PHYS 1403
Stars & Galaxies
Module 1

Light

The Orion Nebula

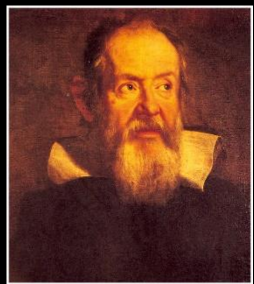
Visible Light

Infrared Light

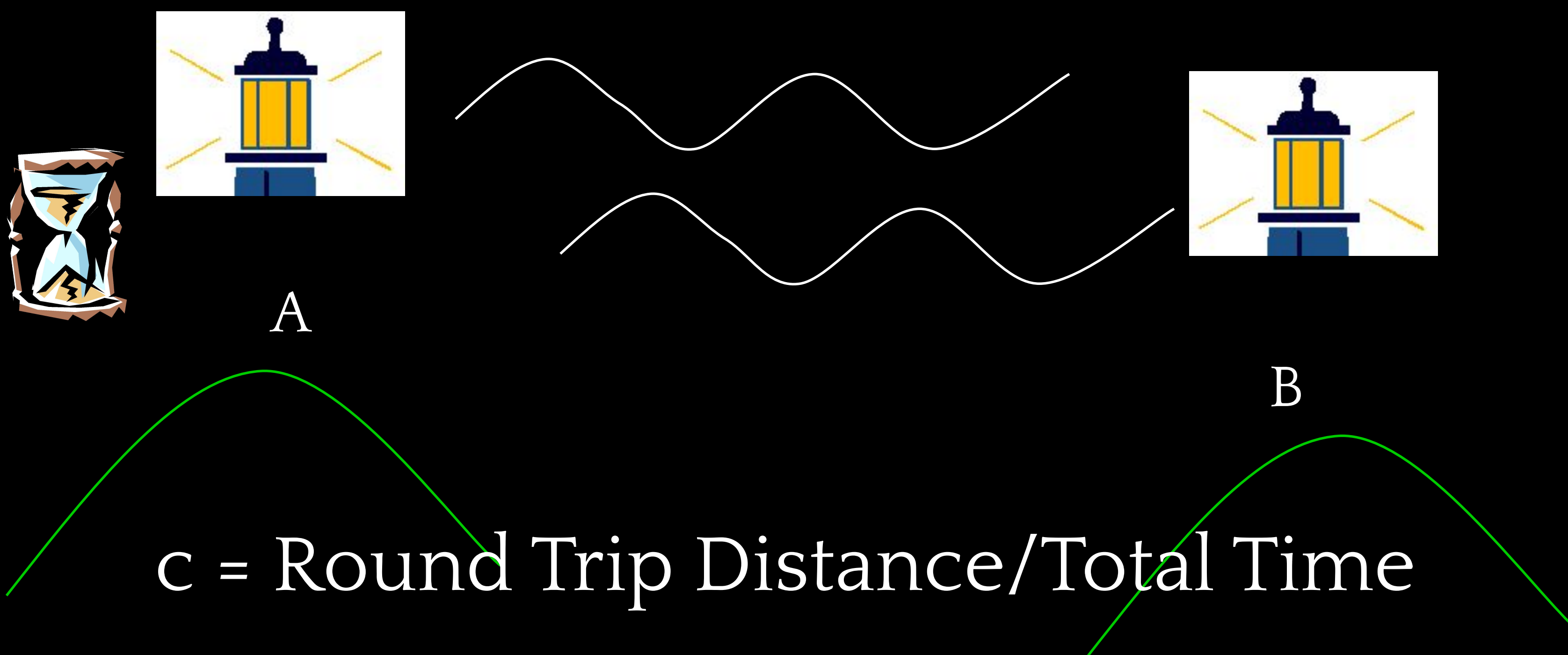
Basic Questions about Light.

How fast is it?

The Speed of Light?



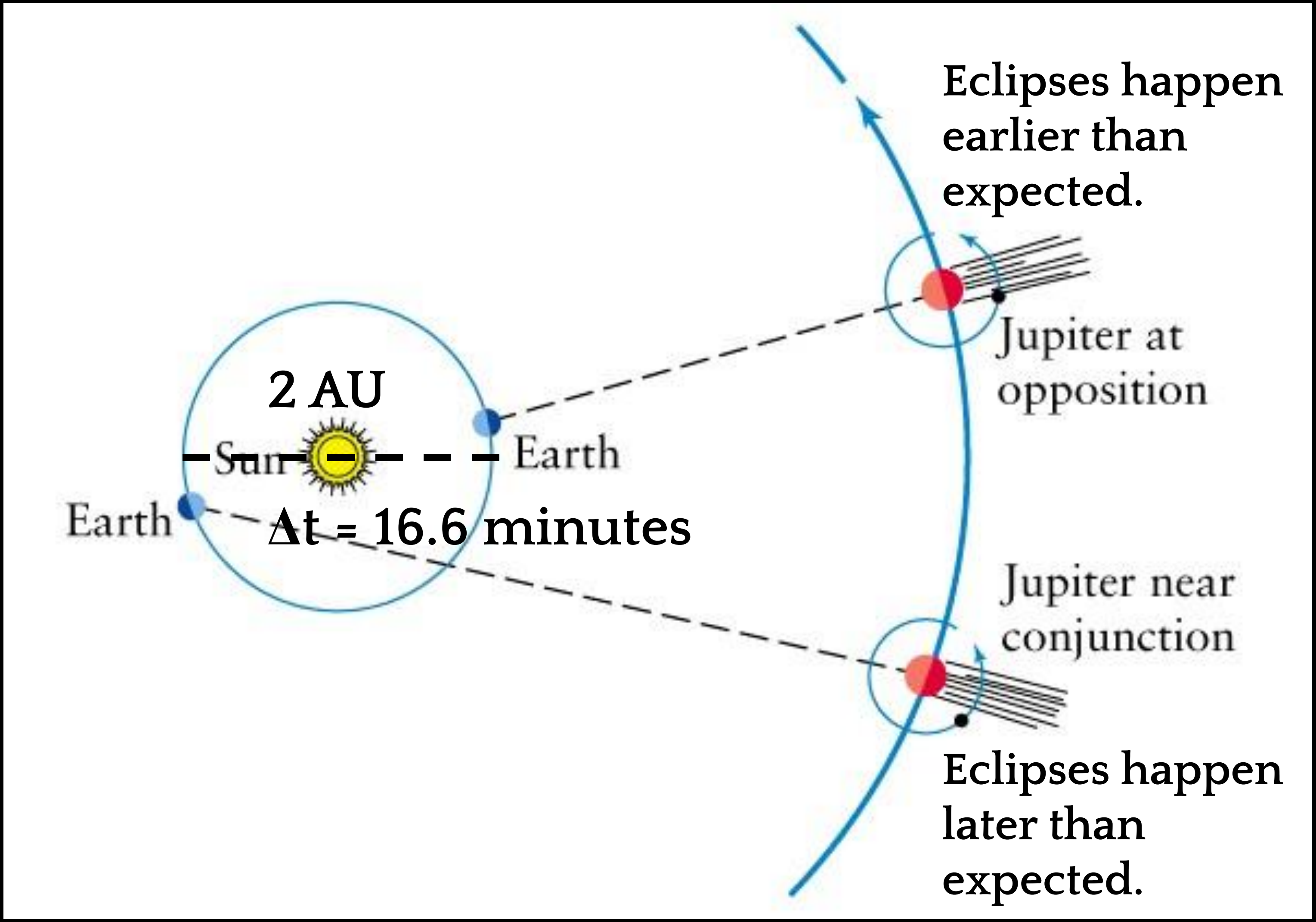
Galileo's Experiment



c = Round Trip Distance/Total Time

As a result, Galileo came to the conclusion that light traveled instantaneously.

Finite Speed of Light – Roemer (1675)



Speed of Light

- c = 299,792.458 km/sec
- We usually just round this off to be 300,000 km/sec $(3 \times 10^8$ m/s$)$
- 186,000 miles/sec $(1.86 \times 10^5$ miles/sec$)$
- Note: This the speed of light in a vacuum!

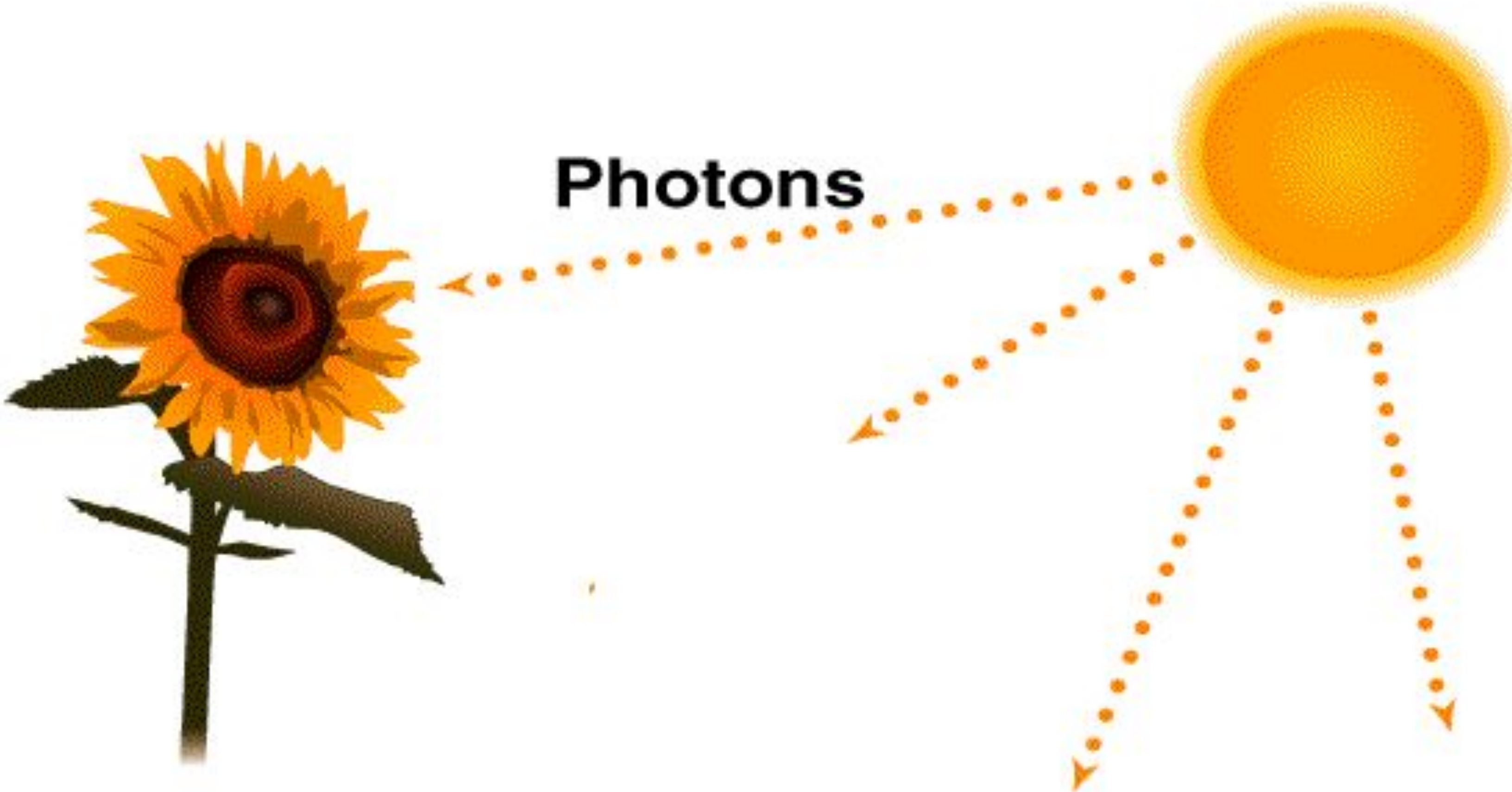
Basic Questions about Light.

What is it made of?

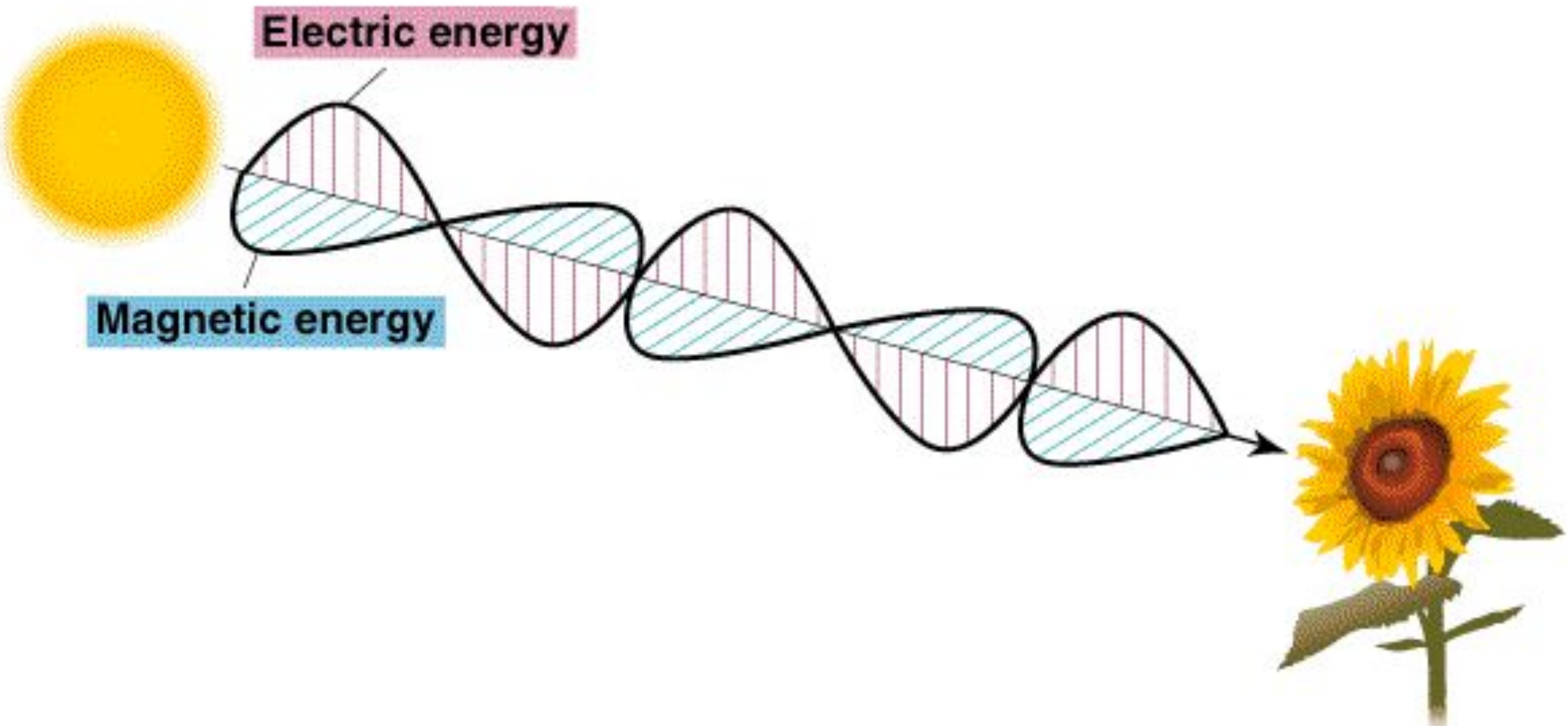
What is Light?

- In 1670, Isaac Newton proposed that light was made of tiny particles (corpuscles).
- In 1678, Dutch astronomer Christian Huygens proposed that light was made of tiny waves.
- In 1801, Thomas Young confirmed the wave nature of light in his double slit experiment.
- In 1860, Scottish physicist James Clerk Maxwell developed a theory describing how electricity and magnetism are related. This theory also explained that light was an 'electromagnetic wave.'
- In 1905, Albert Einstein proposed that light is actually composed of tiny bundles of waves called photons.
- Light has a wave-particle duality.

Models of Light



Models of Light



Light is an Electromagnetic Wave

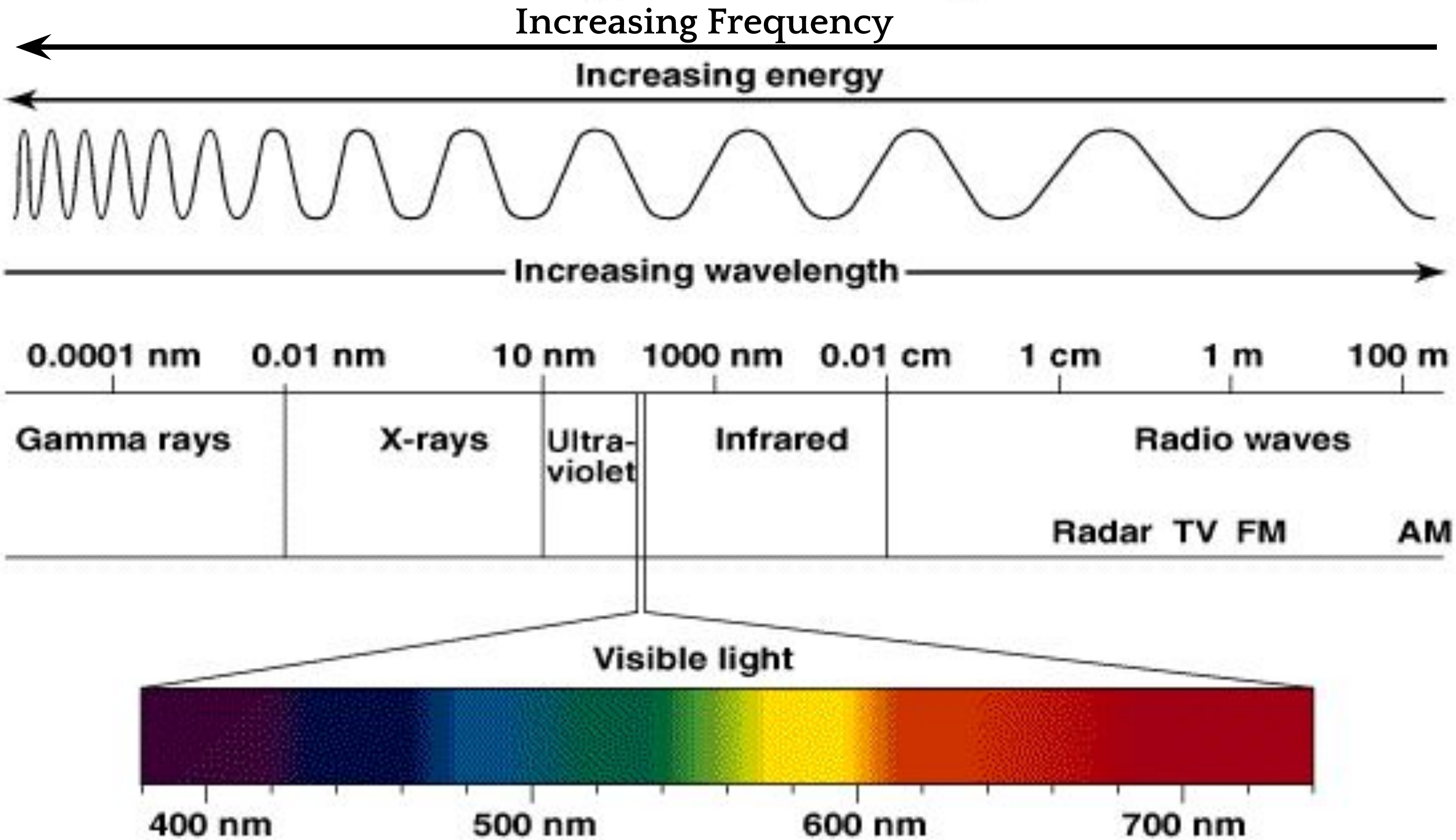
- Electromagnetic Waves are energy-carrying waves emitted by vibrating electrons. EM waves consist of vibrating electric and magnetic fields which are perpendicular to each other.

- EM waves are also known as…
  - Light
  - Radiation
  - Photons

Electromagnetic Wave Speed

- EM wave speed is the same as the speed of light.
- This speed is a constant for all forms of EM waves, radiation, or light.
- It is 300,000 kilometers per second or 186,000 miles per second.
- $c = f\lambda$
- *speed of light (c) = frequency (f) x wavelength (λ)*

Electromagnetic Spectrum



Energy Carried by Light

- "Short wavelength radiation carries more energy than long wavelength radiation".

$$E = hf = \frac{hc}{\lambda}$$

- Planck's Constant – h = 6.6 x 10^{-34} J·s
- Result of this Equation => It shows that light waves can carry quantified amounts of energy which is a particle property.

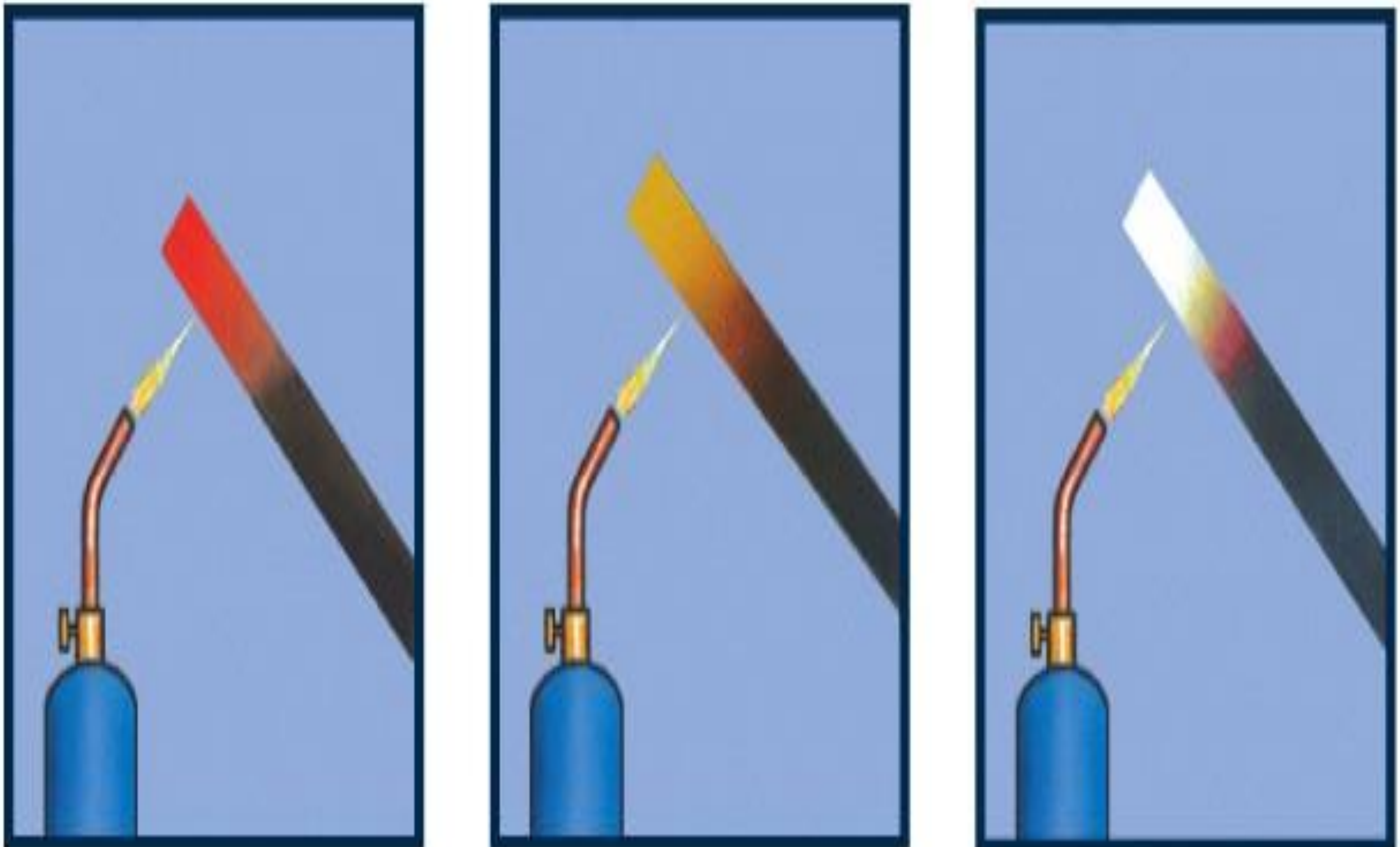
Basic Questions about Light.

How are light and temperature related?

Temperature Scales

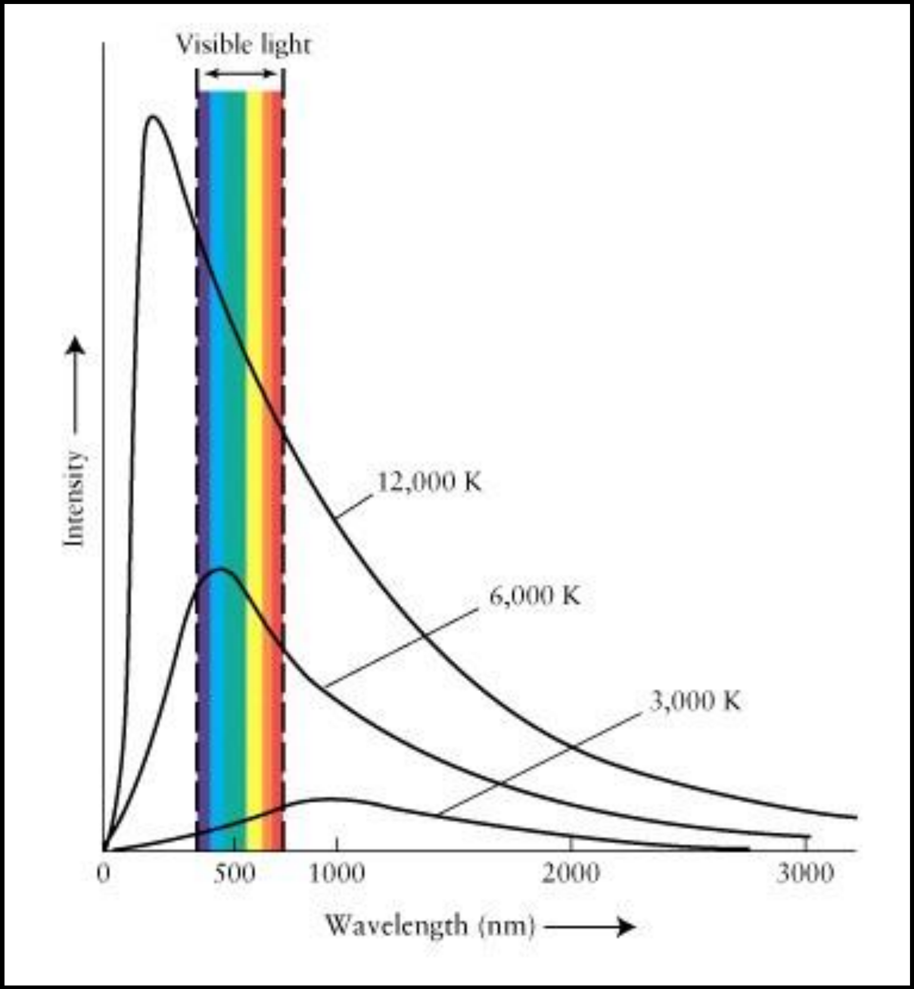
	Fahrenheit	Celsius	Kelvin
Boiling Point of Water	212°F	100°C	373 K
Freezing Point of Water	32°F	0°C	273 K
Absolute Zero	-459°F	-273°C	0 K

TEMPERATURE INCREASES



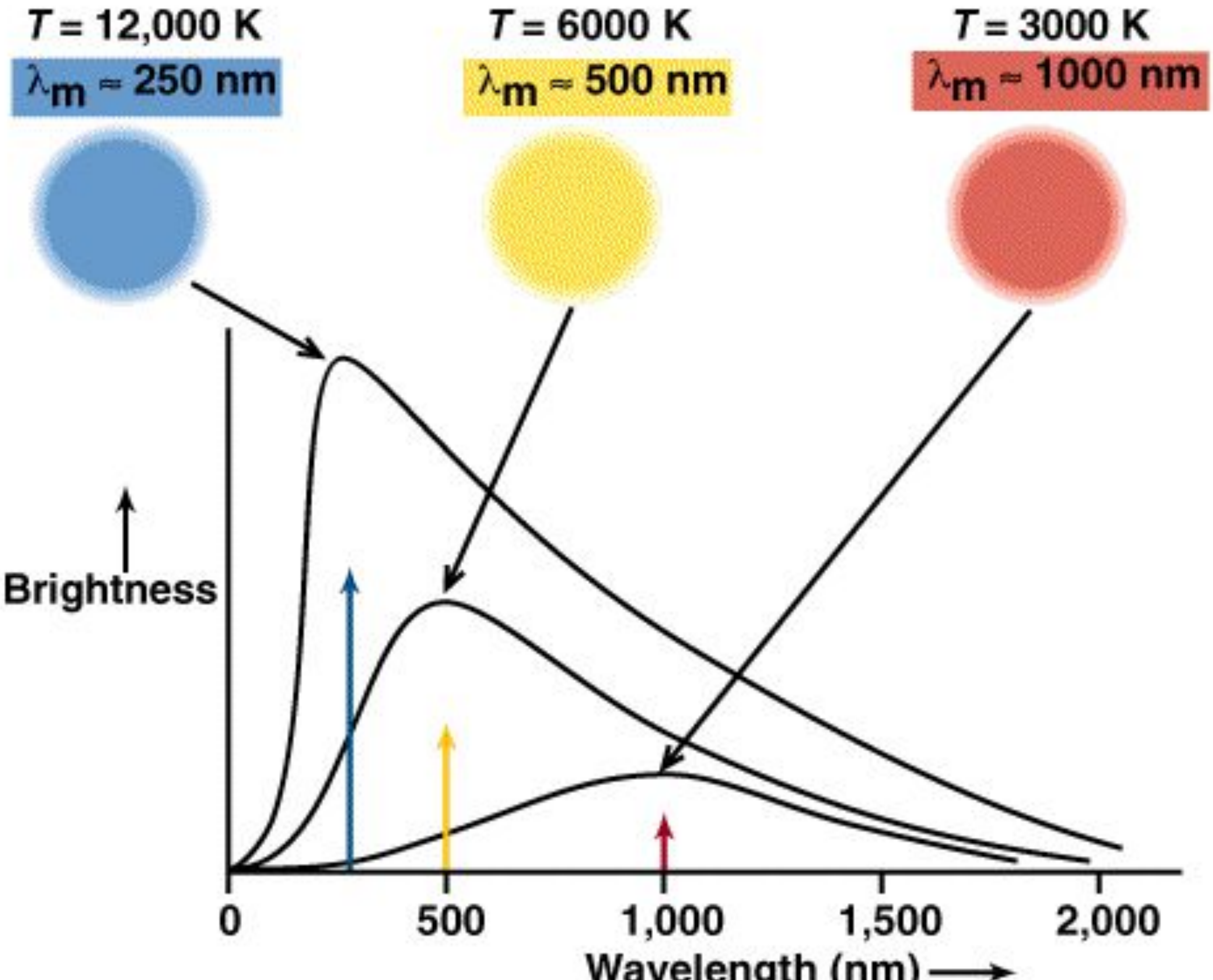
EM ENERGY EMITTED INCREASES

A Blackbody Radiation Curve



Blackbody - theoretical ideal emitter/absorber of EM radiation.

Wien's Law



T = 12,000 K
λm ≈ 250 nm
T = 6000 K
λm ≈ 500 nm
T = 3000 K
λm ≈ 1000 nm
Brightness
0
500
1,000
1,500
2,000
Wavelength (nm)

Wien's Law

- The wavelength of the peak of the blackbody curve is inversely proportional to the temperature.

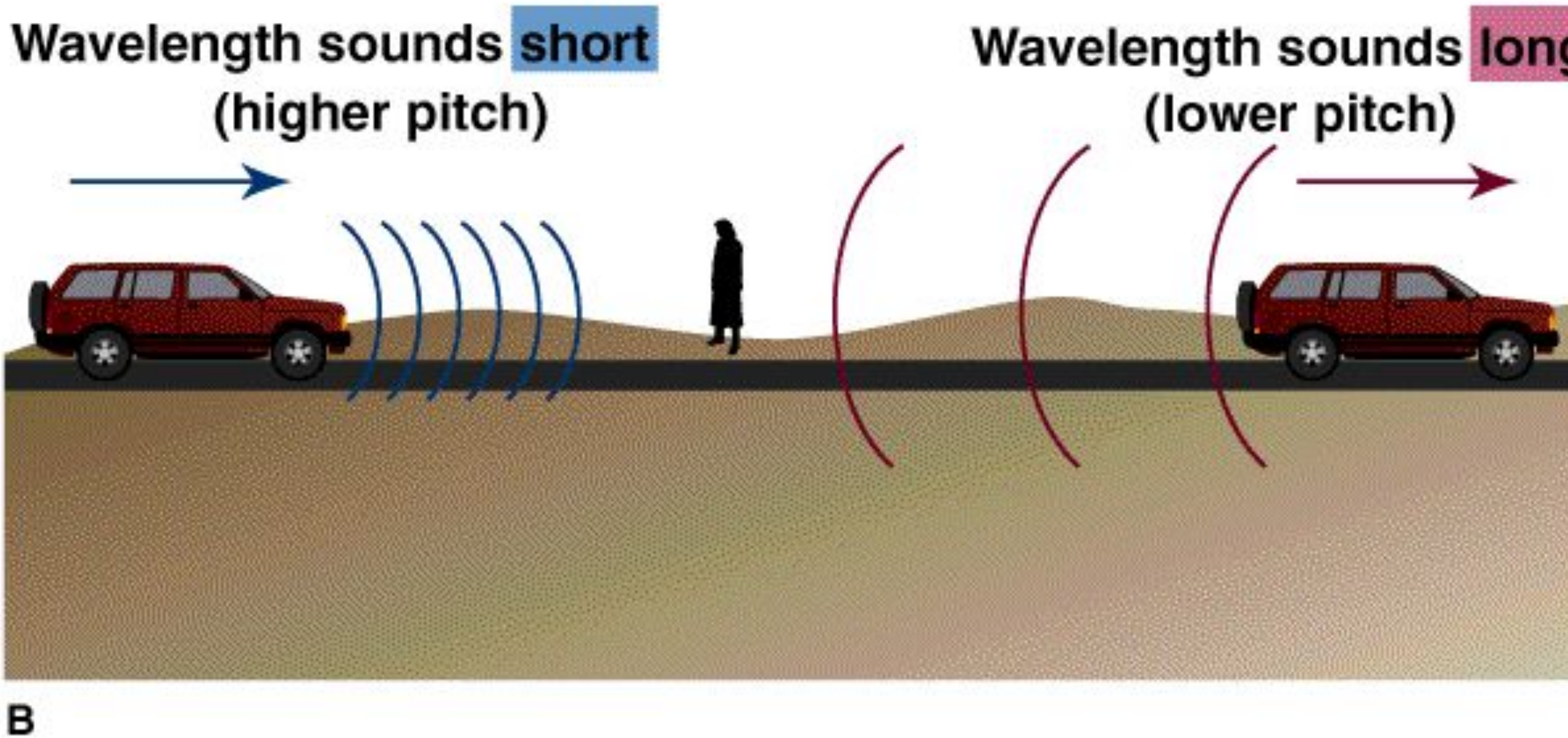
$$\lambda_{\max} \propto \frac{1}{T}$$

$$\lambda_{\max} = \frac{2.9 \times 10^{-3}\, Km}{T} \qquad T = \frac{2.9 \times 10^{-3}\, Km}{\lambda_{\max}}$$

Basic Questions about Light.

Can light tell us something about motion?

Doppler Shift of Sound Wave from a Passing Car



Doppler Effect...

- ...is the change in wavelength of light due to motion of the source of light.

- The Doppler Effect also occurs in water waves and sound waves.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

The Doppler Shift Equation

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c} \Rightarrow v = \frac{\Delta\lambda}{\lambda_0}c$$

This is a more 'useful' form of the equation.

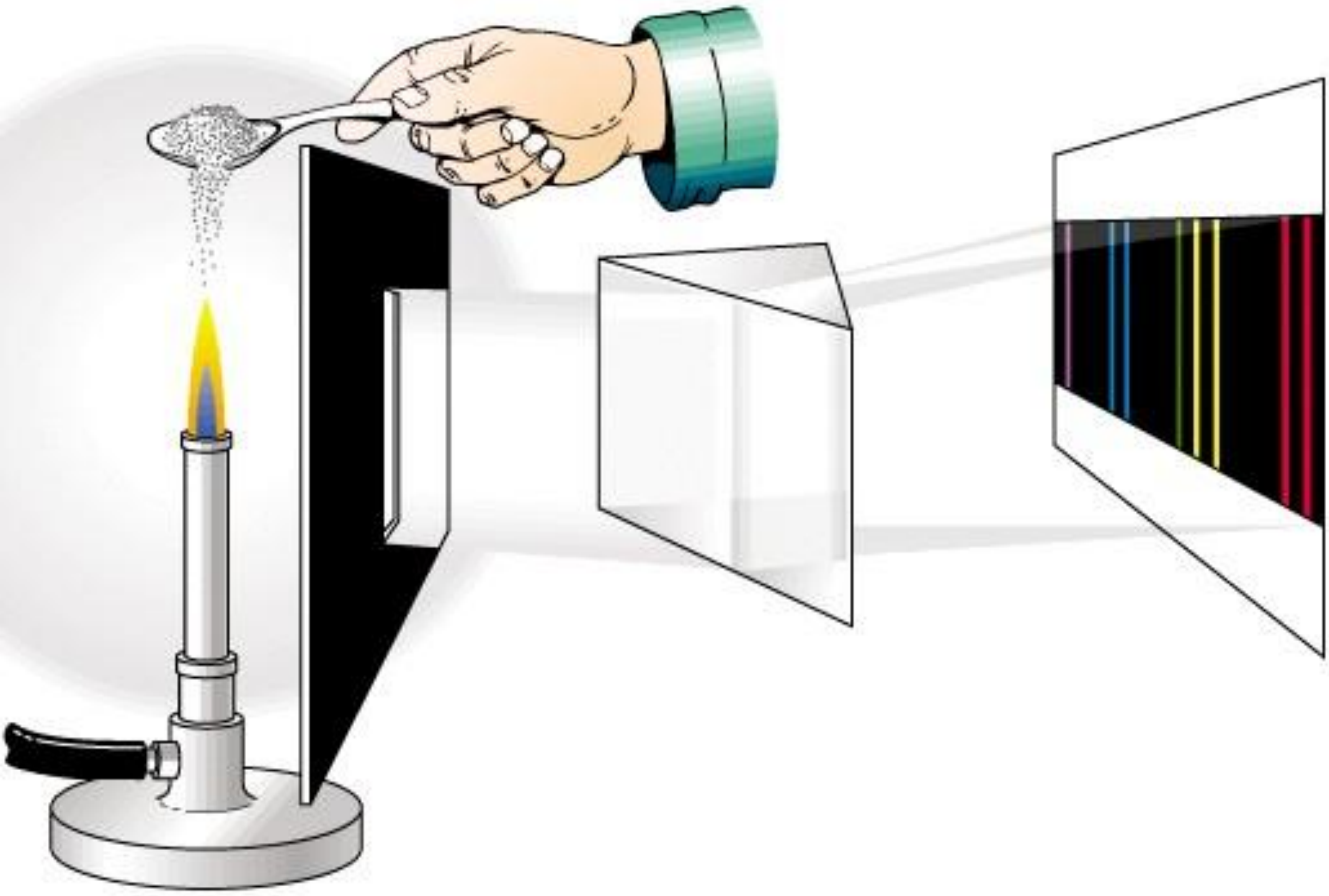
Basic Questions about Light.

Can light tell us what something is made of?

The Kirchhoff-Bunsen Experiment

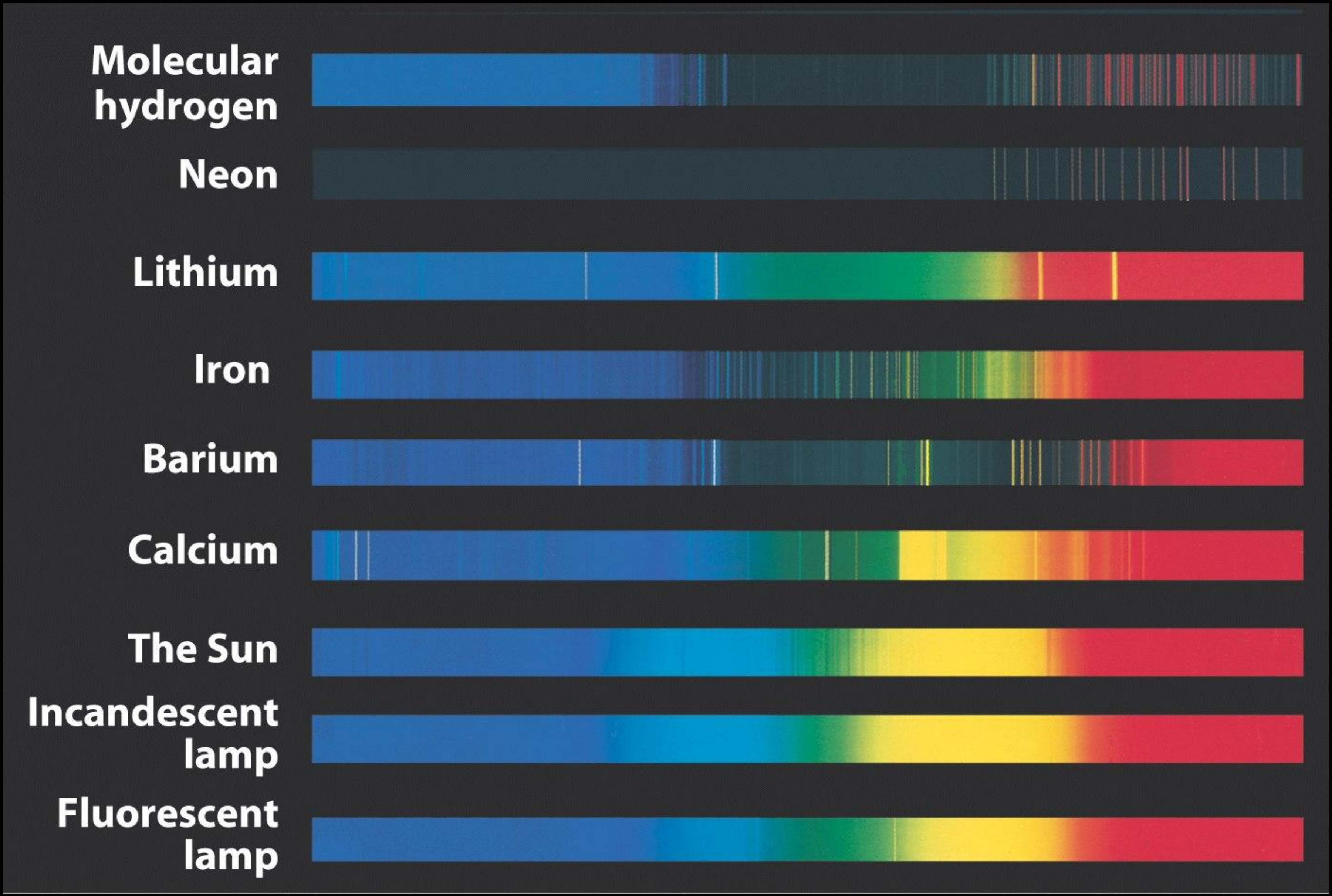
- Burning chemicals over an open flame resulted in a spectrum with bright lines.

- Each chemical element produced its own characteristic pattern of bright spectral lines.

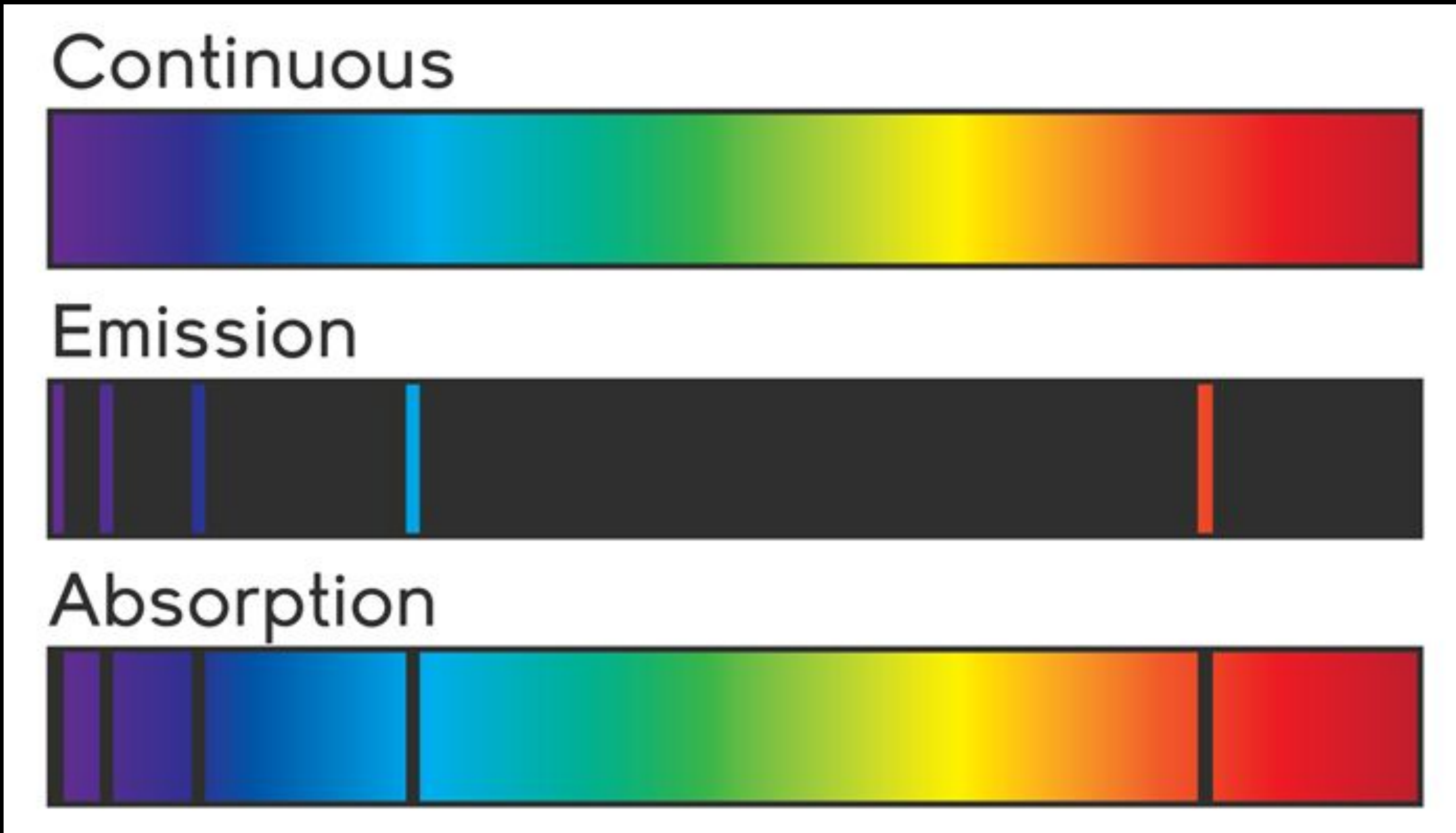


Periodic Table of the Elements

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110	111	112	113					
				58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
				90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

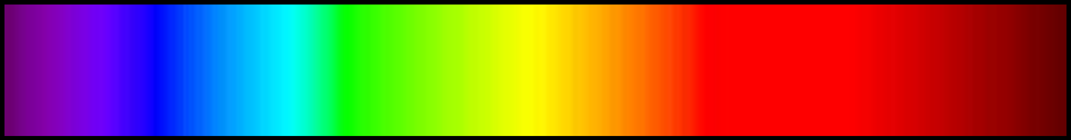


Molecular hydrogen
Neon
Lithium
Iron
Barium
Calcium
The Sun
Incandescent lamp
Fluorescent lamp


Continuous
Emission
Absorption

Kirchhoff's First Law

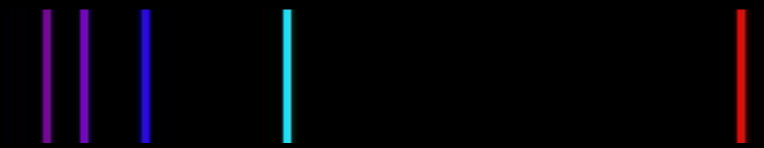
- Hot, dense gases or solids produce a <u>continuous spectrum</u>.
- Example: *Light bulb filament*



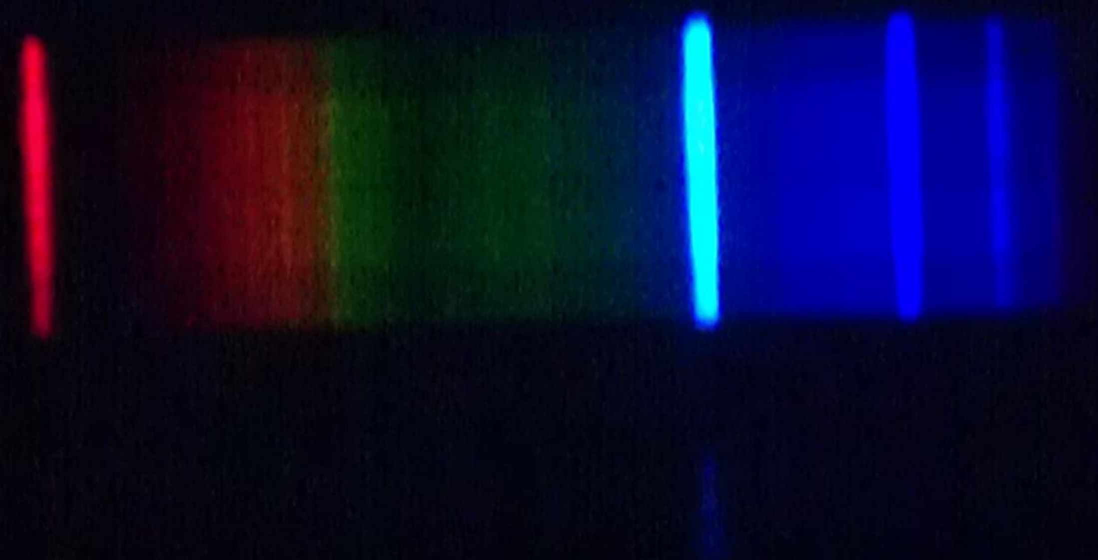
Continuous Spectrum

Kirchhoff's Second Law

- Hot, rarefied (low density) gas produces an <u>emission line spectrum</u>.
- Example: *Neon sign*

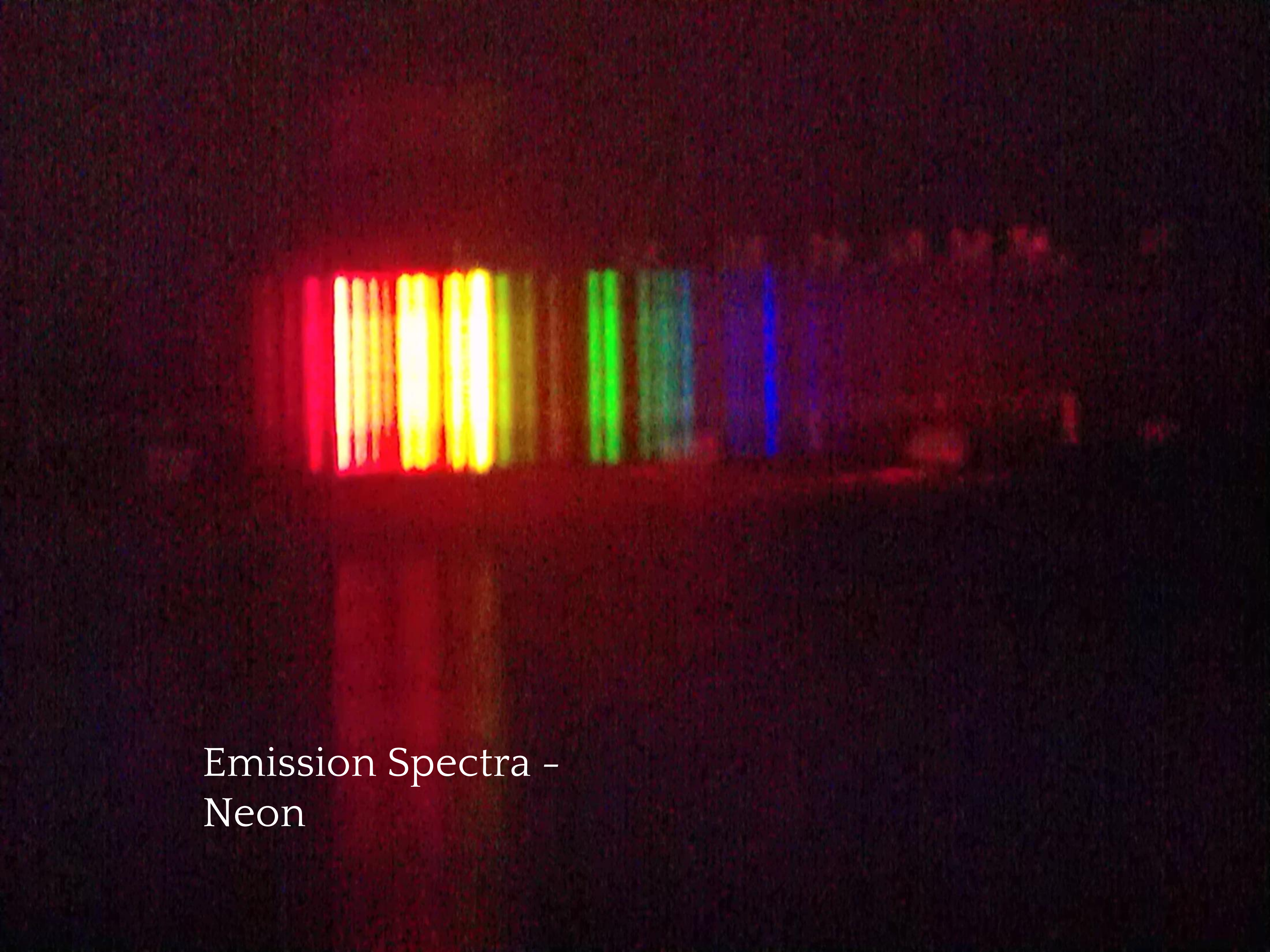


Hydrogen Emission Line Spectrum



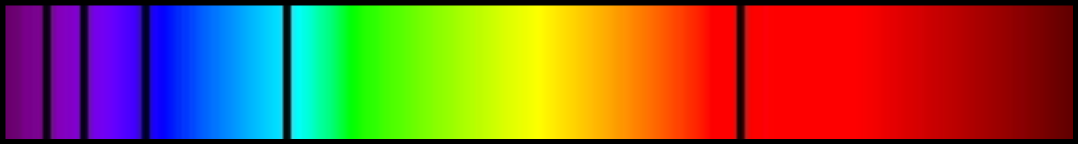
Emission Spectra - Hydrogen


Emission Spectra –
Helium


Emission Spectra -
Neon

Kirchhoff's Third Law

- Cool gas in front of a continuous source of light produces an <u>absorption line spectrum</u>.
- Example: *The Sun*



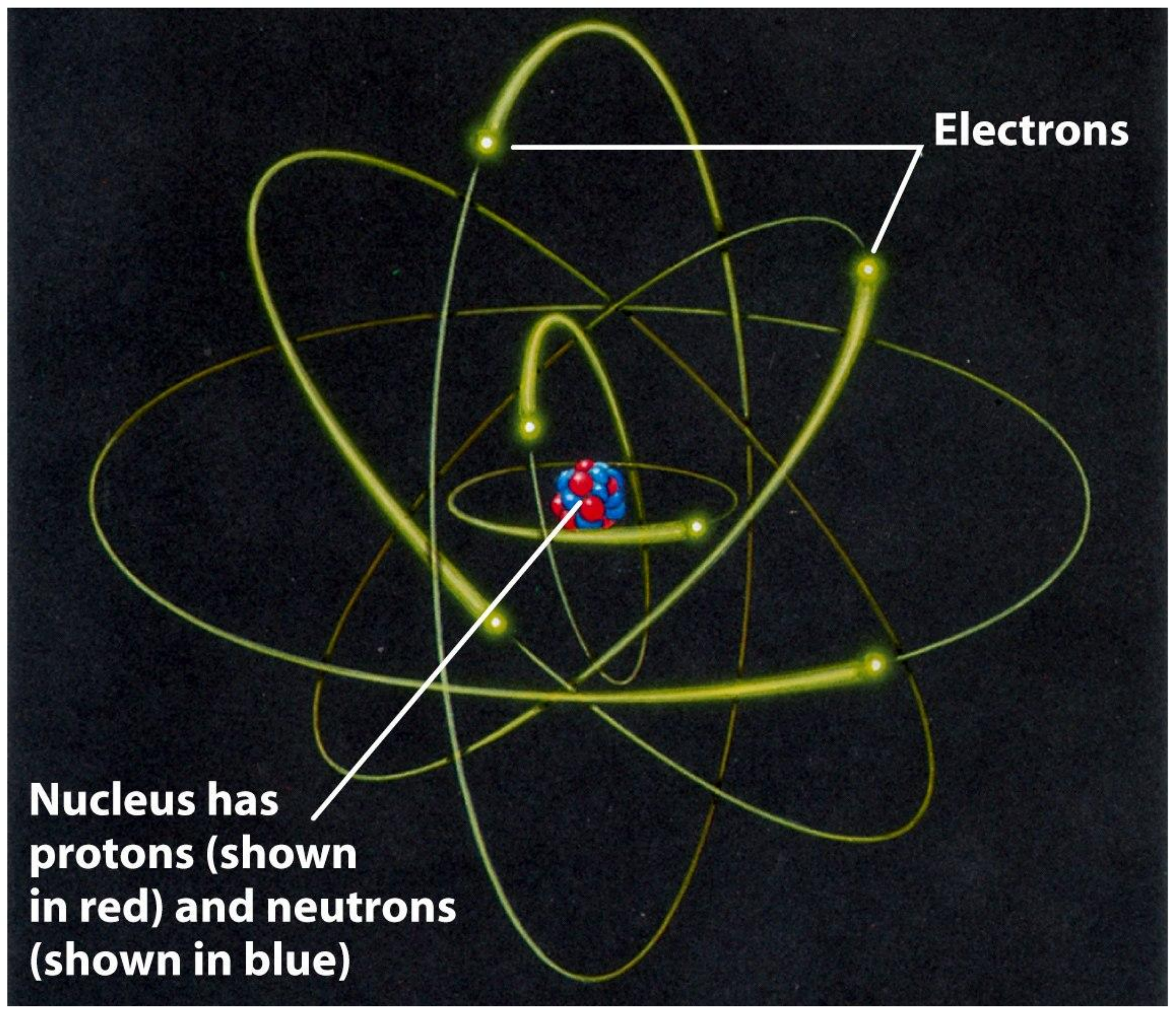
Absorption Spectrum-Showing Hydrogen Lines

The Sun's Spectrum

Iron (Fe) lines in the Sun's spectrum

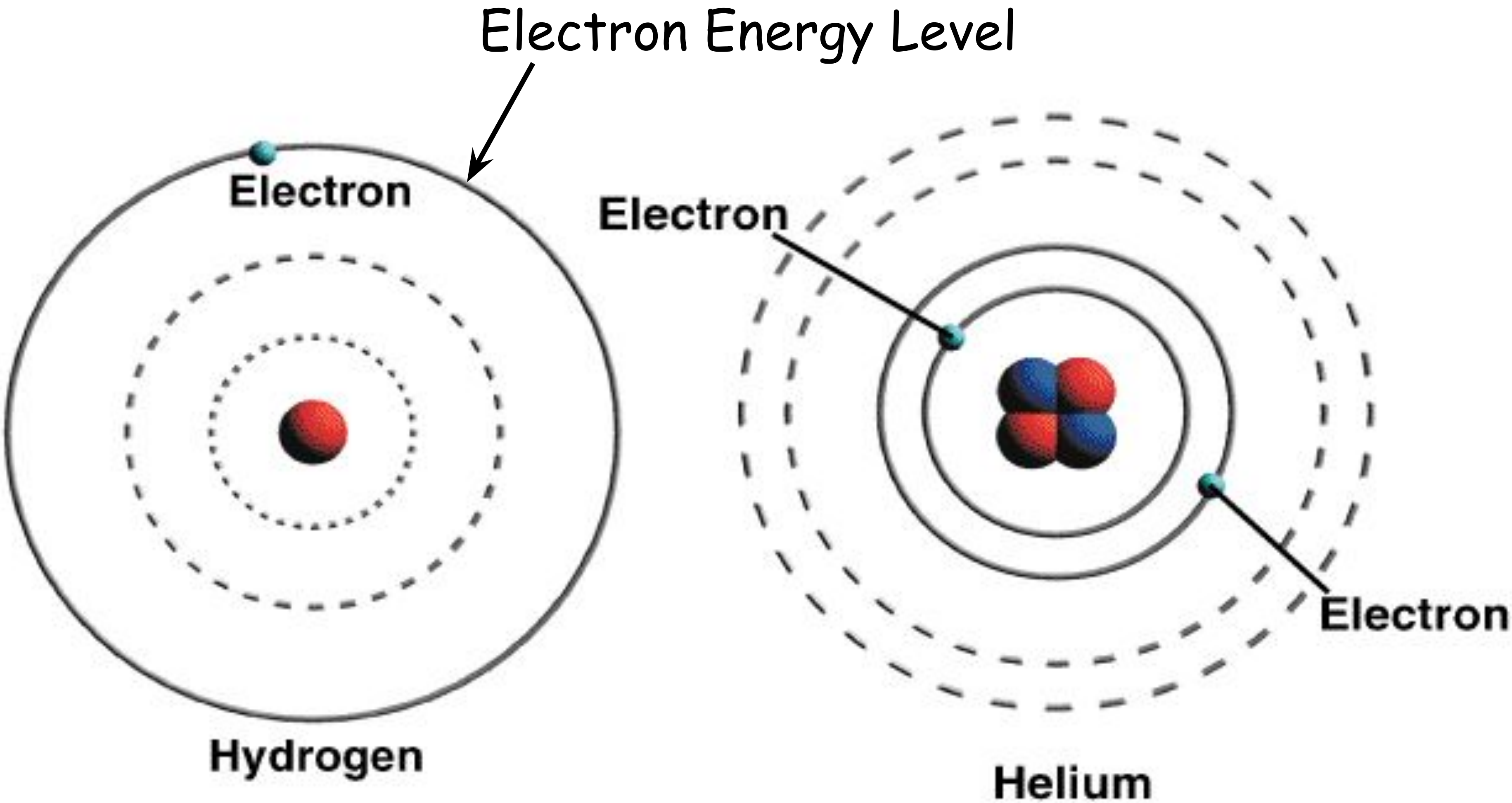
Basic Questions about Light.

Where does light come from really?



LIGHT SOURCE = ELECTRONS

Sketches of Atoms

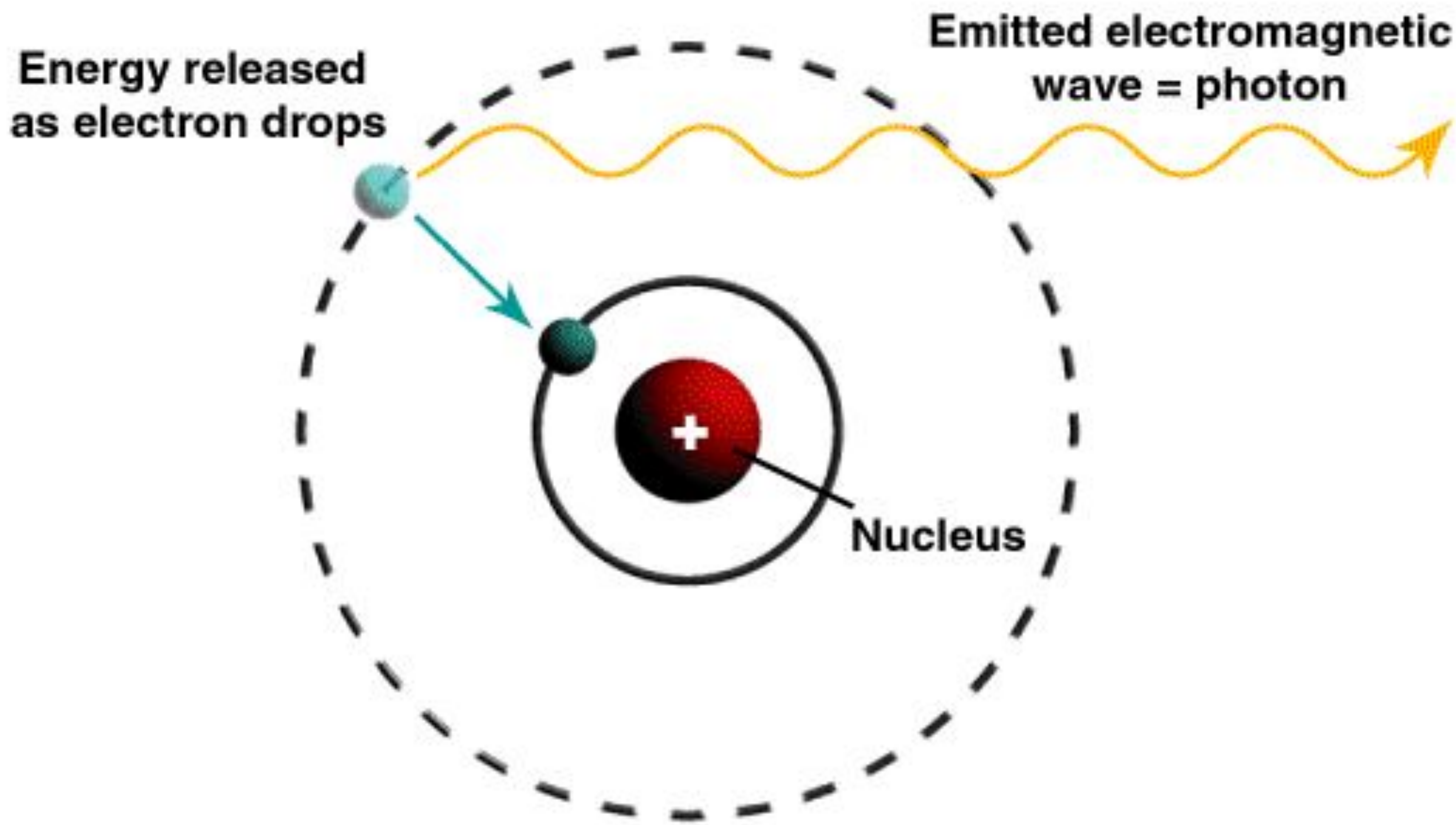


Bohr's Hypotheses

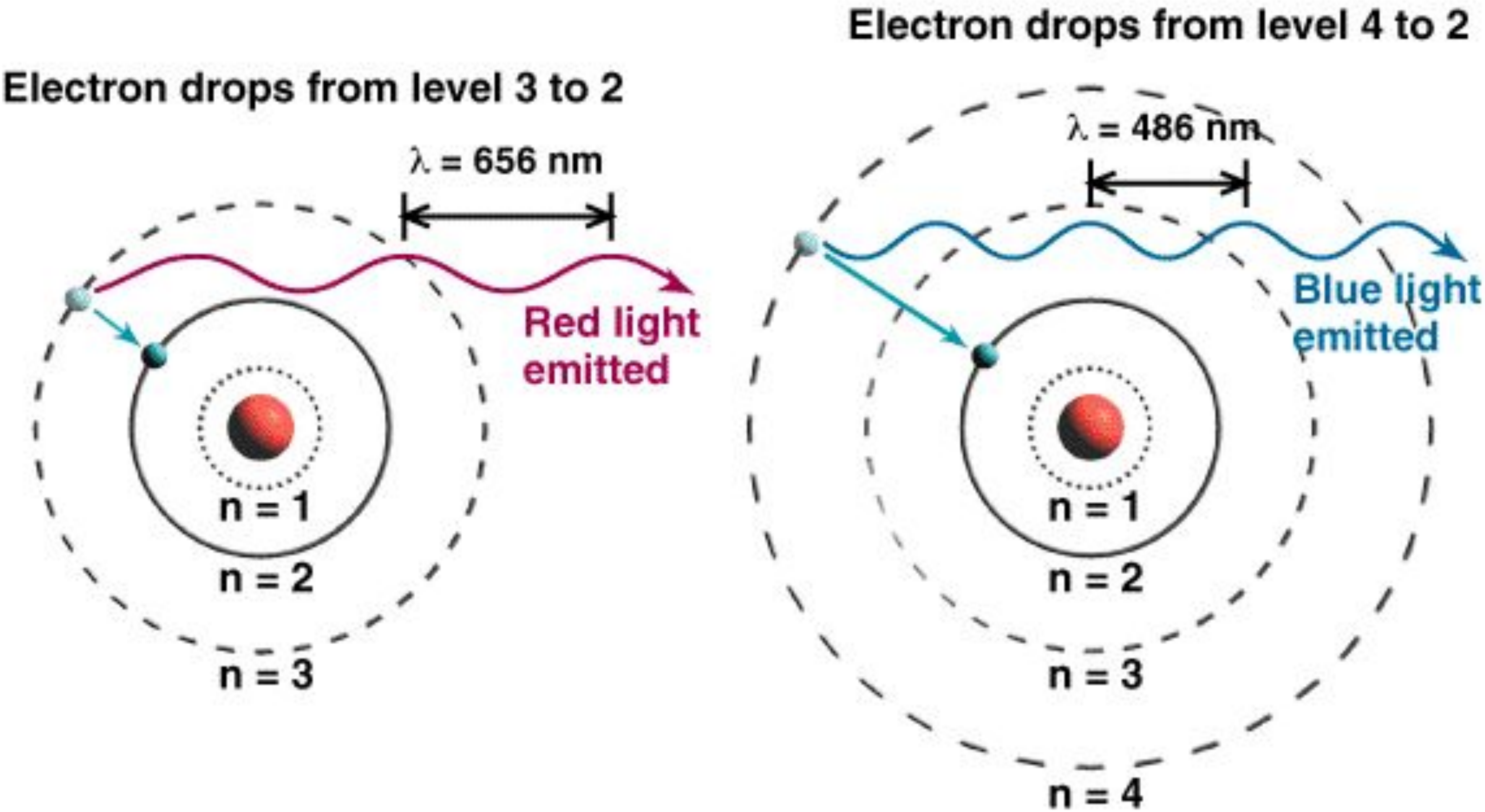
- Electrons can transfer between orbits so long as the electron ends up with the energy of the new level.

- The electron must gain energy to move up to the next energy level.
- The electron must lose energy to move down to the next energy level.

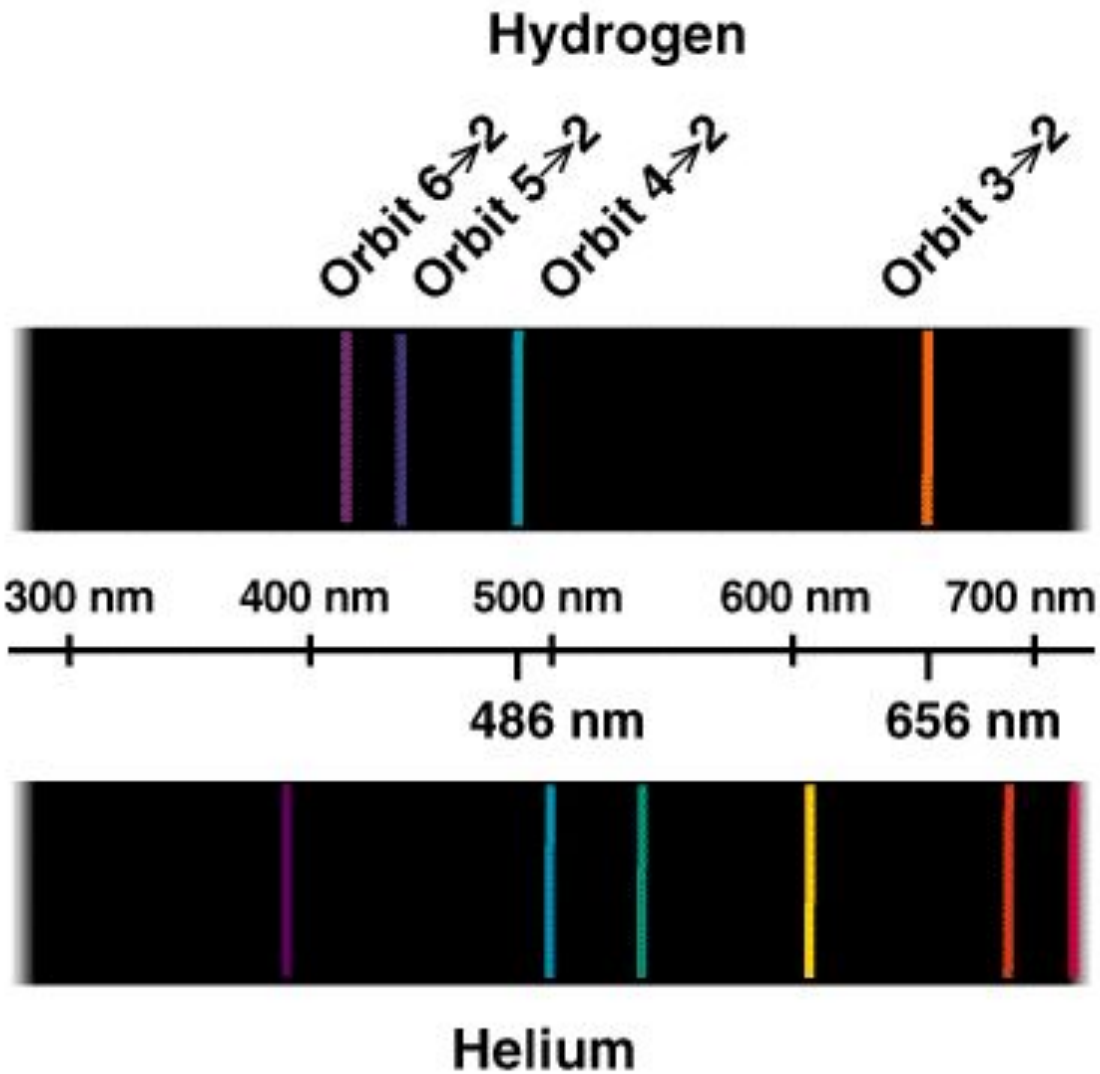
Emission and Absorption of Light



Emission of Light from Hydrogen



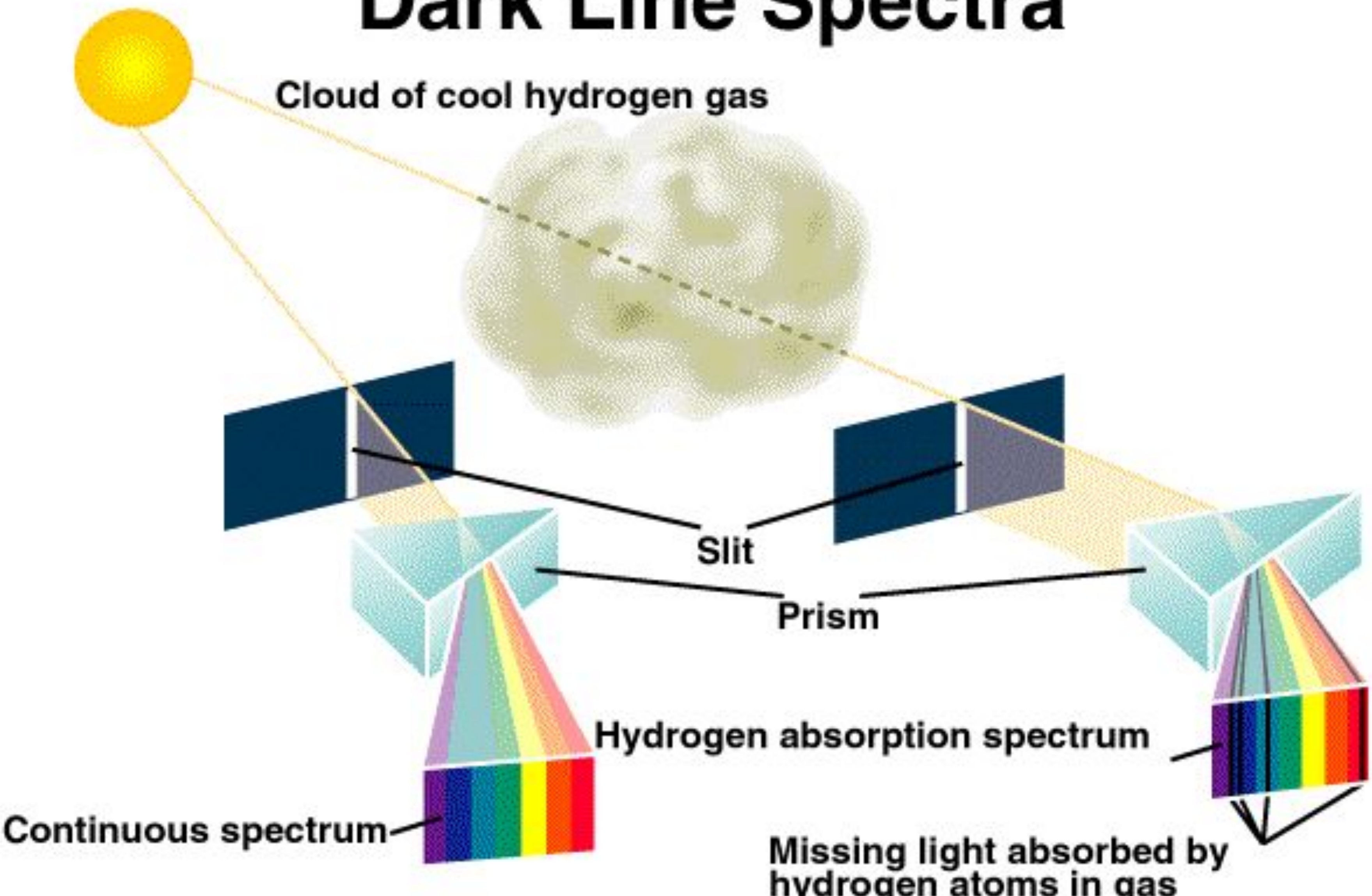
Emission Spectrum of Hydrogen and Helium



Basic Questions about Light.

What is stellar spectra and what can it reveal?

Formation of Emission and Dark Line Spectra



Stellar Spectra

- A star's spectra tells us what types of chemical elements are present in the star.
- A star's spectra can also reveal something about its motion through space.
- A moving star's spectra will exhibit a <u>Doppler shift</u>.

Doppler Shift seen in Stellar Spectra

Spectrum of Hydrogen in Lab

Spectrum a Star

The spectral lines are shifted towards the red.

This is a Doppler shift towards longer wavelengths.

This star is moving away from us.

The Doppler Shift: Waves Appear to Shorten as a Source Approaches and Lengthen as it Recedes