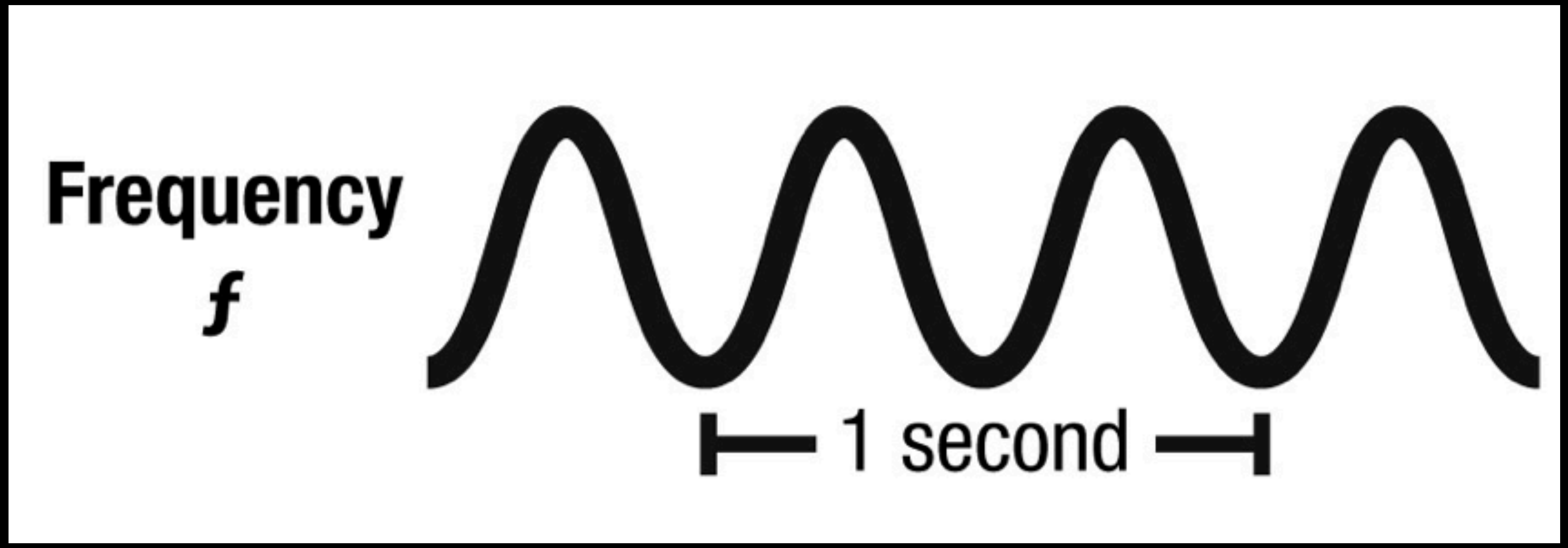
*January, 2018*

# Light “Waves”

# Waves

We visualize waves based on water waves - alternating peaks and troughs in the medium.

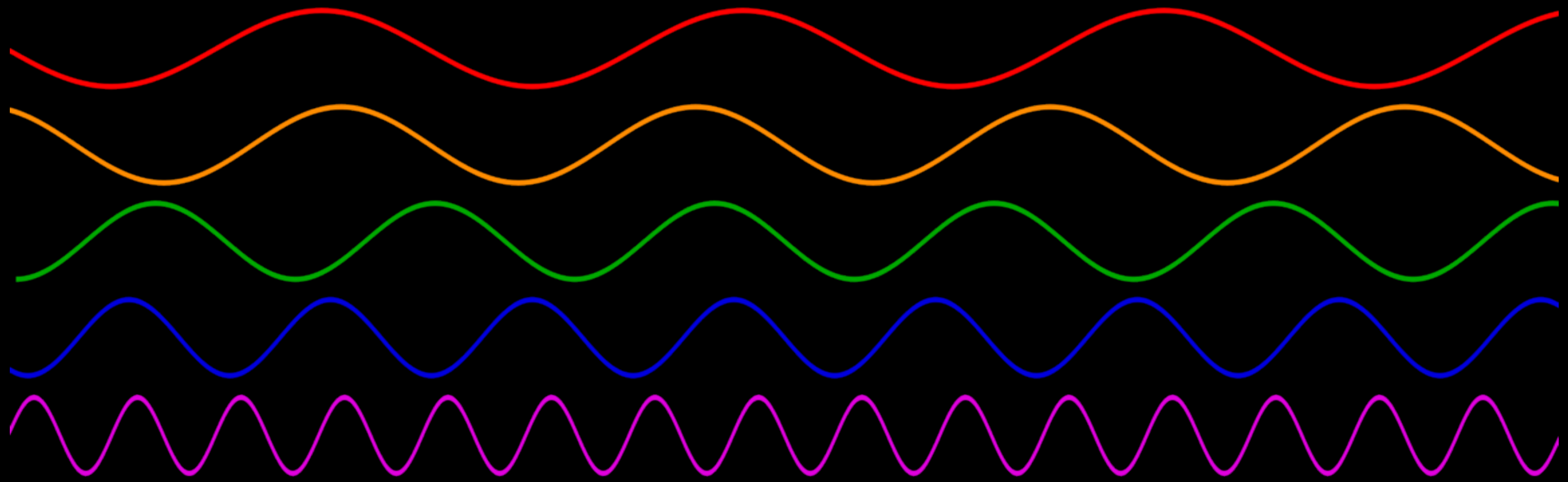



The distance between peaks is the wavelength ($\lambda$) and the time between peaks is the period (T). Frequency is $f = 1/T$.

# Wavelength and Frequency

The frequency (f) and wavelength ($\lambda$) are not independent of each other.



$$v=f\lambda$$

The speed of the wave is the product of its wavelength and its frequency.

The SPEED of the wave is fixed by the medium in which it travels. Light travels at the speed of light: $c=2.9979 \times 10^8$ m/s

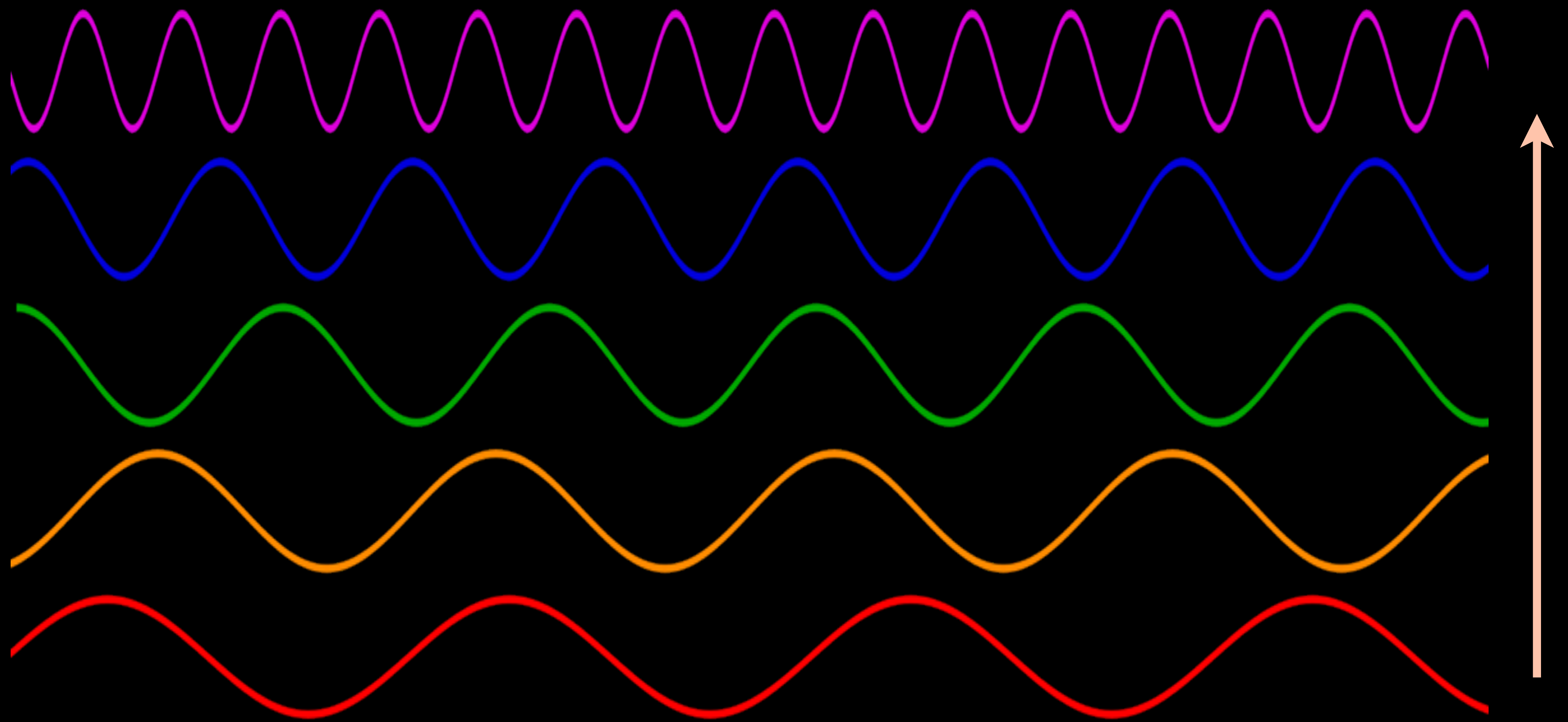
# Energy of a Wave

The energy contained in the wave depends on two things: amplitude and frequency.

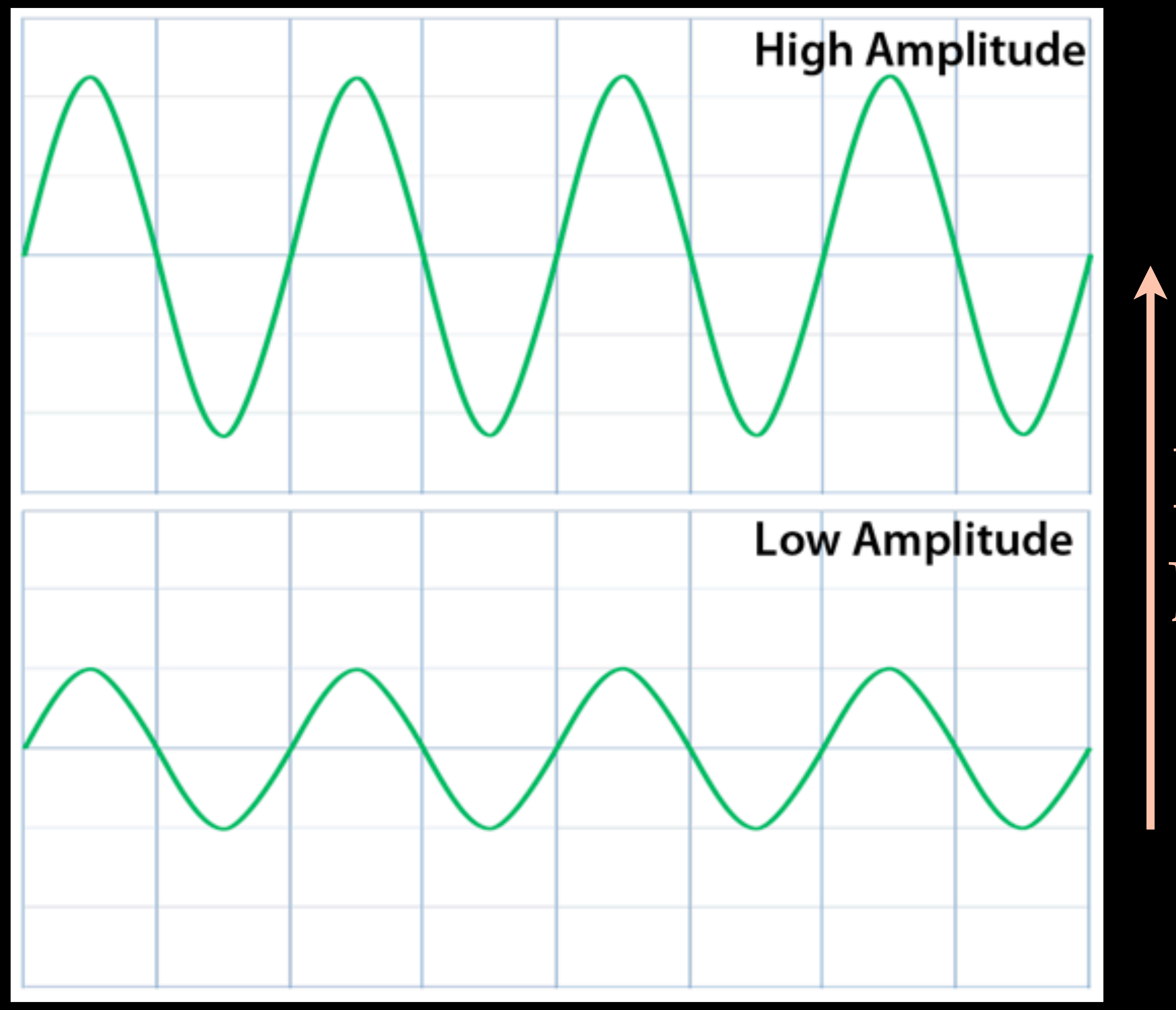
Faster a wave oscillates = higher energy wave.

We experience amplitude as brightness.

So higher brightness = higher amplitude.



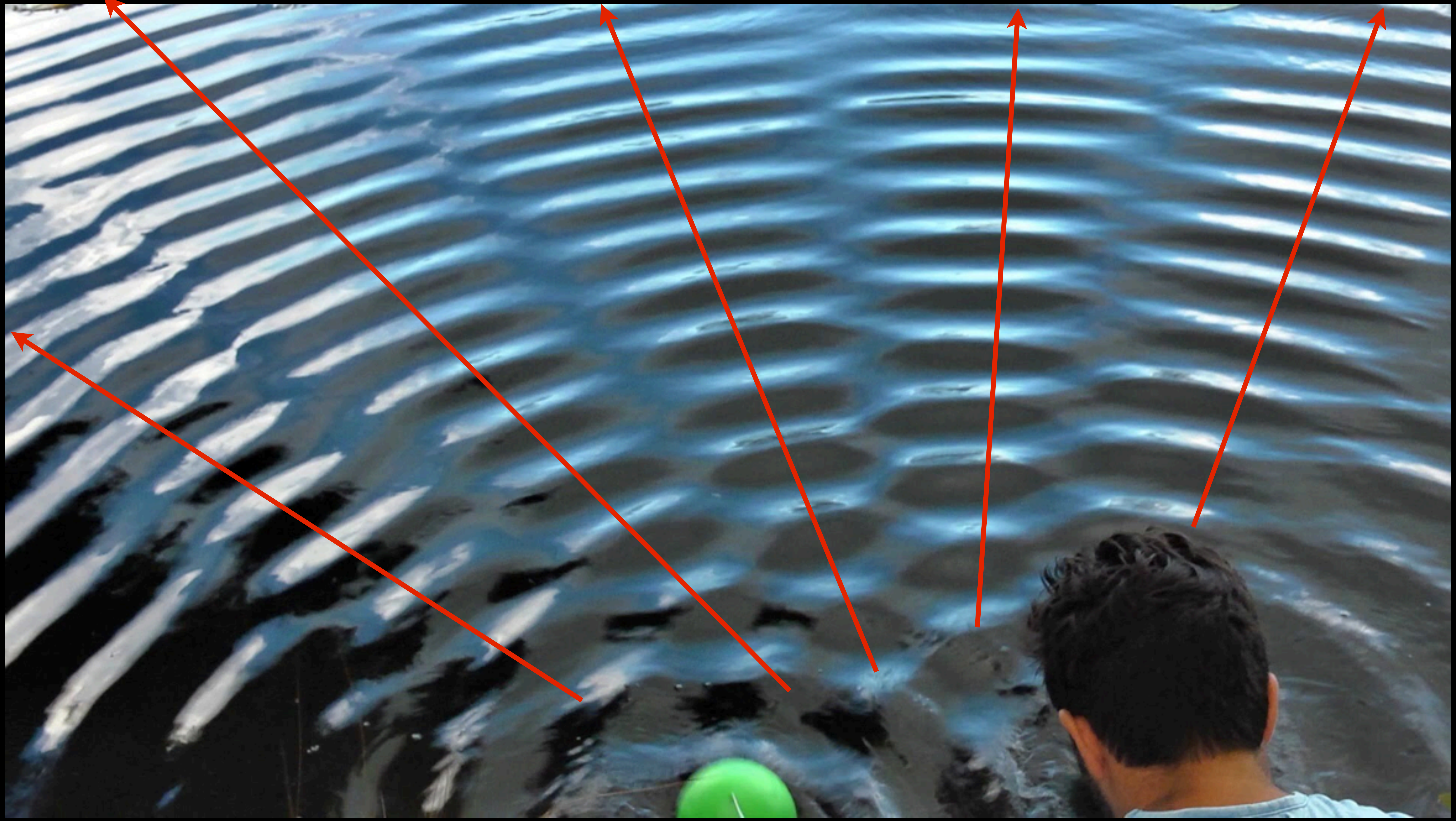
Increasing Energy




Increasing Brightness

# Waves

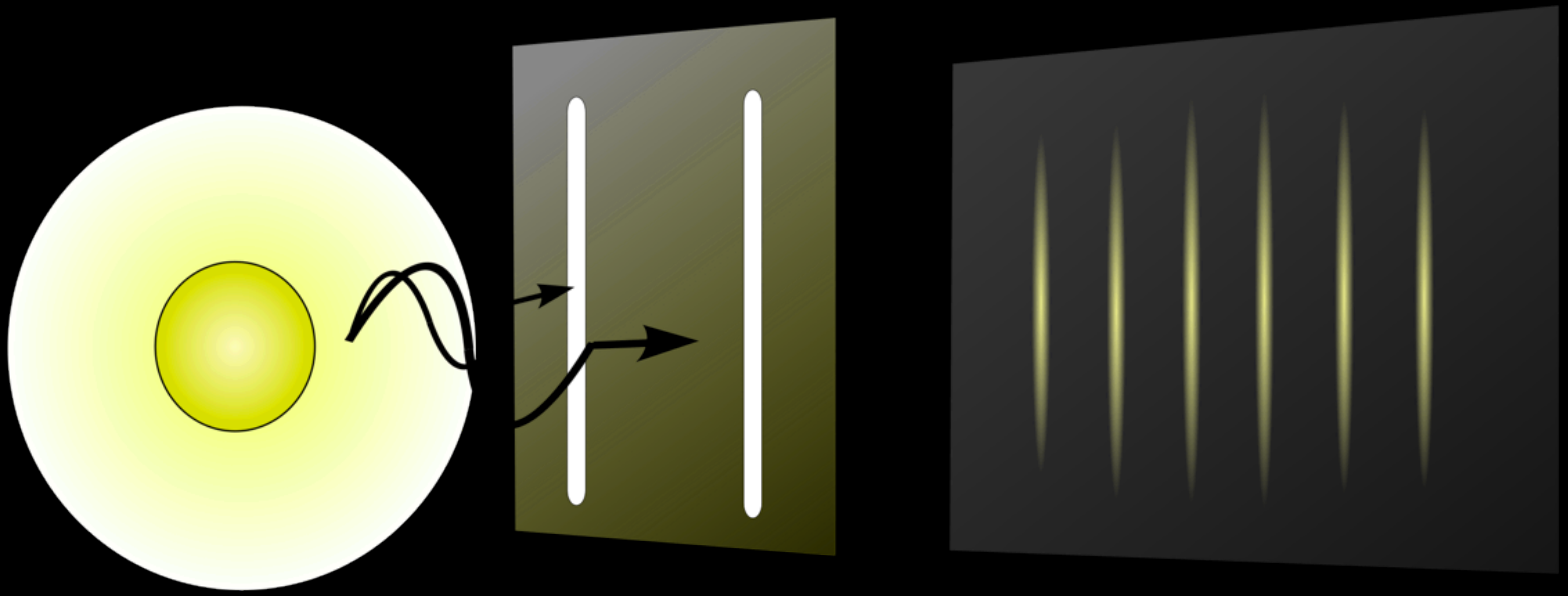
Technically, a wave is a propagation of energy that experiences interference/ diffraction.

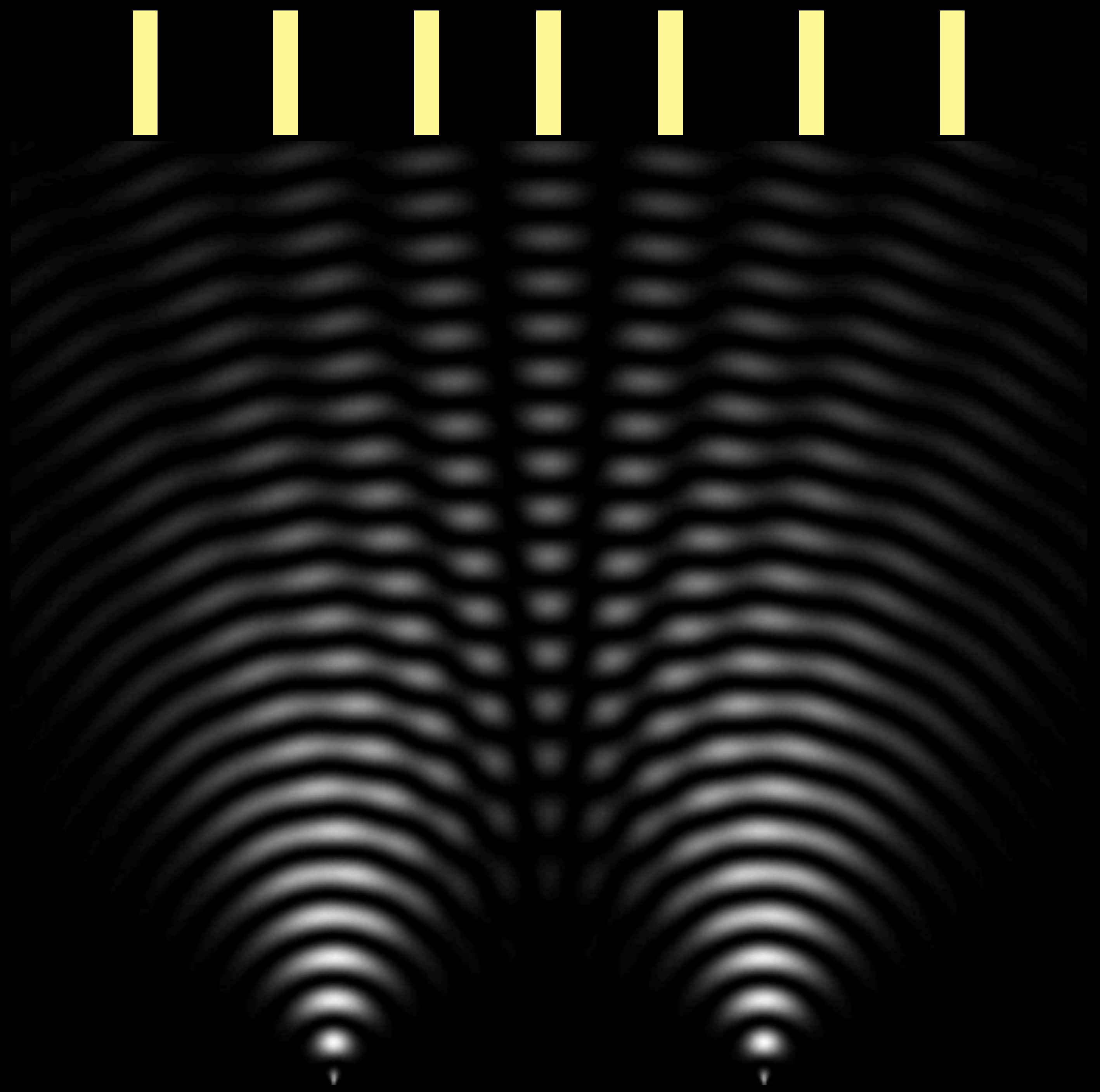


This is when two sources of waves combine to either amplify or cancel out their amplitude.

# Light Waves

We say that light is a wave because of this - it carries energy and it undergoes interference.





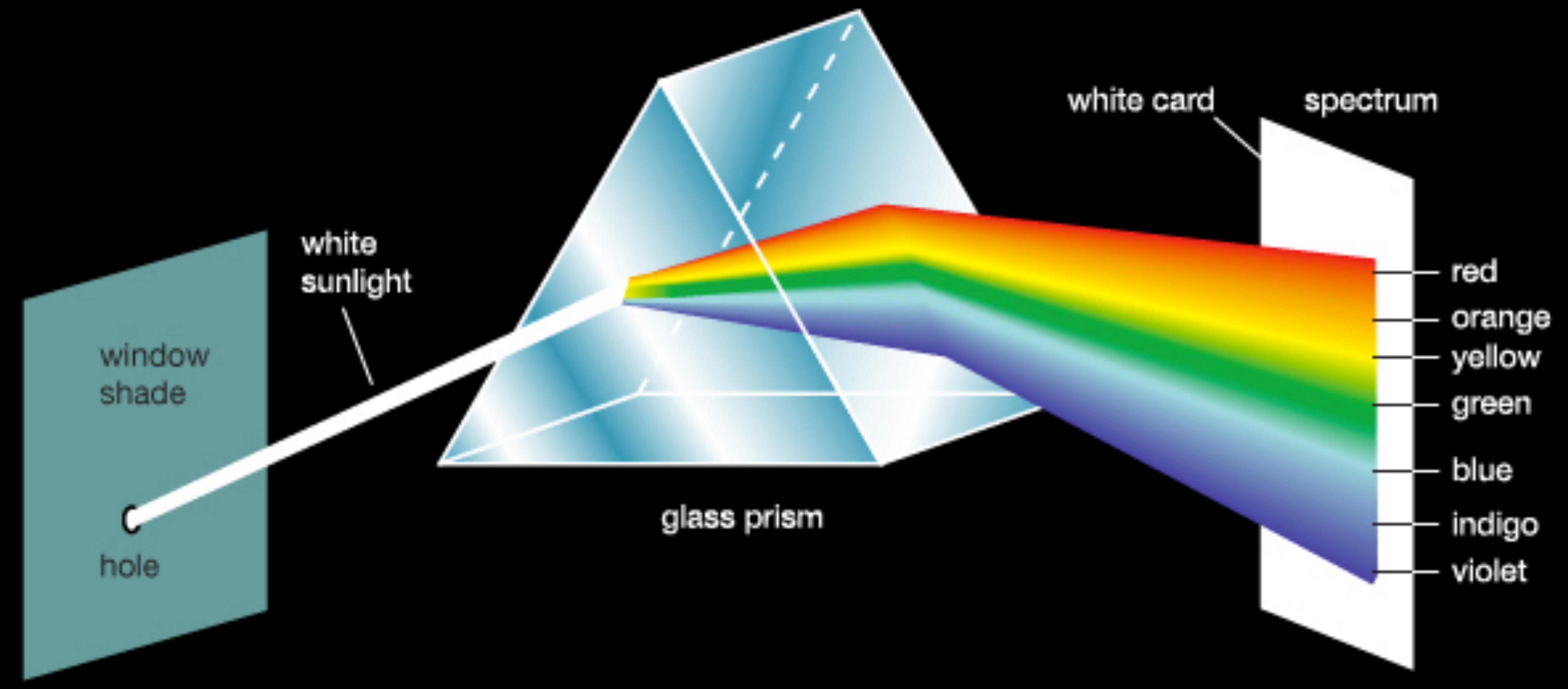
There should be only 2 columns of light if light doesn't interfere - two lines representing slit regions. Interference creates more columns!

# Experiencing Light

Colour is simply the word we use to describe our experience of light.

All colours combined produces “white” light.

The “white” light produced by the Sun can be separated out into the separate colours using a prism or diffraction grating.

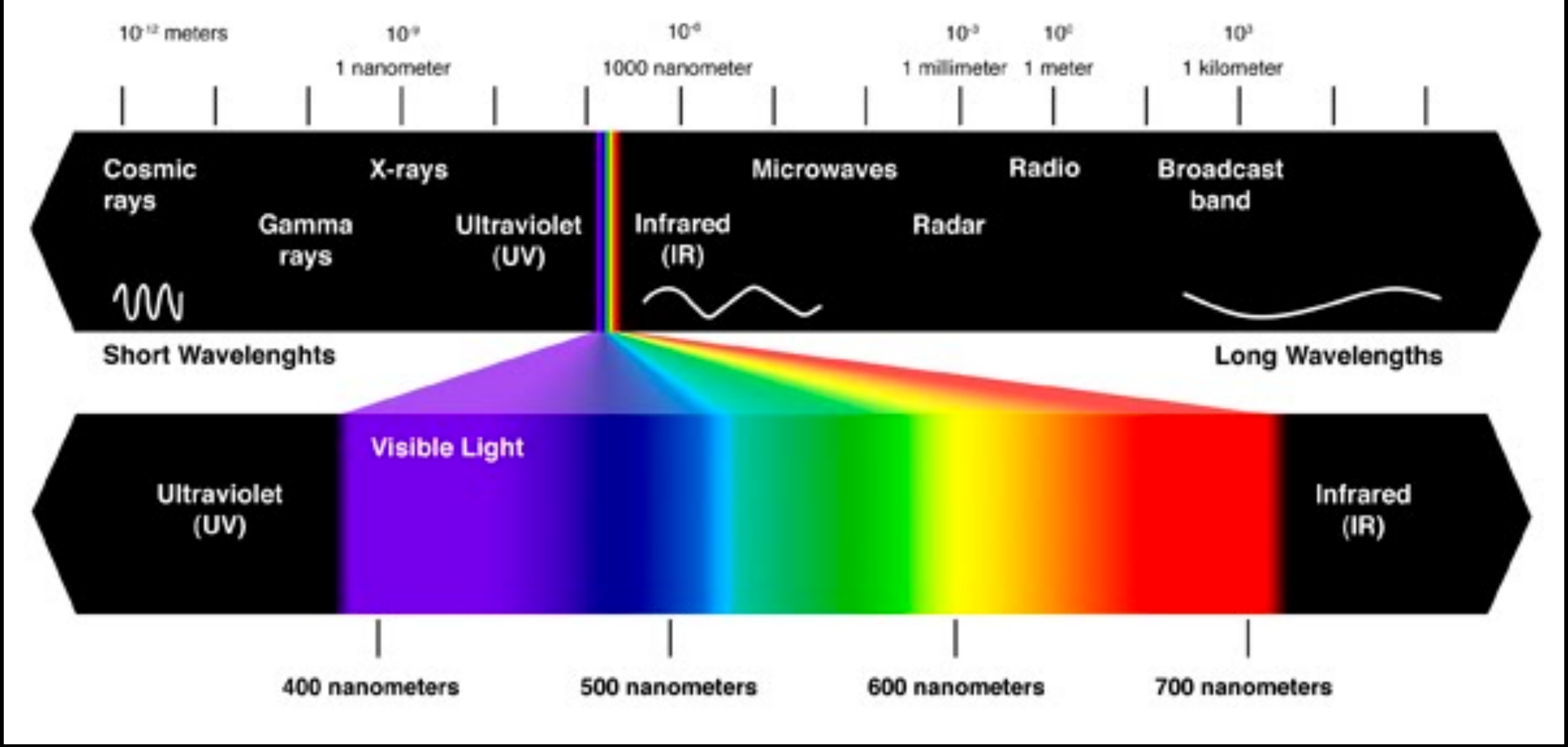





But there is much more that we can’t see.

# Spectrum

The wavelength of visible light is just 400-700 nm (1 nm = 1/Billion m).



# Transmission of Light

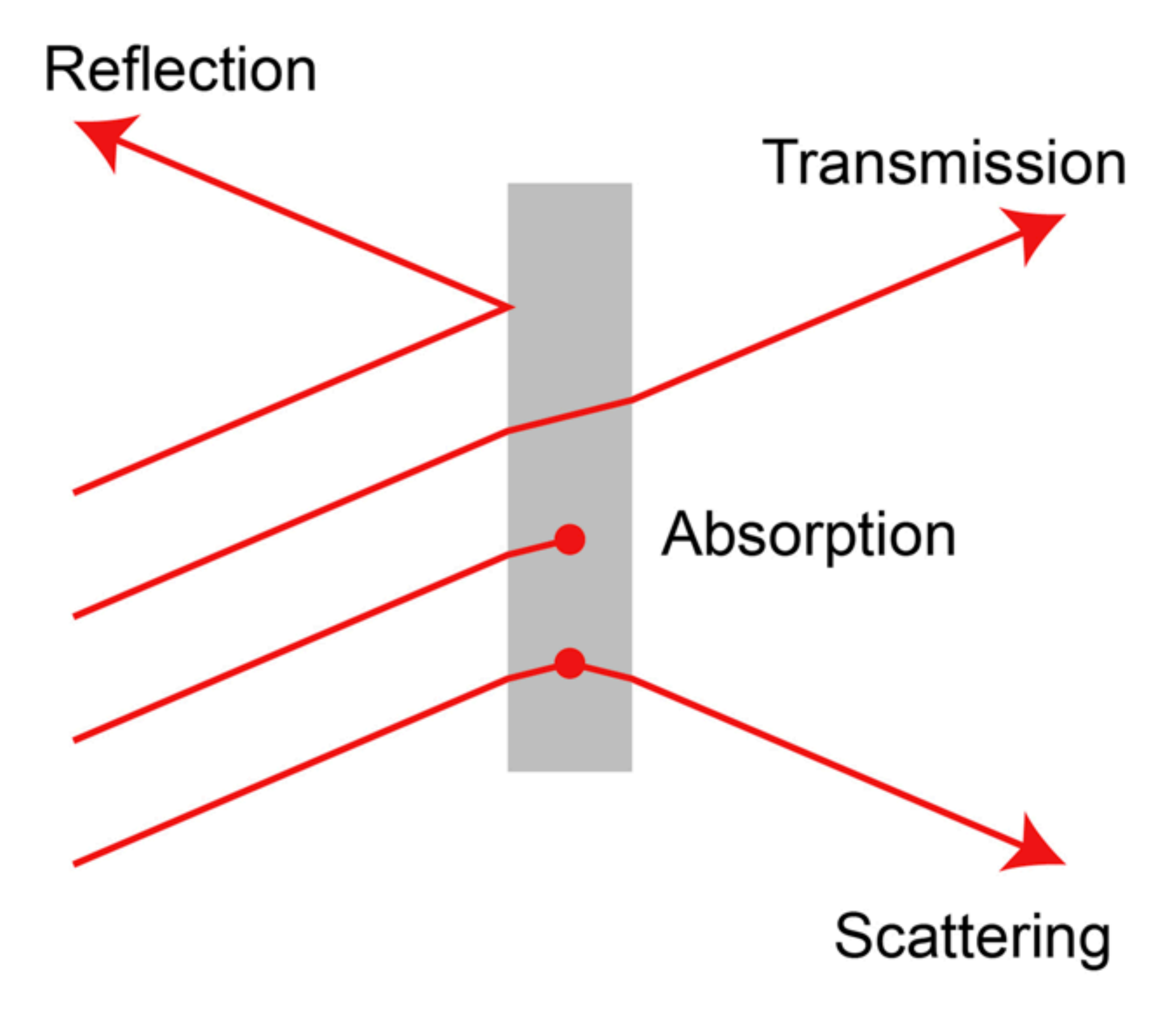
When light strikes a material, it can do one of four things.

The relative % of each of these determines how we experience that object.

High reflectivity, low scattering = mirror

High absorption = dark material

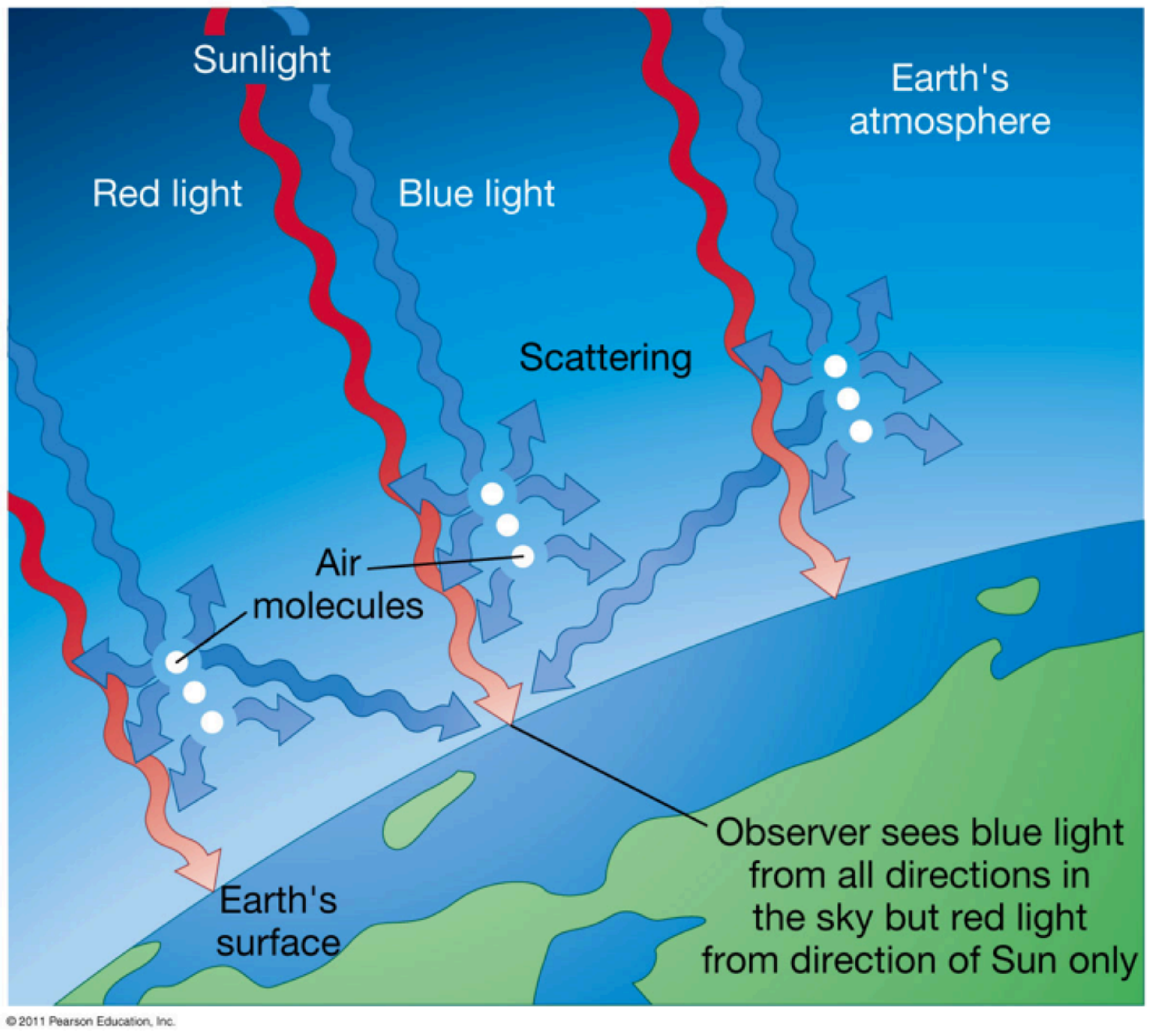
High transmission, low scattering = transparent



# Transmission of Light

Every material behaves differently for each frequency/colour of light. This explains why we see the colours and opacities that we do.

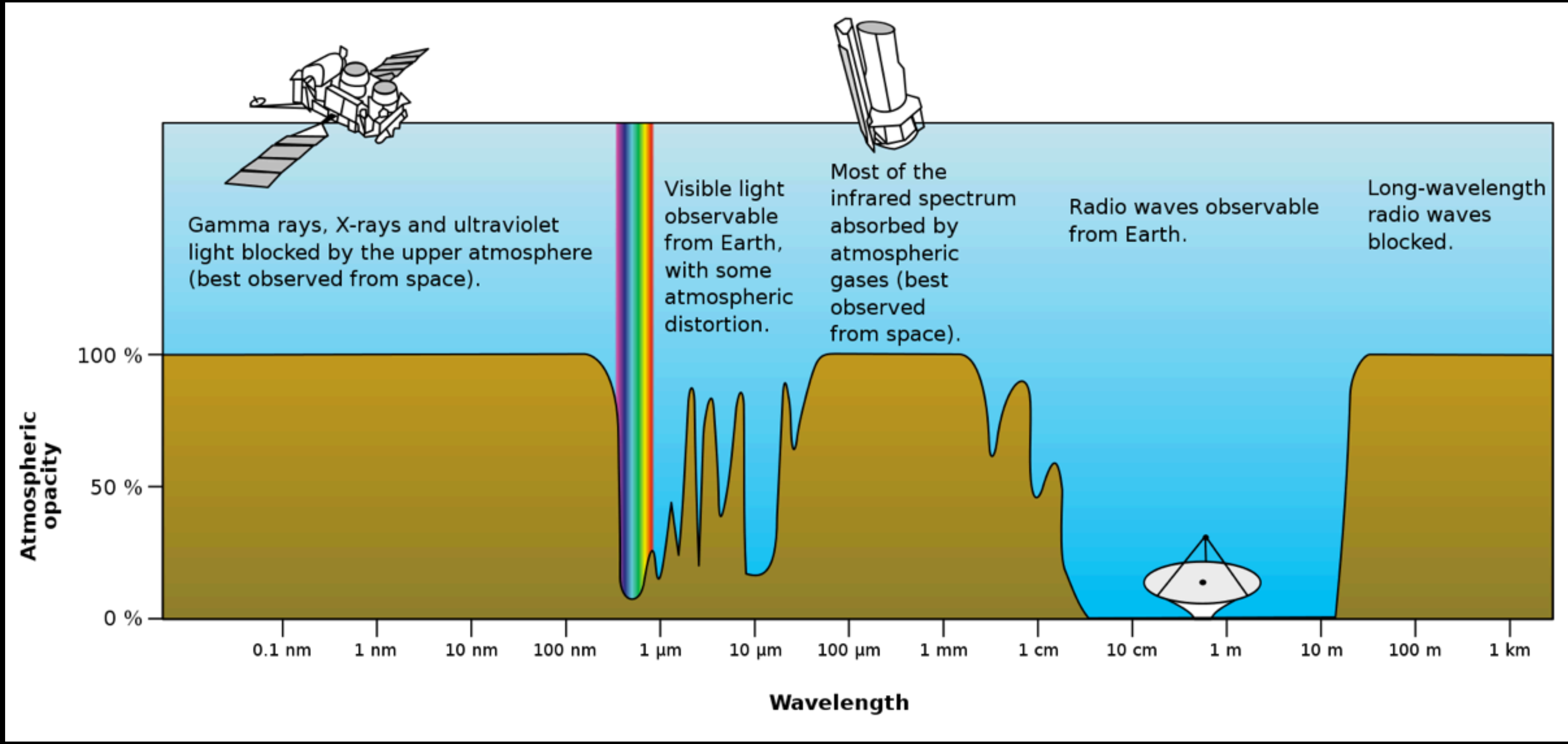
e.g. The atmosphere scatters blue light more than red light, which explains why the sky looks blue.



# Transmission of Light

For other colours/frequencies, our atmosphere behaves very differently.

This has a huge effect on astronomy: we can only make Earth based telescopes that see light within those narrow gaps!



# Sources of Light

All light is produced by the motion of charged particles (electrons & protons). When a charged particle accelerates/changes state, it emits/absorbs light.


Note: Some temperatures are listed in Kelvin (K), some in Celsius (°C).
Kelvin temperatures are 273 degrees larger than Celsius.

Changes of state occur in two primary ways: collisions and excitations.

(thermal) (atomic)

# Thermal Light

Question: A hot object that is glowing orange will become redder as it cools.

a. True

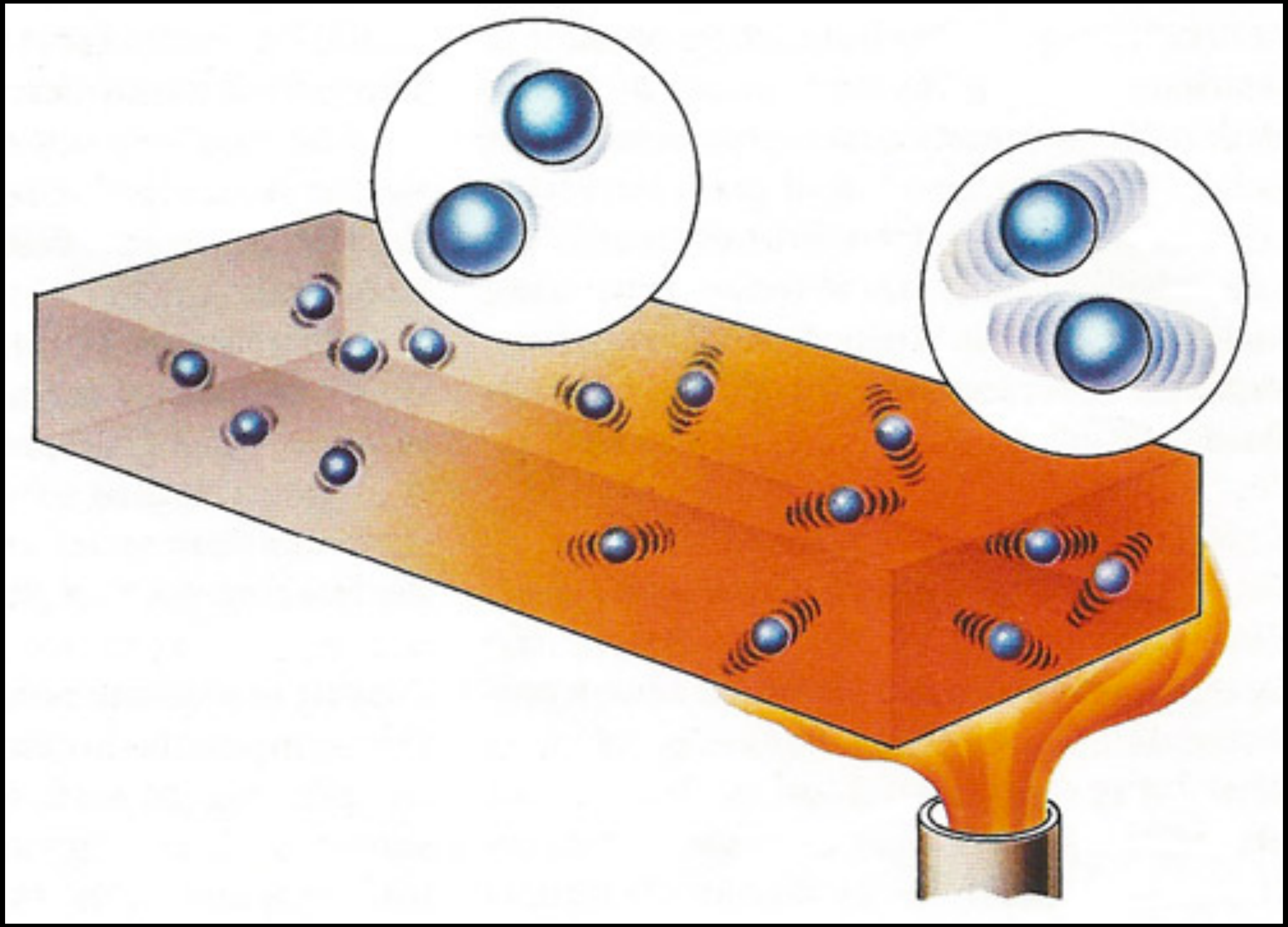
b. False

# Thermal Motion

Temperature measures the average speed of particles - faster speed, higher temperature.

Even in solids, the particles can vibrate at higher speeds.

Higher speed collisions results in higher energy light emitted, which is higher frequency of light.



# Thermal Light


Infrared light is lower frequency than visible light. Thus, things that emit infrared light are actually relatively cold!

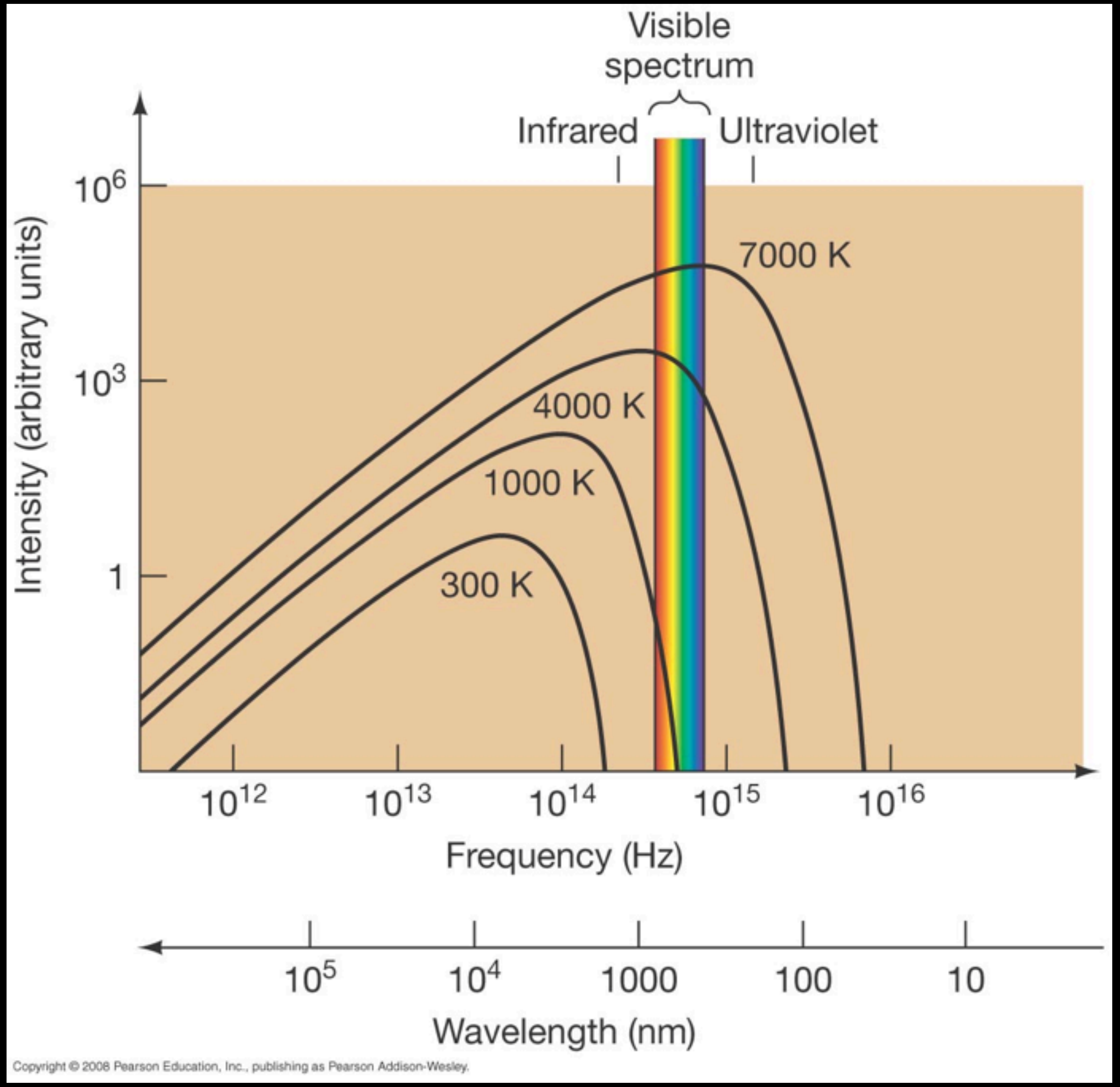
Visible light is higher frequency, so things that emit visible light are actually quite hot!

# Blackbody Radiation

We call this type of light: blackbody radiation. This is because this type of light is just as easily absorbed as it is emitted - and “black” things absorb.

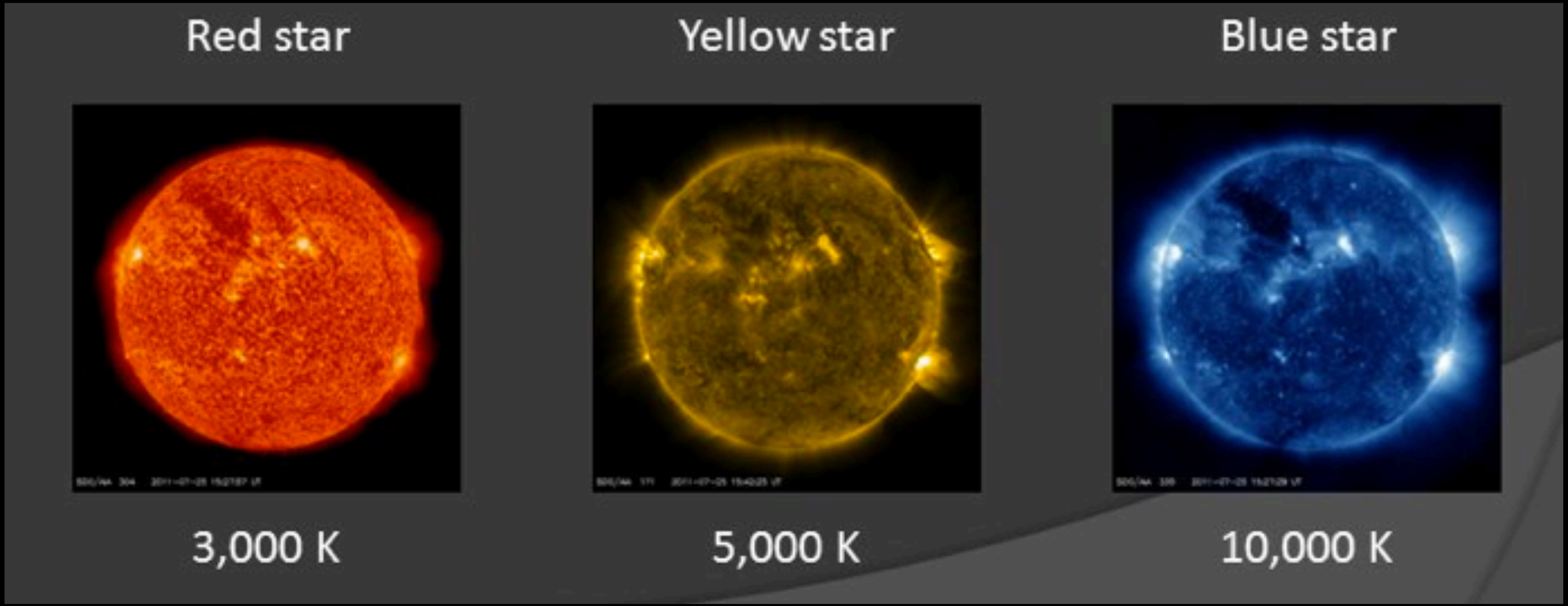
A range of frequencies are emitted.

The peak frequency corresponds directly to the TEMPERATURE of the object.



# Blackbody Radiation

We can use this to determine the temperature of distant objects.

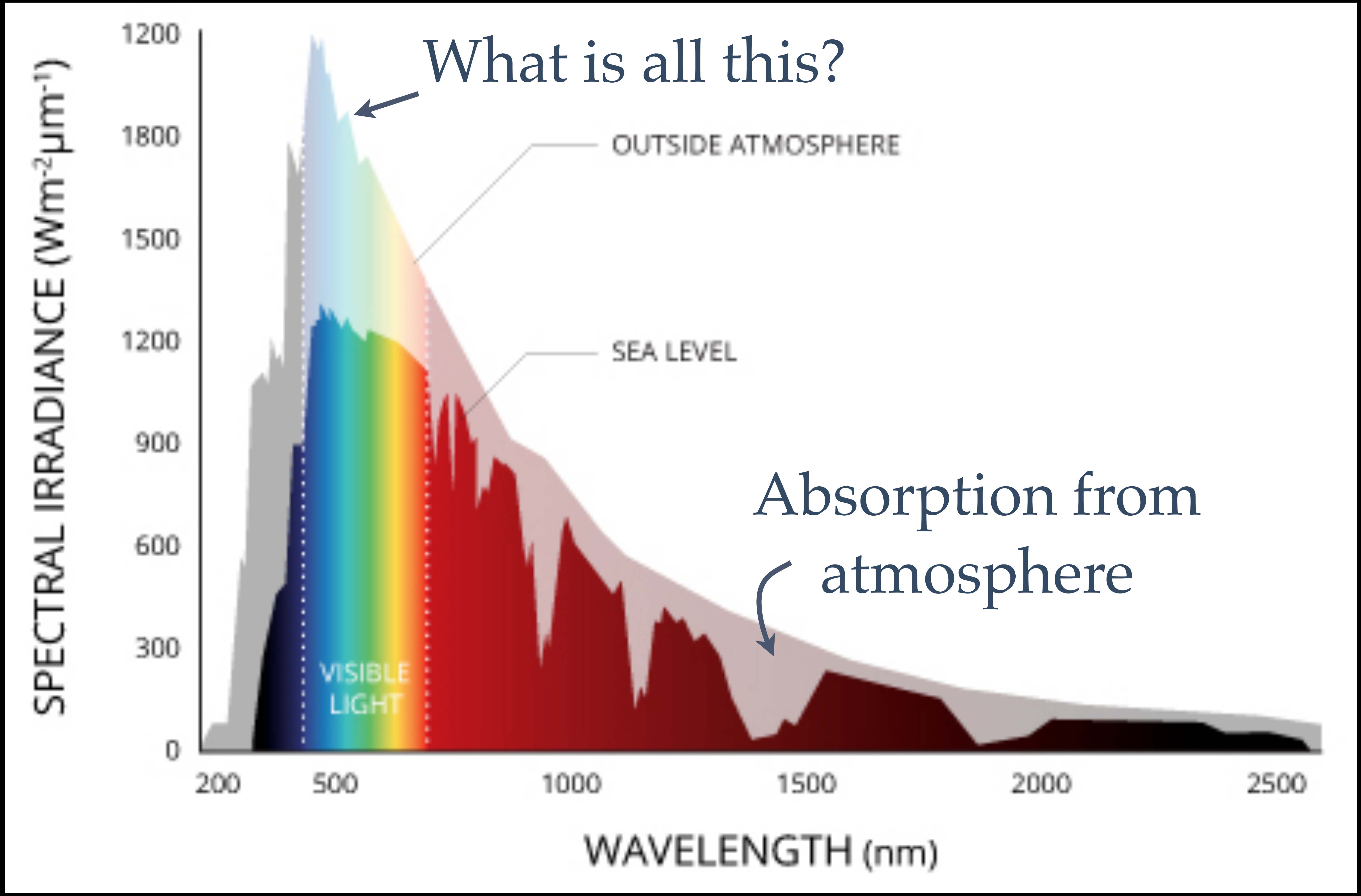



Star colour indicates temperature, but blackbody radiation of planets, asteroids, and nebula all indicate temperature, too.

# Sun through our atmosphere

Due to the opaqueness of our atmosphere, we don’t see all the Sun’s light.

Blackbody light is a smooth, continuous spectrum. So what are the jagged parts?

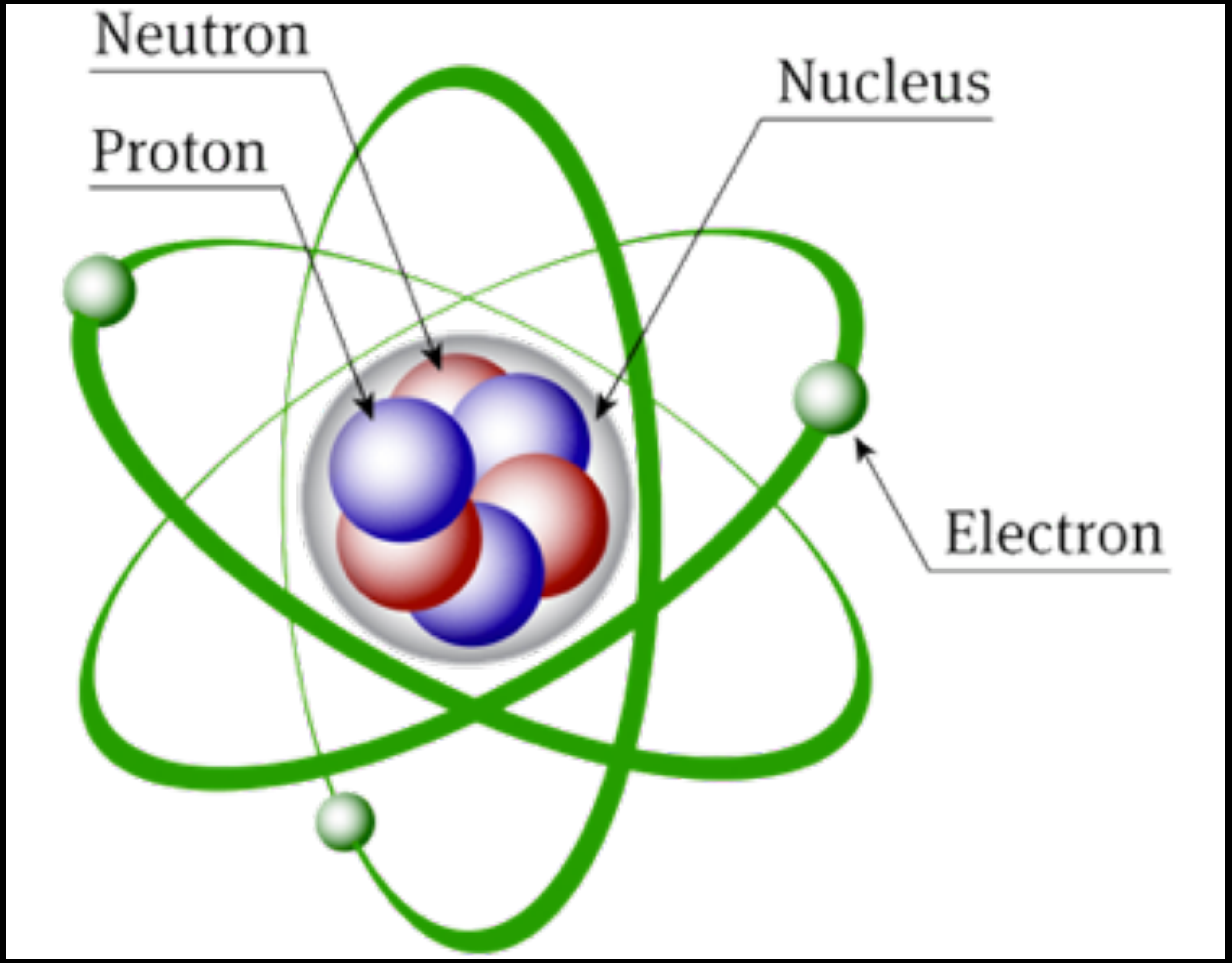


# Atomic Light

# Atoms

A common understanding of atoms is given by the Bohr Model.

In the Bohr Model, protons and neutrons bind together tightly in the nucleus, while electrons orbit around.




This model is actually an analogy to orbits in our solar system.

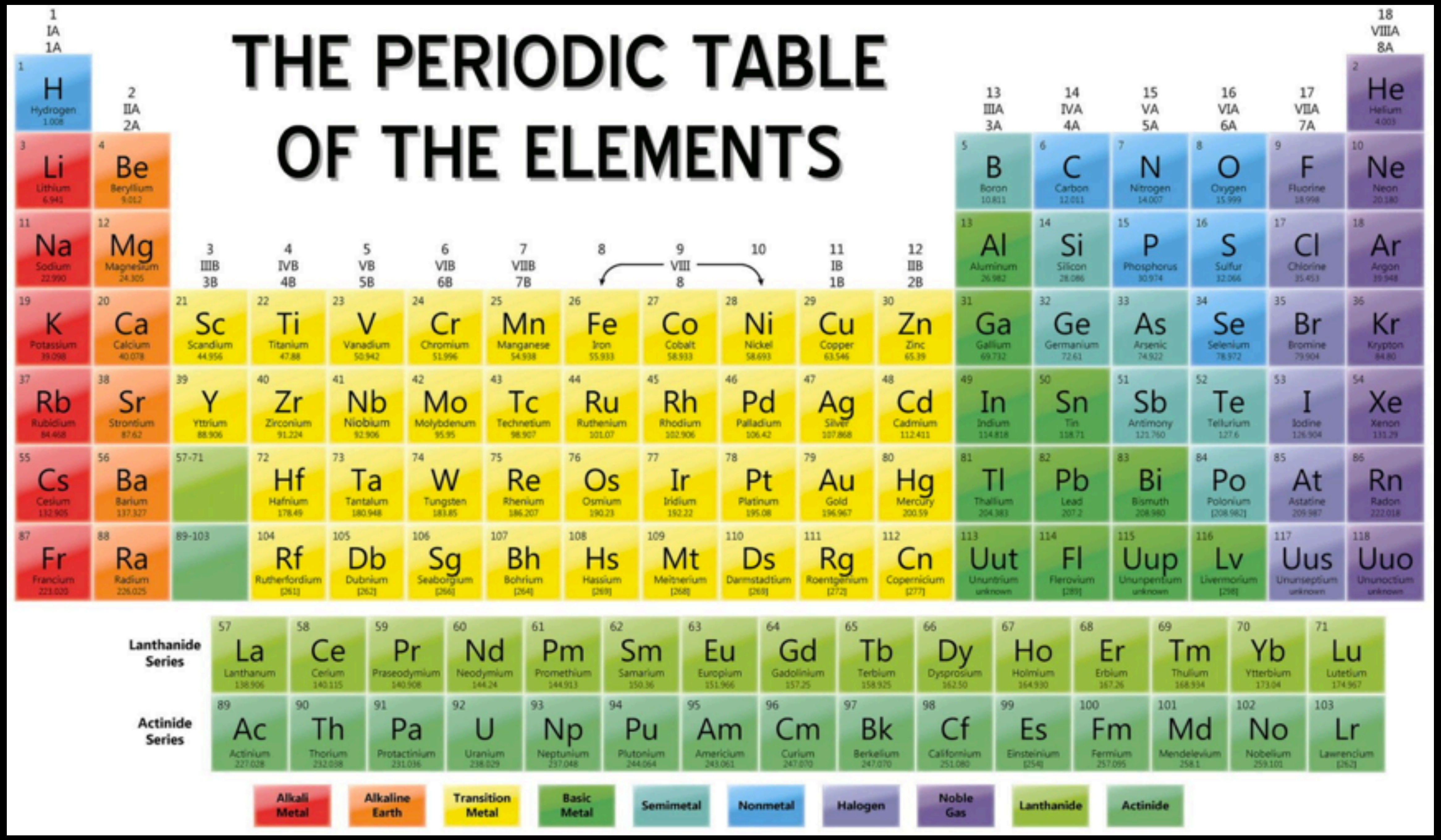
(Note: This model is not accurate by modern standards, but good enough.)

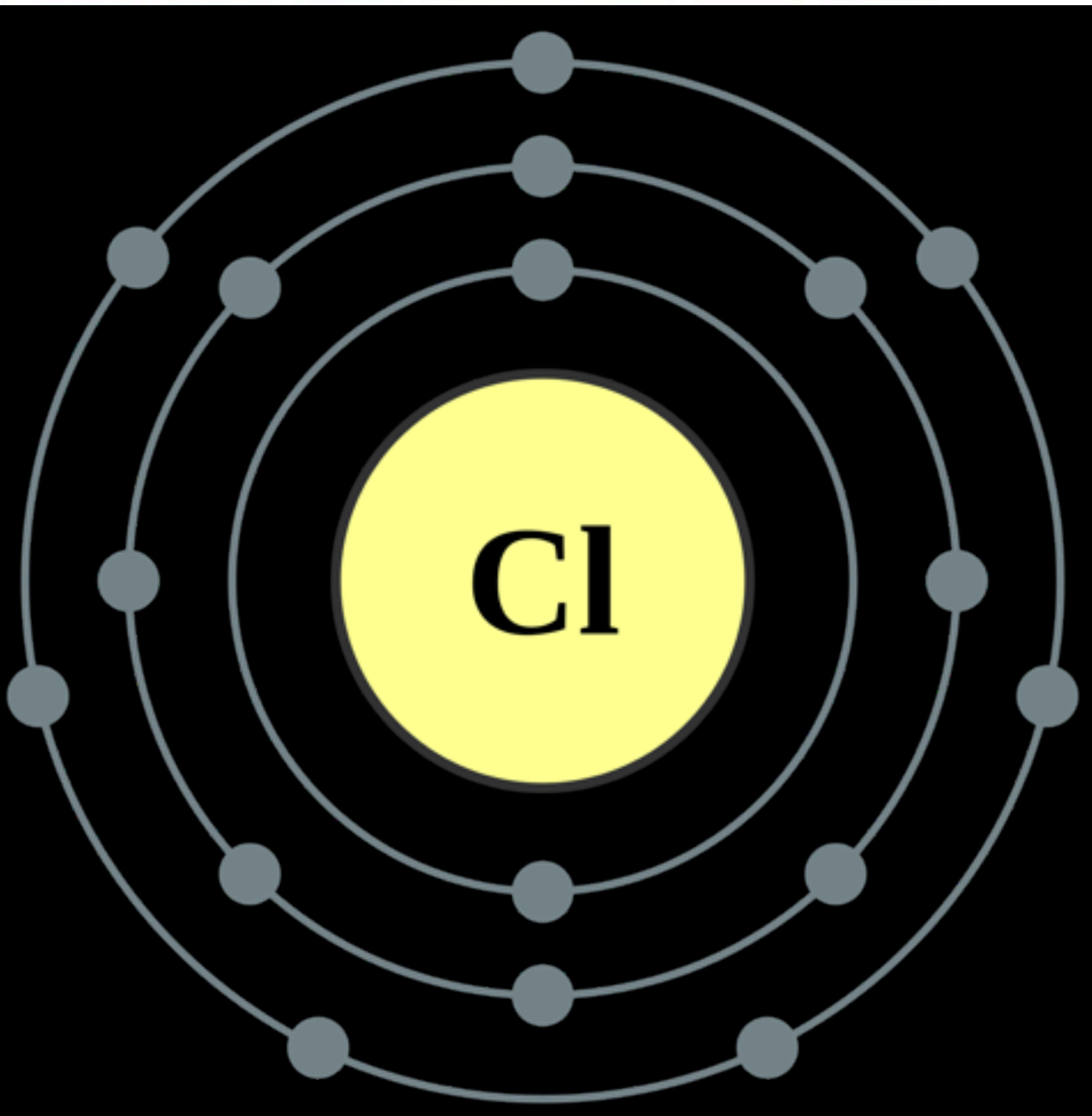
# Atoms

The Bohr Model was sufficient enough to explain the periodic table of elements.

The number of protons (+ charge) in the nucleus determines the element number.

Each electron orbital can only hold a max number of electrons: 2, 8, 8, 16, 16, 32, 32...



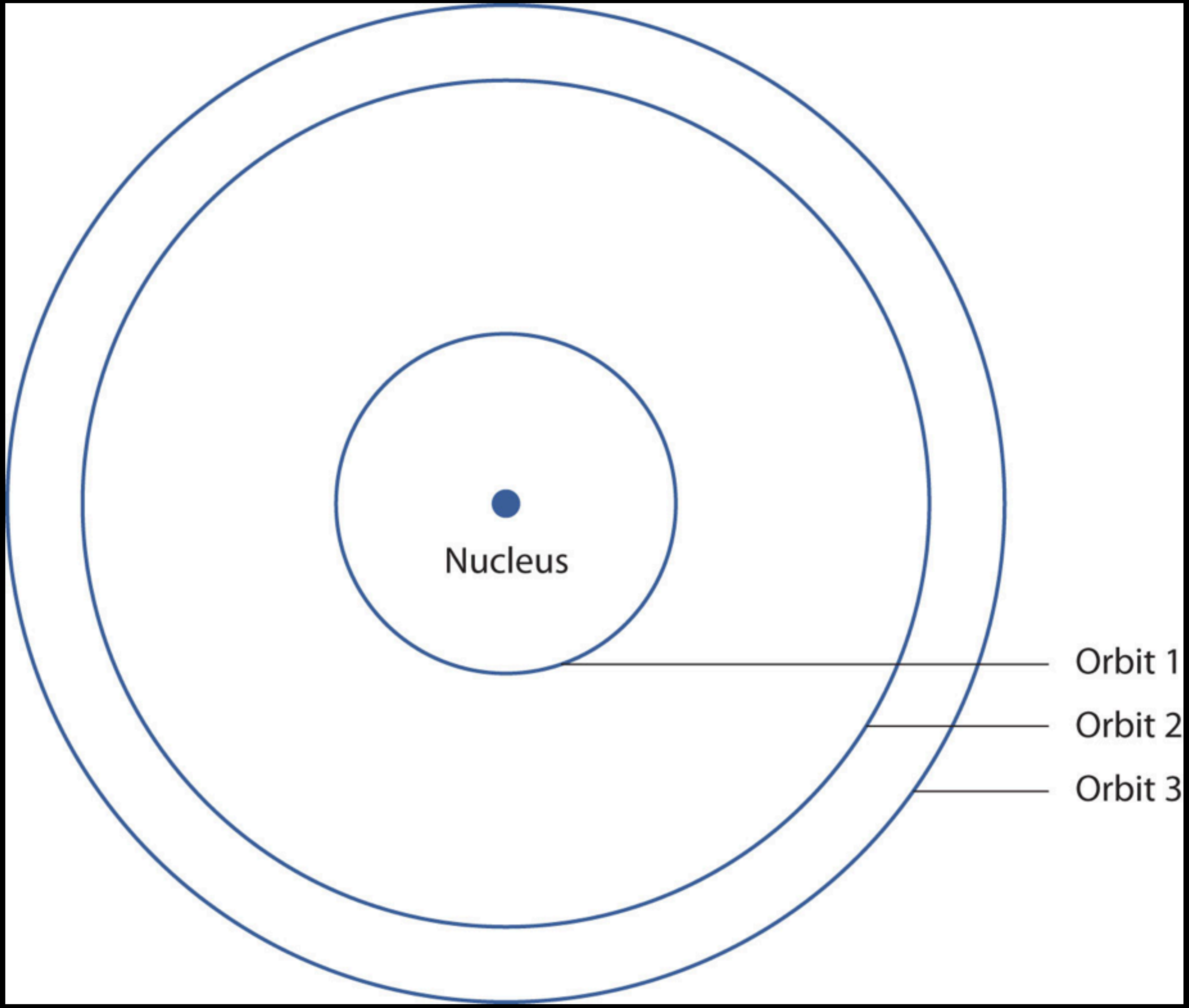



# Electron orbits

Electrons are arranged into orbitals based on the symmetries studied in Quantum Mechanics.

The orbits are not equally spaced, and the higher the # of protons in the nucleus, the closer the orbitals are to the nucleus.

Remember: Protons attract electrons.

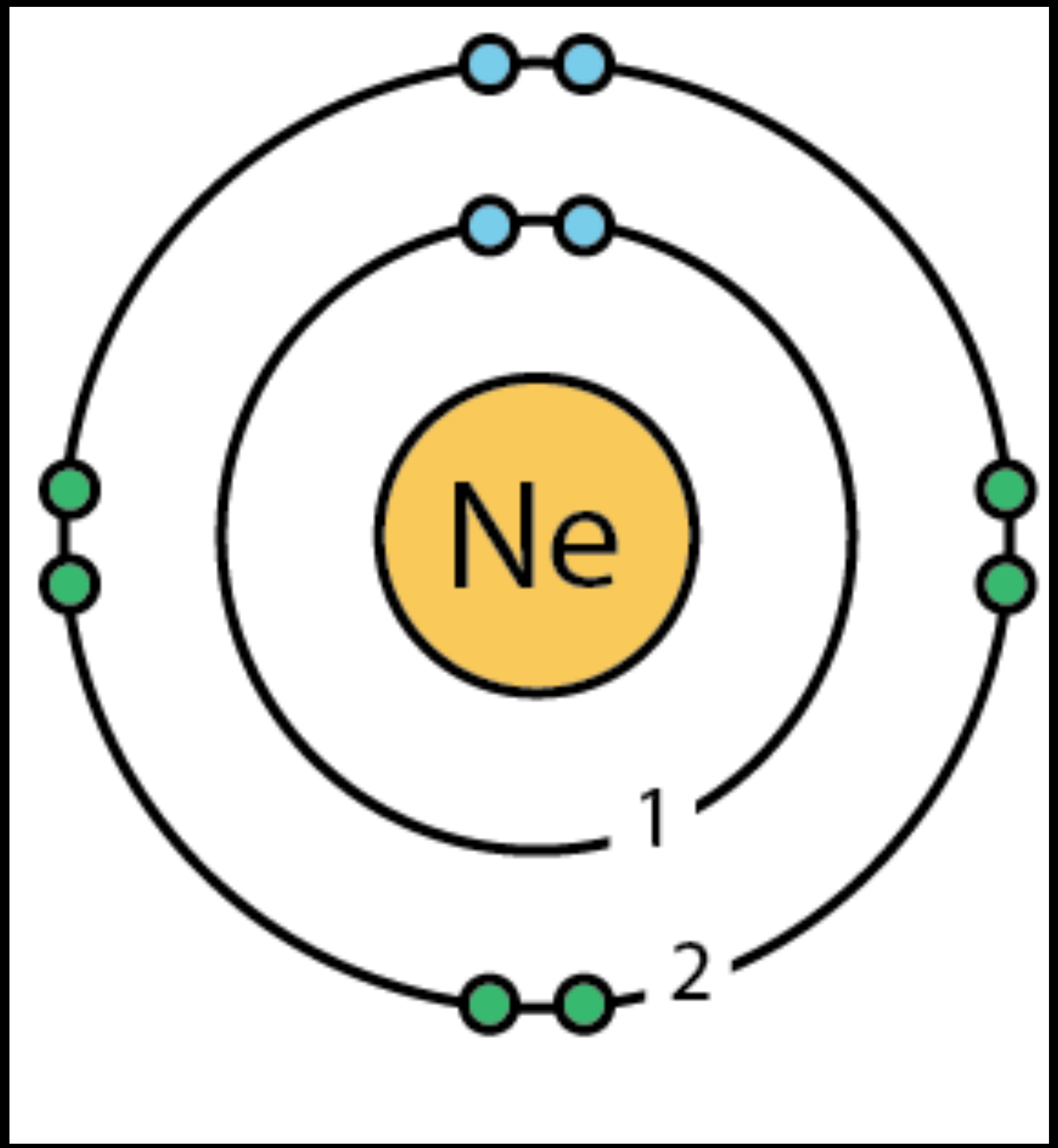


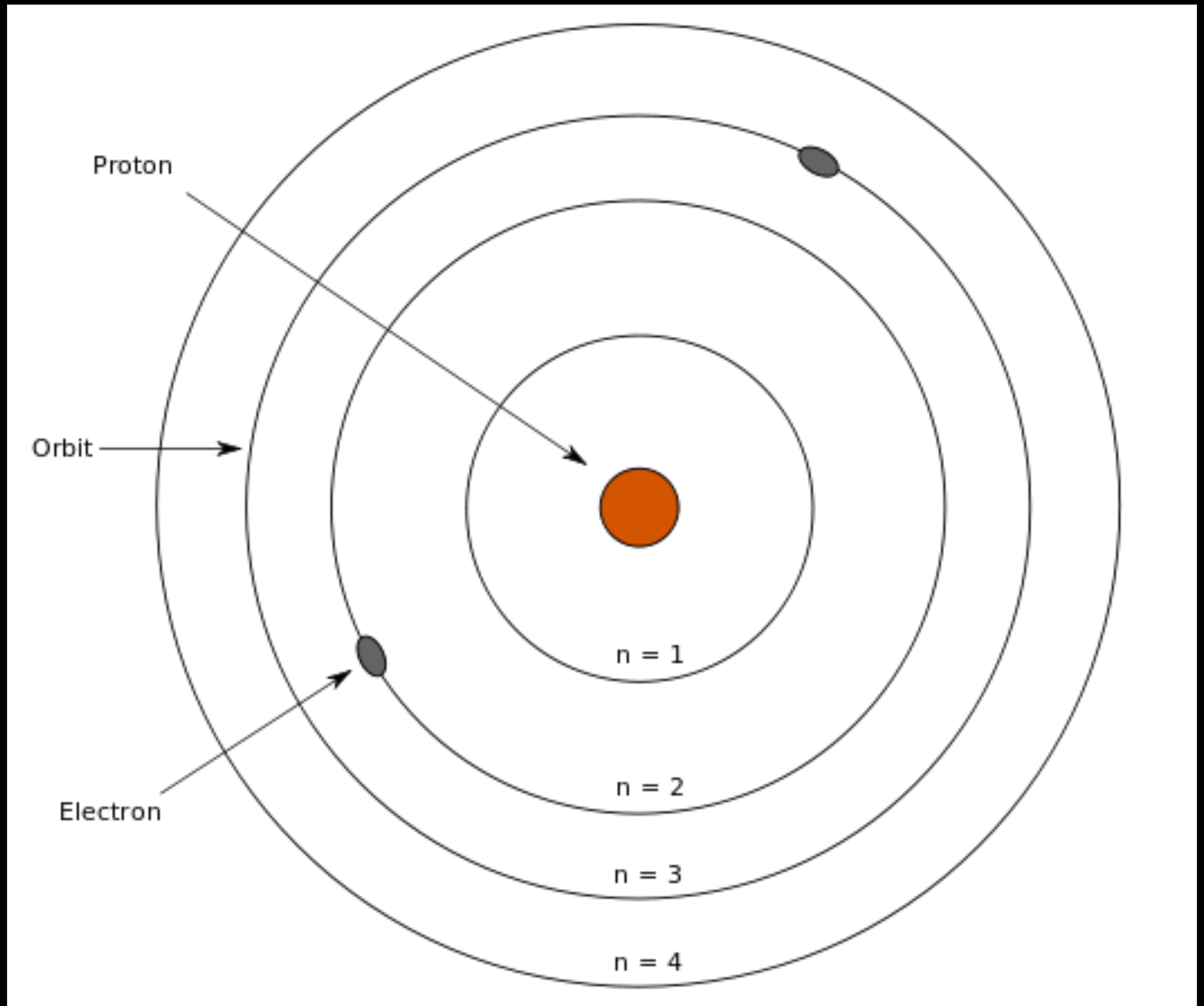
# Cold Atoms

For cold atoms, all the electrons fill up the orbitals as close to the nucleus as possible.

This is commonly shown in orbital diagrams as the ground state.

Even if there are no electrons in the orbital, however, the orbital still exists as an empty space.



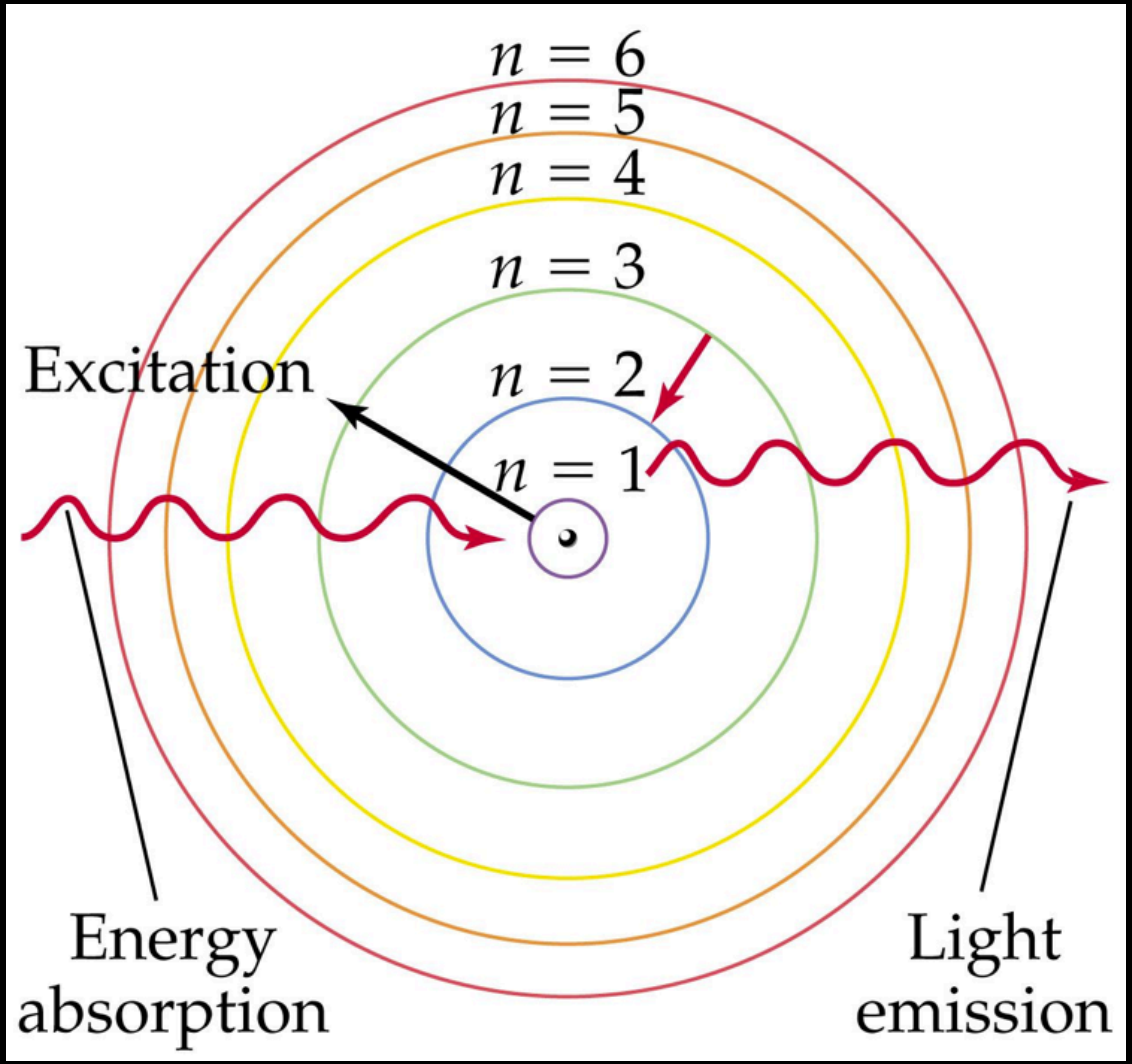



# Atomic Spectra

The energy needed for electrons to move between orbitals depends on the orbital number (n).

When light of the exact right frequency (energy) hits the atom, the electron can absorb it to boost to a higher orbital.

The electron can't absorb partial energies, only the EXACT energy needed to excite.



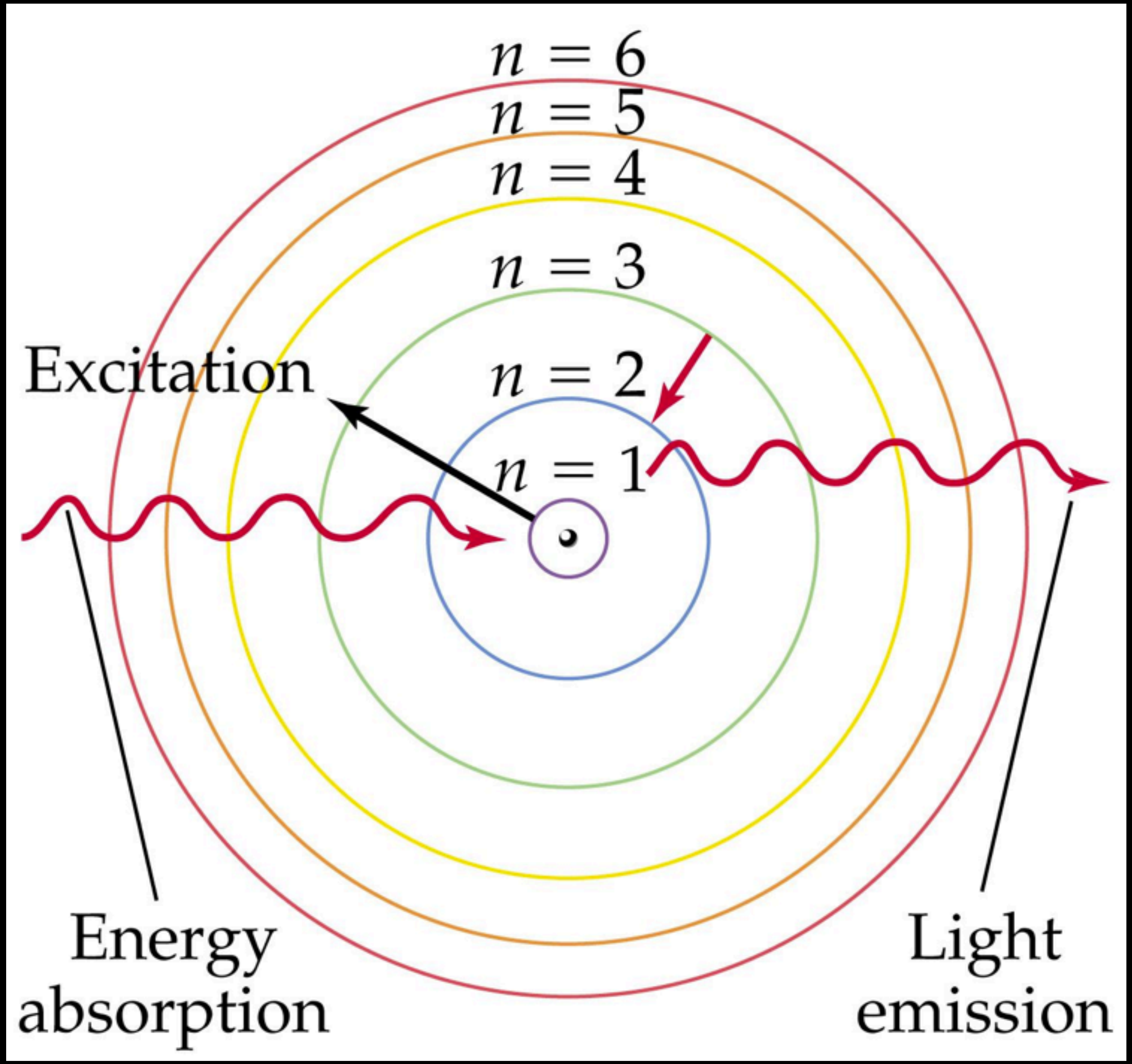
# Atomic Spectra

After a short period of time, the electron always de-excites down to lower orbitals, releasing the energy in a random direction.

It doesn’t have to drop to the original orbital. It can take any downward path!

e.g. 6 -> 3 -> 2 -> 1 or 6 -> 4 -> 1

All of the possible emission energies for an atom combine to form that atom’s EMISSION SPECTRA.

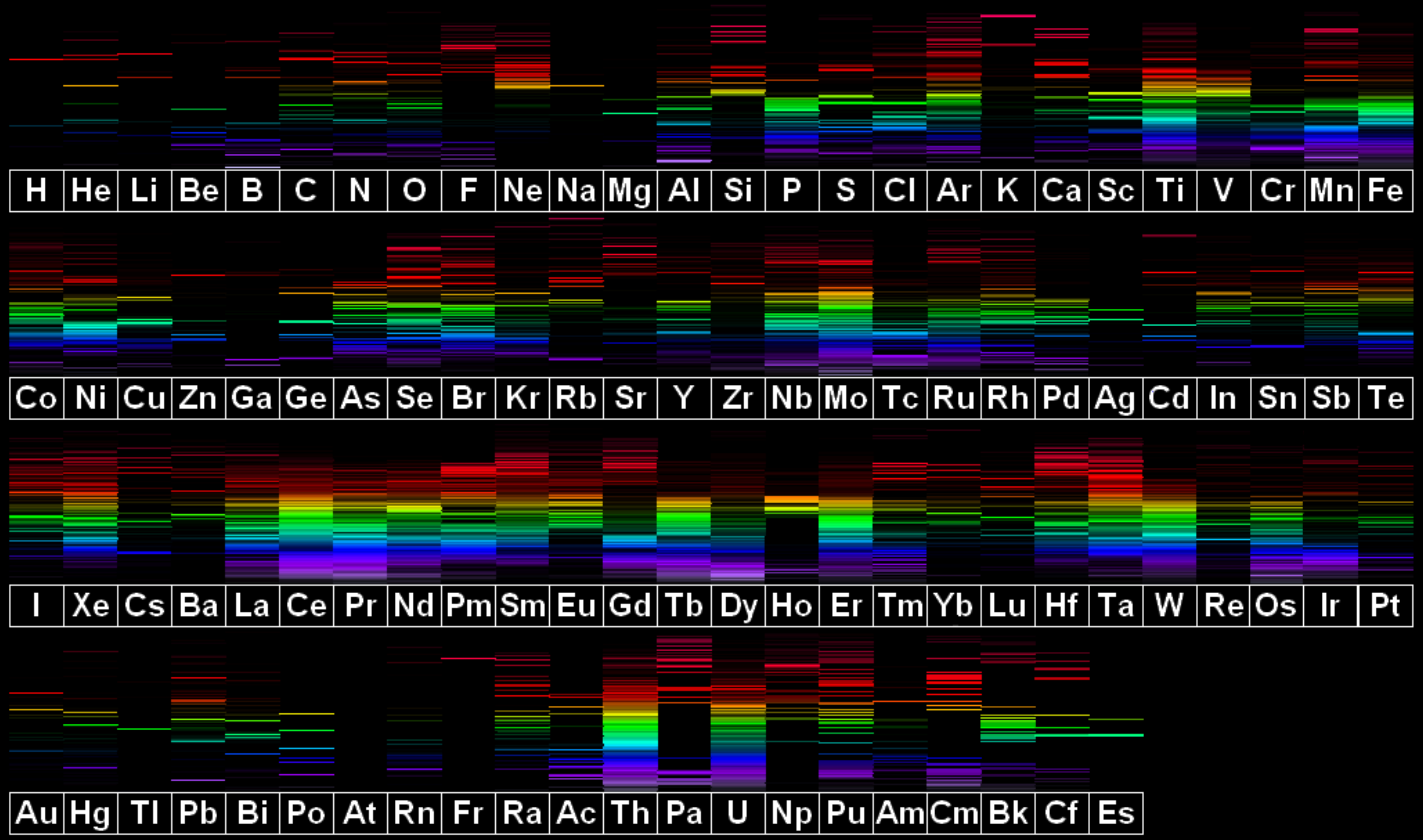


# Atomic Spectra

Each atom has its own distinctive spectra.

This spectra uniquely identifies the atom - there are no duplicates!

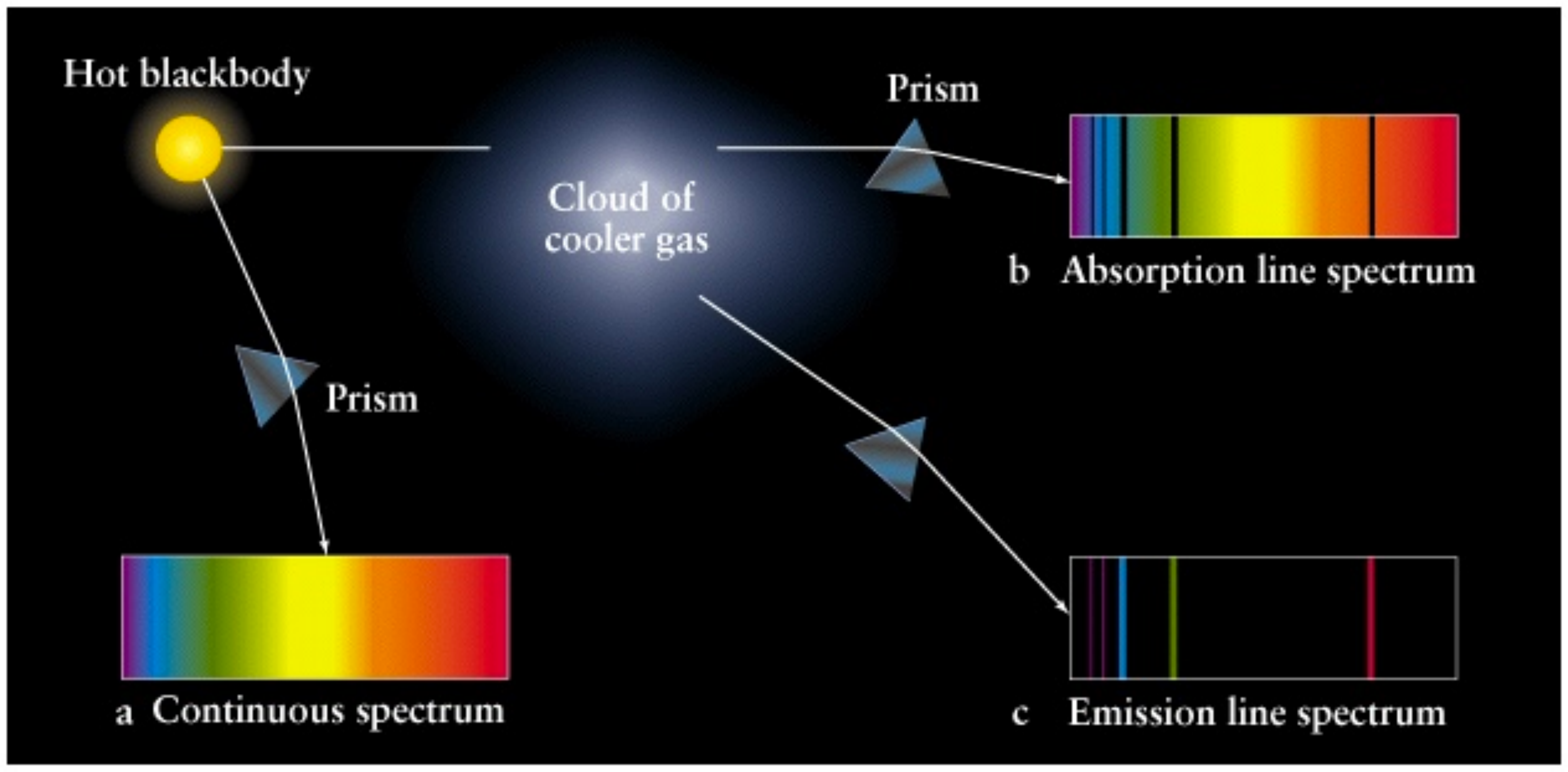
Even molecules have their own spectra.



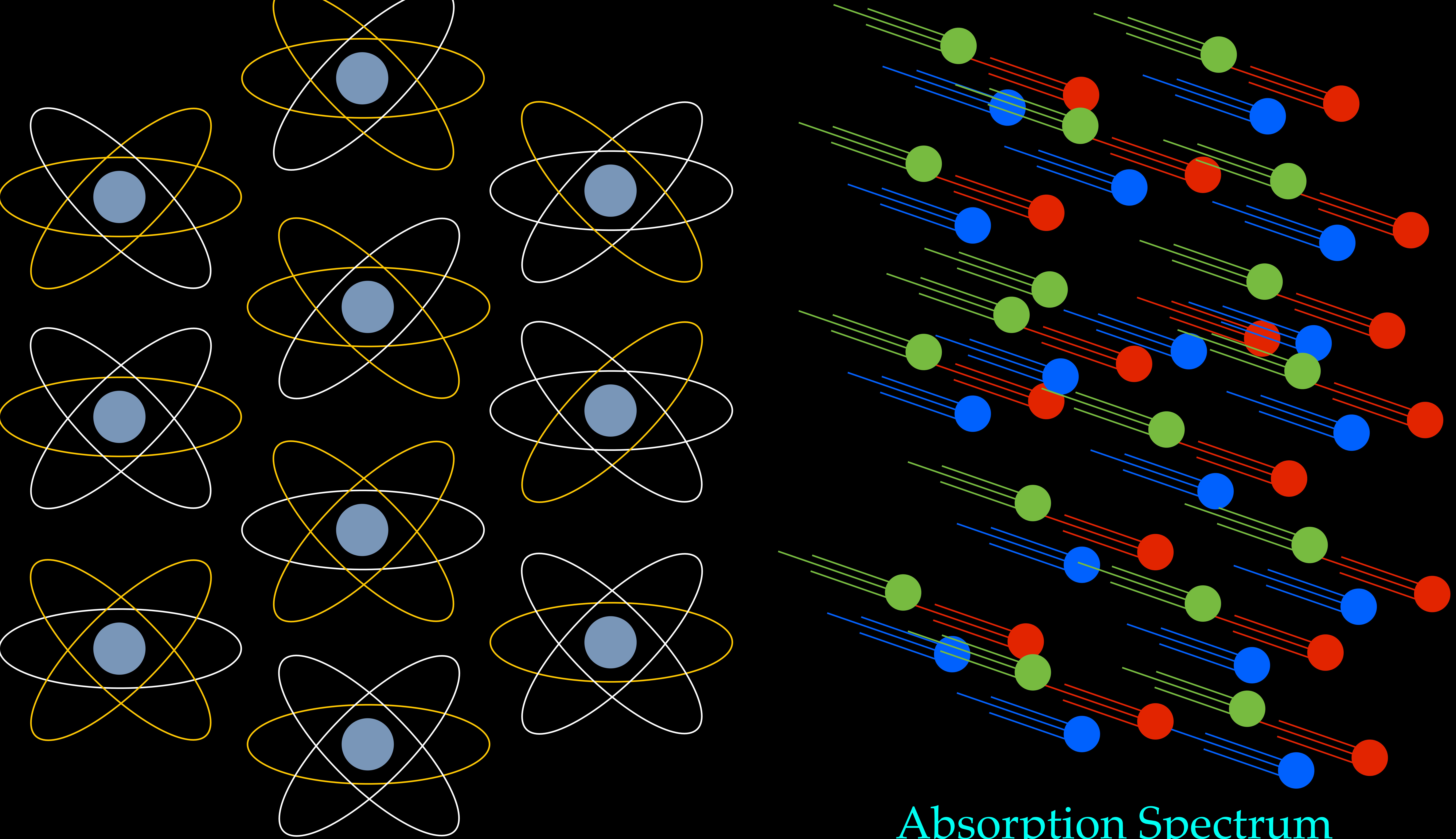
# Three types of spectra

Thermal light passing through a gas cloud produces an absorption spectrum, where the light absorbed by the atoms is now significantly reduced in brightness.

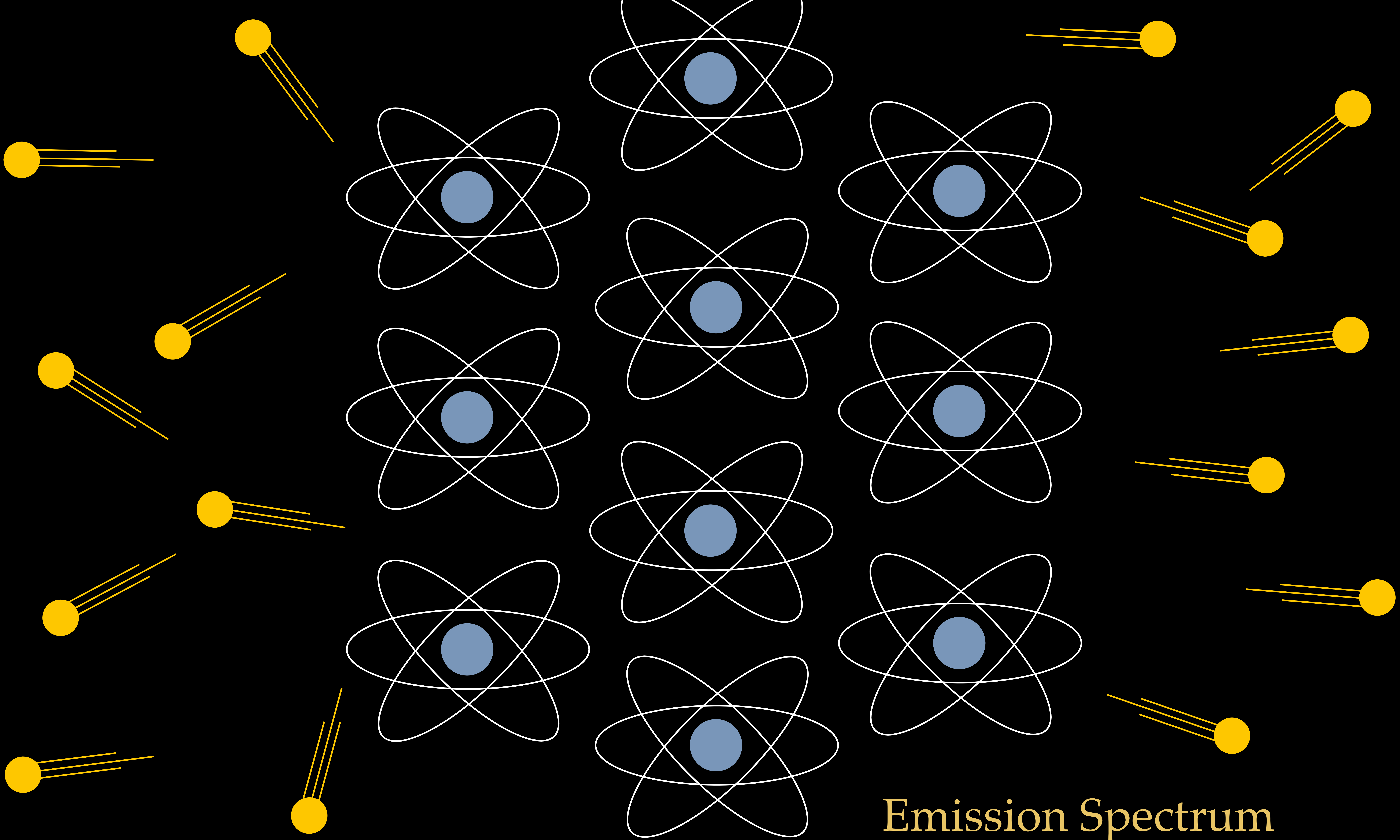
But that light gets re-emitted in all directions and appears as an emission spectrum.



# Blackbody Spectrum



Absorption Spectrum



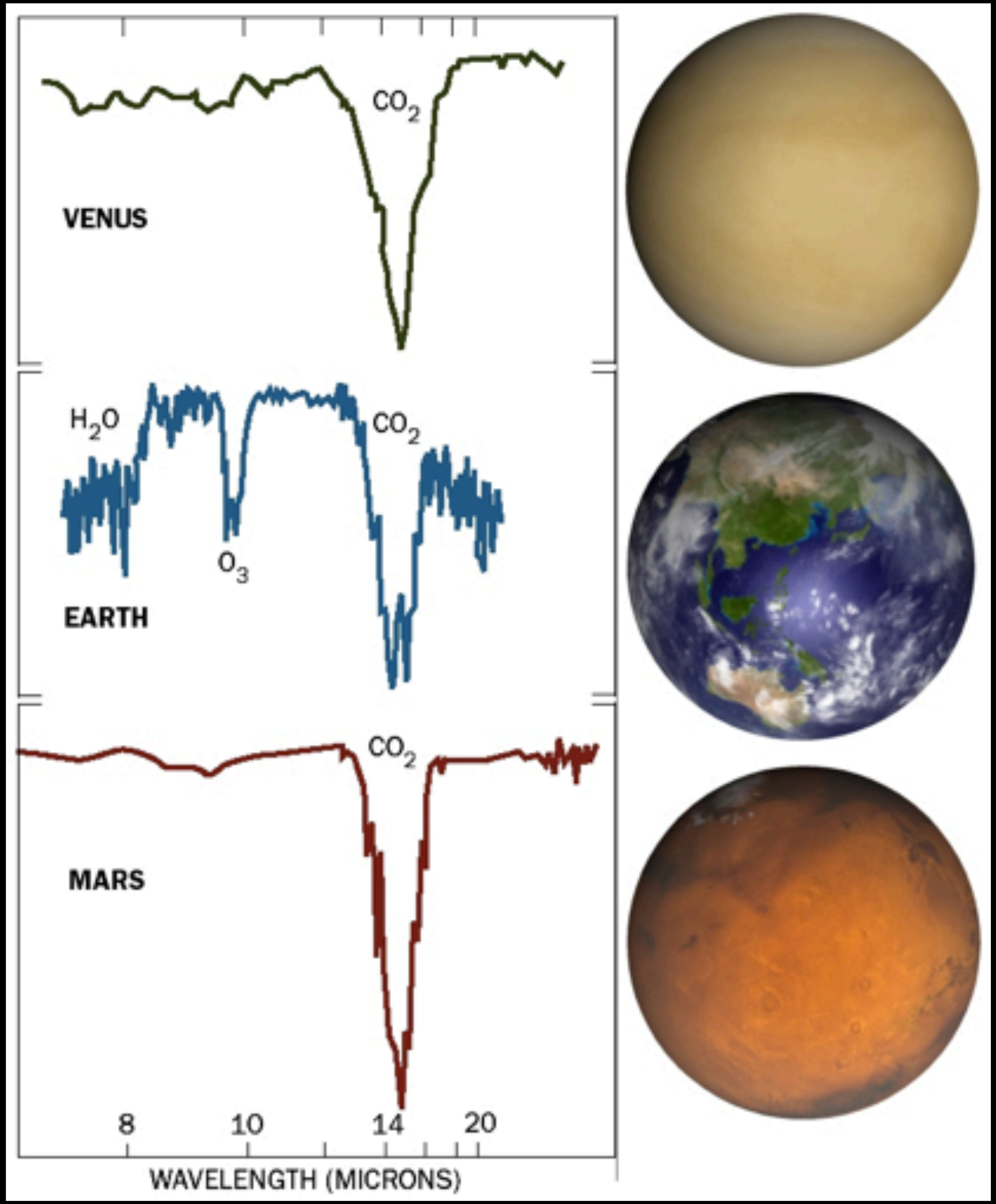
# Emission Spectrum

# Atmospheres of Planets

We can tell the atmosphere of a planet by looking at its emission/absorption spectrum!

Blackbody light produces absorption lines. See visible emission lines from Sun’s light interacting with atmosphere.

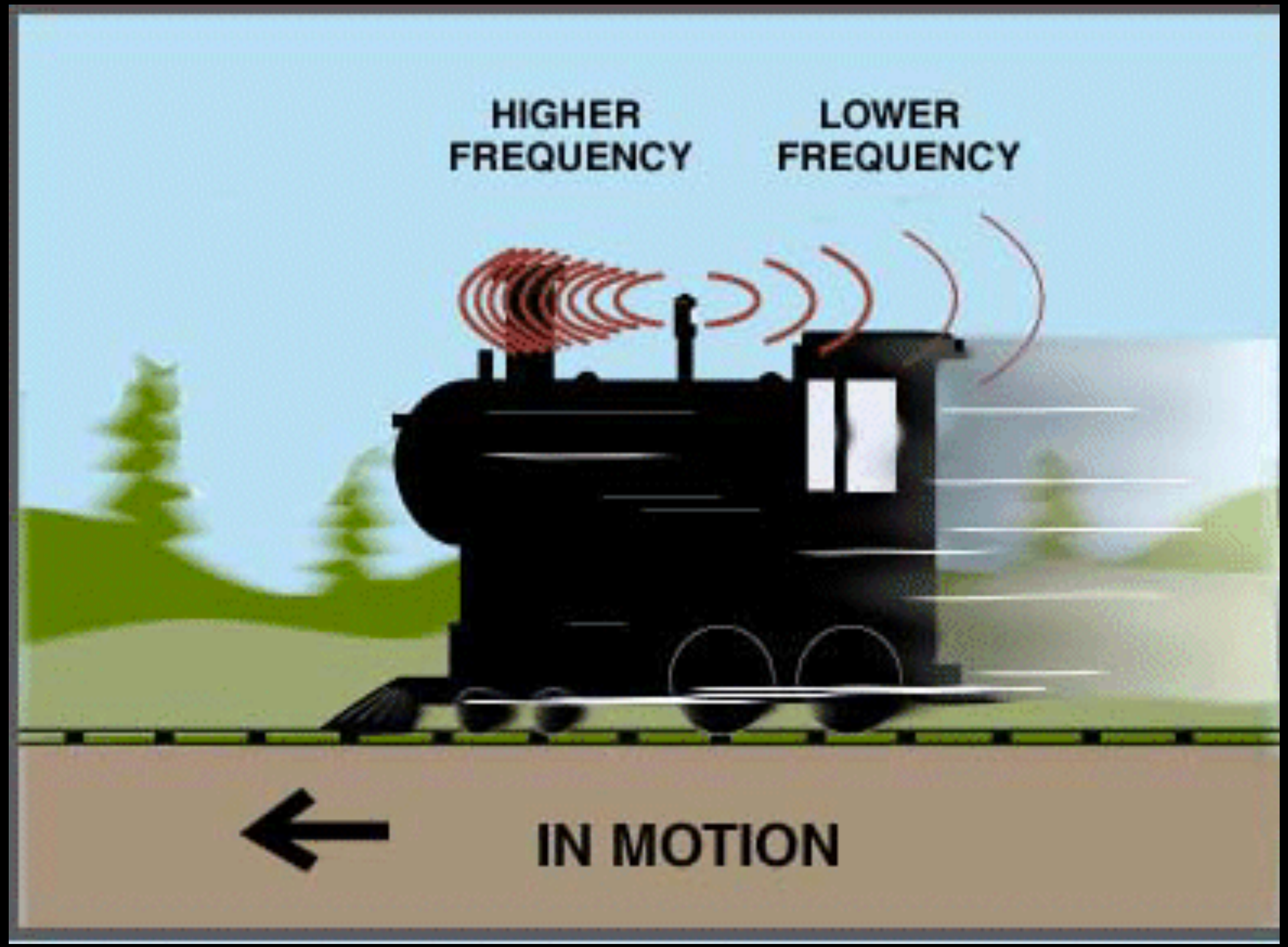
We don’t even have to visit the planets to know a lot about them.



# The Doppler Effect

# Doppler Effect

Waves experience a shift in their frequency / wavelength when emitted by a moving object




Remember, wavelength and frequency have an inverse relationship.
When one increases, the other decreases!

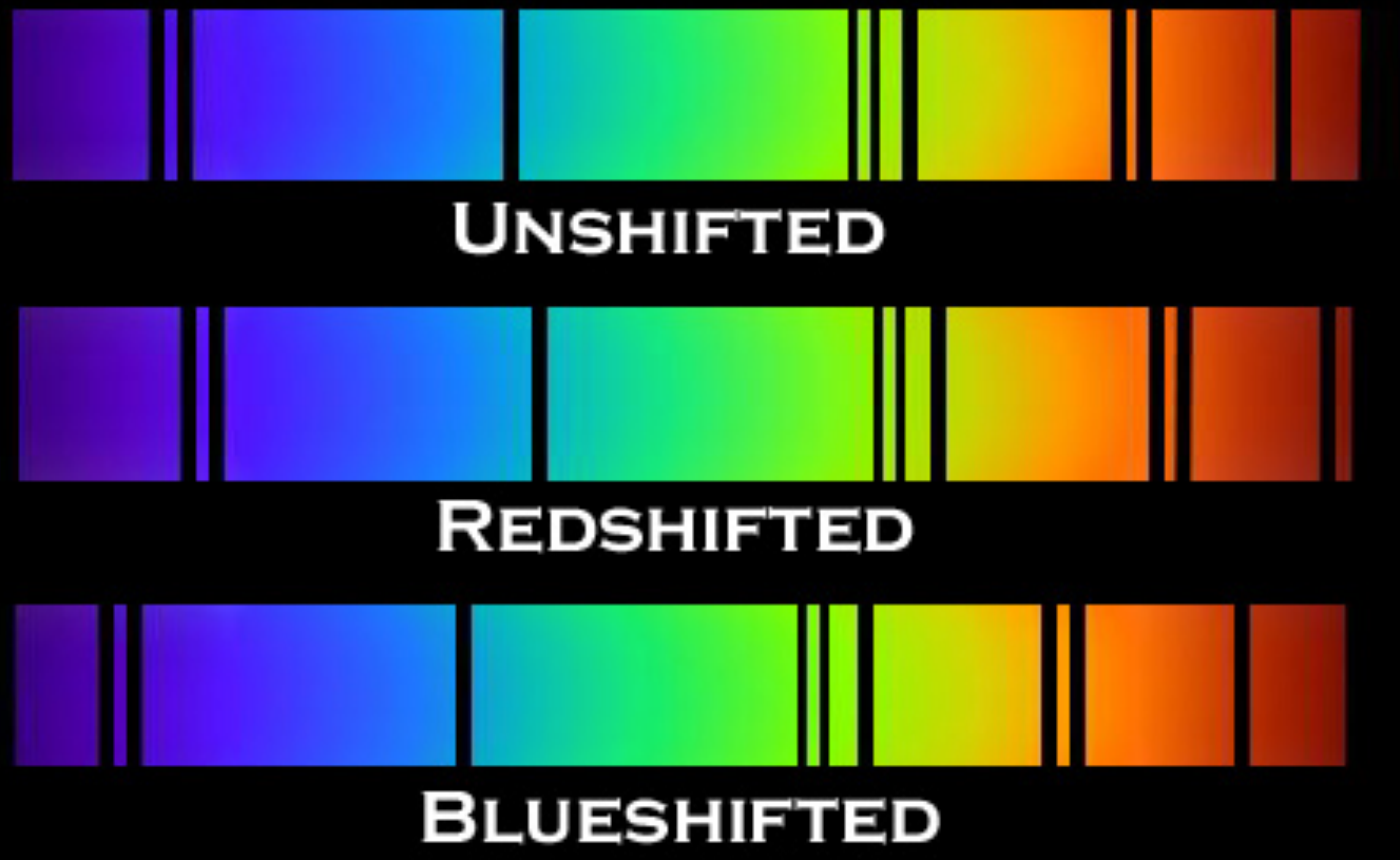
Frequency increases and wavelength decreases in direction of motion, and vice-versa for direction away from motion.

# Doppler Shifted Spectra

When looking at absorption or emission spectra, the lines are shifted based on the doppler effect.

Things that are moving away from us are "red shifted" to a lower frequency.

Things that are moving towards us are "blue shifted" to a higher frequency.



# Measuring Radial Speed

We can measure the angular velocity of objects by looking how they move in the sky.

Doppler shifts of blackbody spectra would just look like a higher/lower temperature object.

Size of Doppler shift is proportional to radial velocity:

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{V}{c}$$

$\lambda$ = observed wavelength

$\lambda_0$ = wavelength if source isn't at rest

V = radial velocity of moving source

c = speed of light

Because atomic spectra occur at characteristic frequencies, we can use this to determine the radial speed (towards/away).