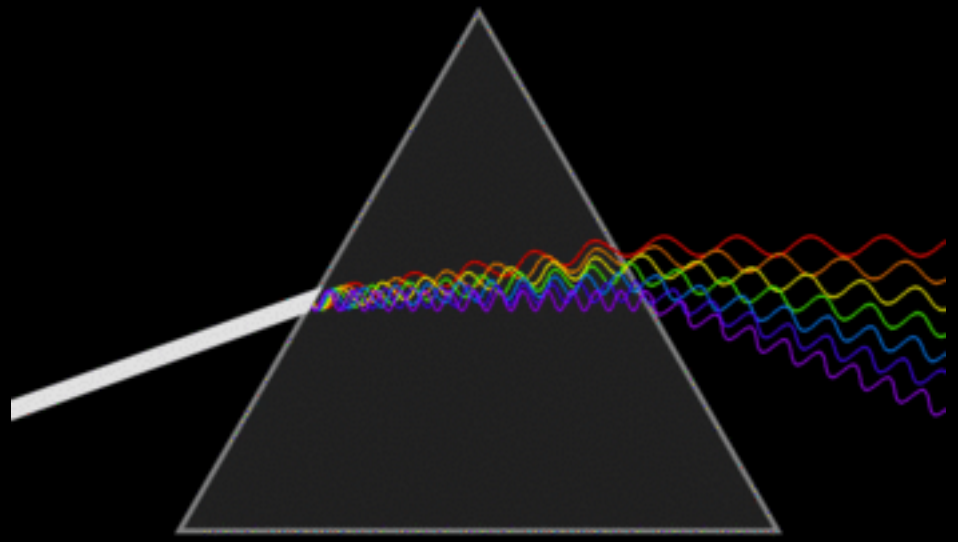
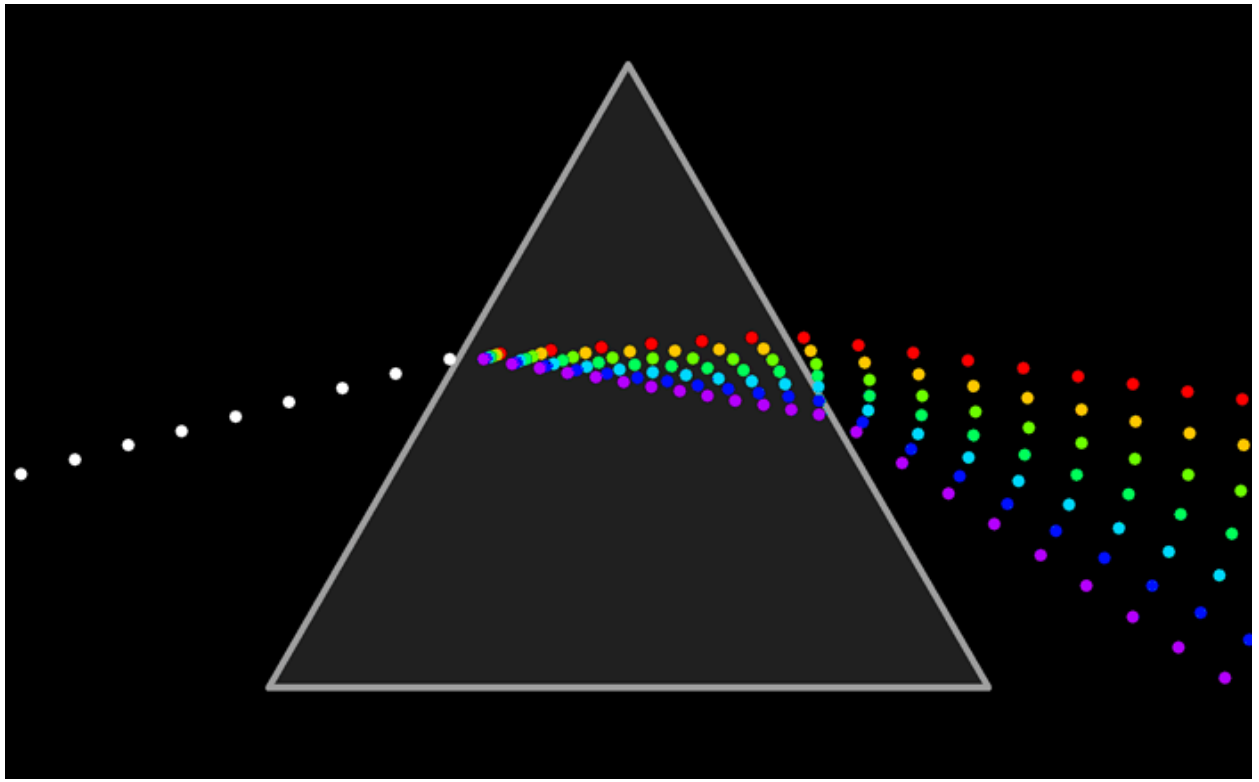


CH301 Unit 2

REVIEW ONE: ELECTROMAGNETIC RADIATION AND INTRODUCTION TO QUANTUM

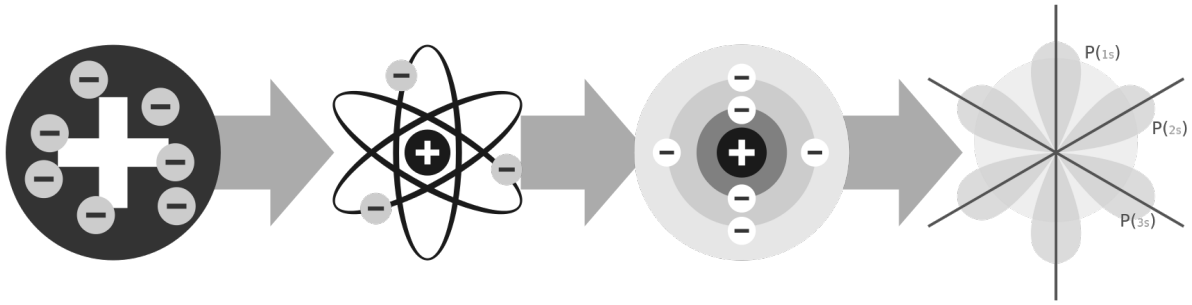
Goals for Today: Light, Quantum Mechanics

- Discuss the properties of light in a vacuum
- Review the photoelectric effect conceptually and quantitatively
- Introduce quantum mechanics and the experiments that provide evidence for the current model of the atom (saving this for next week)



Overview of Unit 2: Atomic Theory

- Characterize and quantify electromagnetic radiation
- Electrons
  - Electron configurations
  - Periodic trends
  - Quantum Numbers
- In between, we discuss the relationships between the two via our understanding of quantum mechanics:
  - Photoelectric effect
  - Absorption/Emission spectrum
  - Blackbody radiation
  - Wave function



Quantifying Light

- Modern physics defines light as photon particles exhibiting wave-like properties:

$$c = \lambda\nu$$

  - This equation states that the **speed of light** (c) is equal to the **frequency** (ν) times the **wavelength** (λ)
  - Remember this relationship: **wavelength and frequency are inversely proportional**

- You can also calculate the energy per photon:

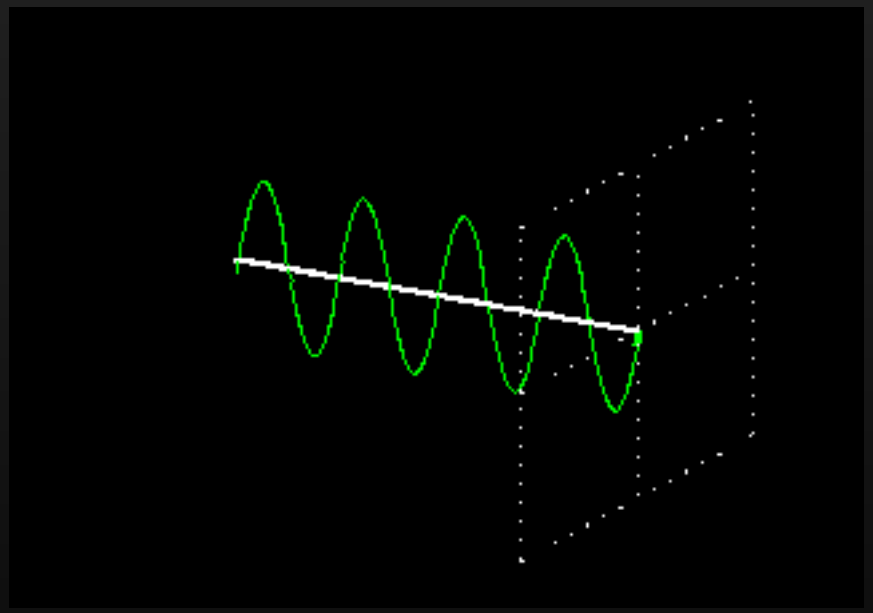
$$E_{photon} = \mathrm{h}\nu \text{ or } E_{photon} = \mathrm{h}\frac{c}{\lambda}$$

  - This equation states that the **energy of a photon** (E) is equal to the **frequency** (ν) times the **Planck's constant** (h)
  - **Energy and frequency are directly proportional**
  - **Energy and wavelength are inversely proportional**

THE SPEED OF LIGHT AS A CONSTANT

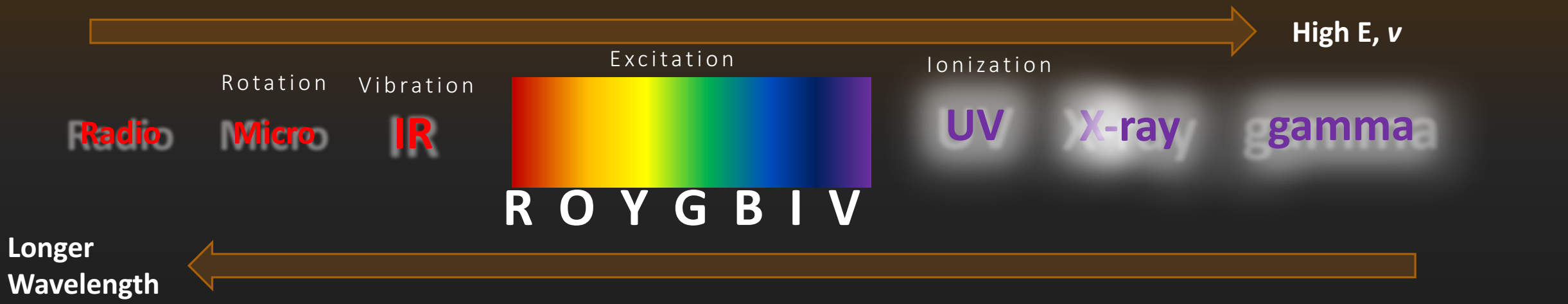
$$c = \lambda\nu$$

- c represents the speed of light in a vacuum.
- Frequency and wavelength will oppose one another to equal the speed of light. Therefore, we think of speed of light in a vacuum as a constant.



THE ELECTROMAGNETIC SPECTRUM

$$c = \lambda\nu \; ; E_{photon} = h\nu$$



- Microwaves: enough energy to begin rotating a molecule
- IR: enough energy to begin vibrating a molecule
- Visible (700nm to 400nm): enough energy to begin exciting electrons
- UV and beyond: begins the full ionization (breaking) of electrons/bonds

Concept Check

Compare the two light waves:

Light A: 630nm

Light B: 430nm

Light A has a _____ wavelength, meaning it has a _____ frequency and a _____ energy.

Which light wave moves faster through a vacuum?

Concept Check

Compare the two light waves:

Light A: 630nm

Light B: 430nm

Light A has a **higher** wavelength, meaning it has a **lower** frequency and a **lower** energy.

Which light wave moves faster through a vacuum? **The same**.

Calculation

A light ray has a frequency of $6.2 \times 10^{14}\ s^{-1}$. What is the wavelength of the light?

A) 562 nm

B) 464 nm

C) .464 nm

D) .682nm

E) 928 nm

F) 0.882nm

G) 334 nm

$$c = \lambda \cdot \nu$$

$3 \times 10^8 \text{ m/s}$ $\qquad$ $6.2 \times 10^{14} \text{ s}^{-1}$ // Hz

$$\frac{c}{\nu} = \lambda \qquad \frac{3 \times 10^8 \text{ m/s}}{6.2 \times 10^{14} \text{ s}^{-1}} = \lambda \; \underline{\underline{m}}$$

$$= 4.84 \times 10^{-7} \text{ m}$$

$$\Downarrow \times 10^9 \frac{\text{nm}}{\text{m}}$$

$$\boxed{484 \text{ nm}}$$

Calculation

A light ray has a frequency of $6.2 \times 10^{14}\ s^{-1}$. What is the wavelength of the light?

A) 562 nm

B) 464 nm

C) .464 nm

D) .682nm

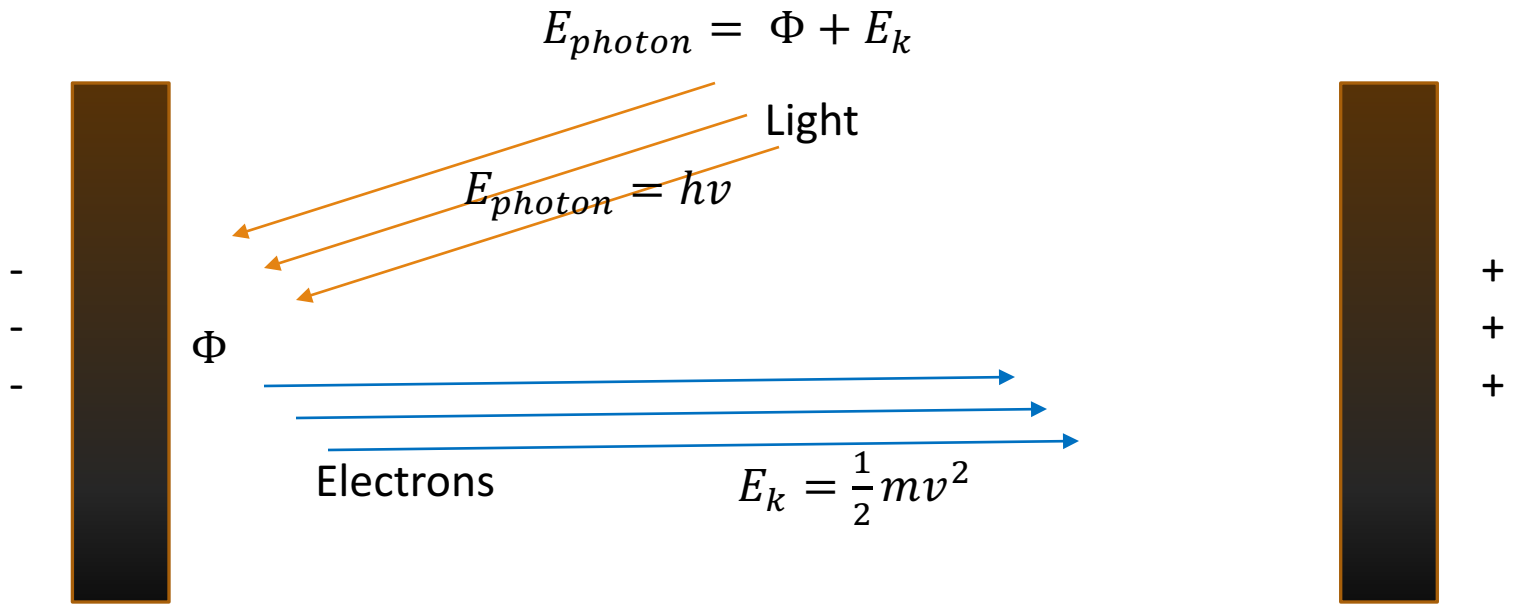
E) 928 nm

F) 0.882nm

G) 334 nm

Quantum Mechanics: Photoelectric Effect

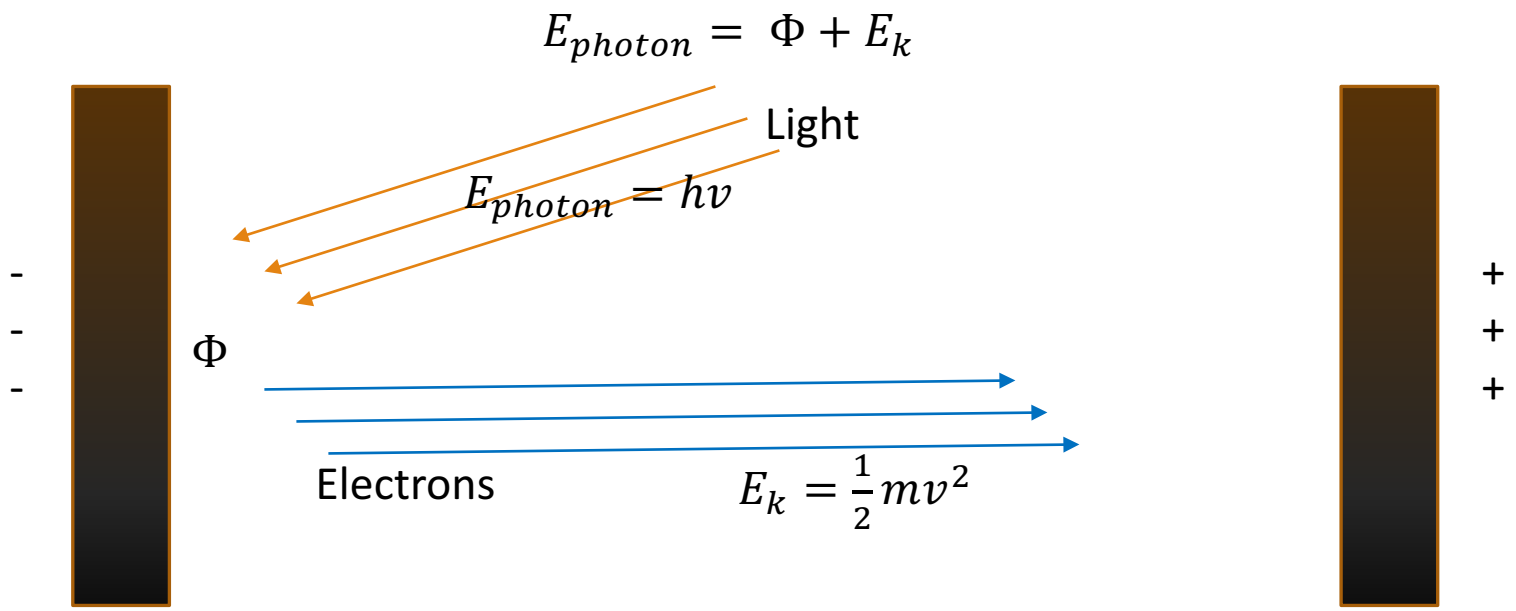
- **Photoelectric Effect**: a metal will eject electrons if a beam of light reaches a threshold energy
  - Demonstrates how light can interact with matter (the electrons of a metal)
  - Quantifies this interaction using the equations shown below:



Key points:

- If an electron is not ejected, your light does not have sufficient energy (you must decrease wavelength or increase frequency)
- Increasing the intensity will result in more electrons ejected **if the threshold is reached.** If the threshold is not reached, increasing the intensity will do nothing

Quantum Mechanics: Photoelectric Effect



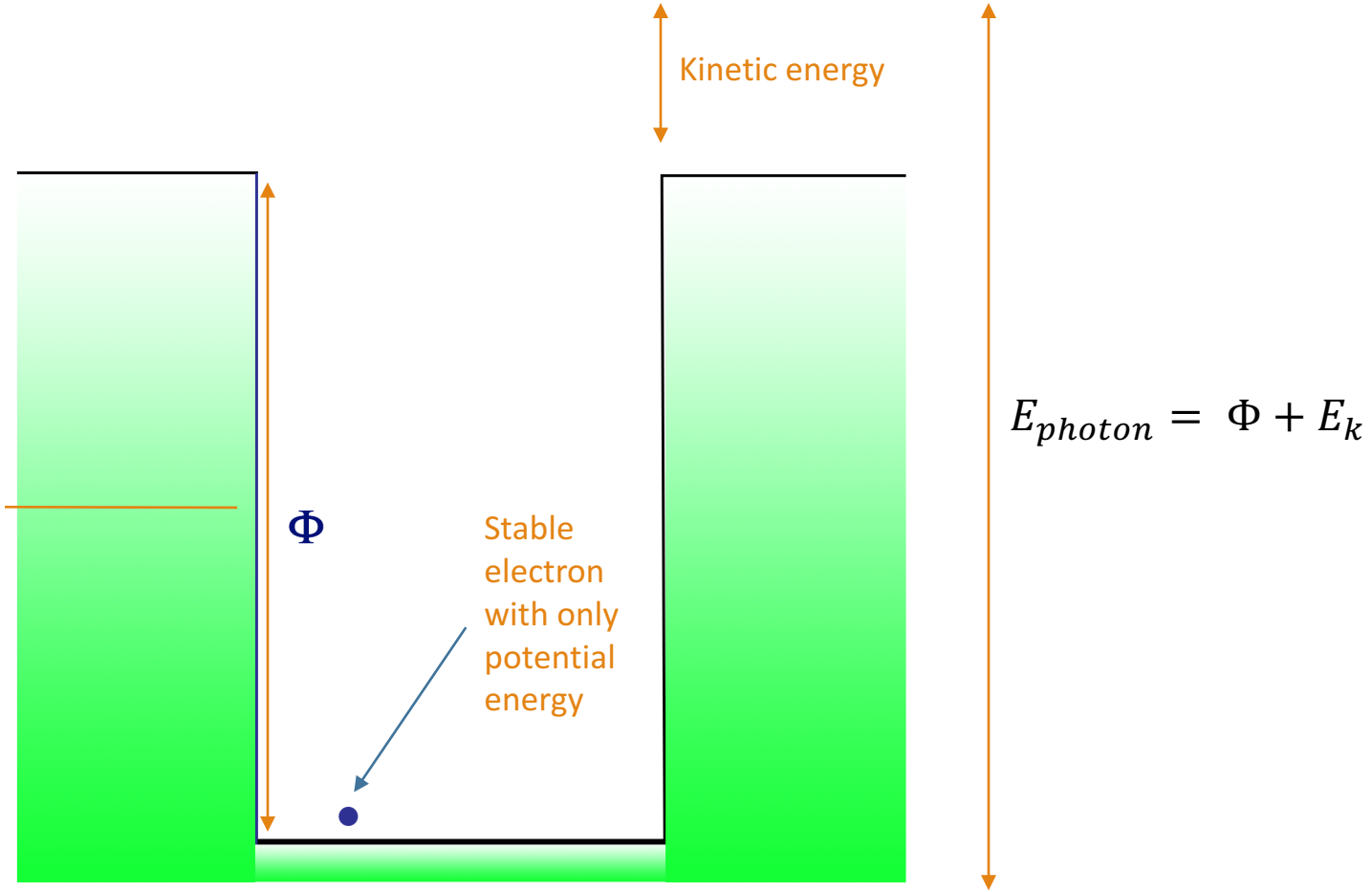
IF THE WORK FUNCTION IS REACHED:

- Increasing intensity:
  - Increases the number of emitted electrons
  - Has NO EFFECT on the kinetic energy/ velocity of the emitted electrons
- Increasing the energy of the photon (or increasing the frequency/decreasing the wavelength):
  - Increases the kinetic energy of the emitted electrons
  - Increases the velocity of the emitted electrons
  - Has NO EFFECT on the number of electrons

Unit the work function is reached ($E_{photon} < \Phi$):

- Increasing intensity has no effect
- Note: photon energy is NOT additive. Two 2.5eV photons does NOT equal 5eV overall.

Potential Energy Well



The "depth" of the potential energy well represents the amount of energy needed to release the electron from the metal

$$E_{photon} = \Phi + E_k$$

$$E_{photon} = h\nu$$

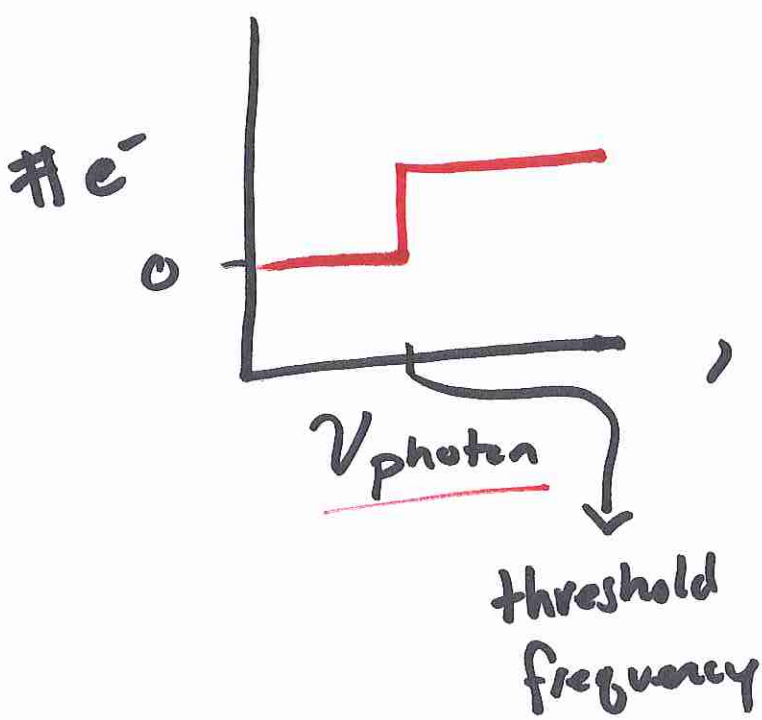
If threshold is met:

$$E_{photon} = \Phi + E_k$$

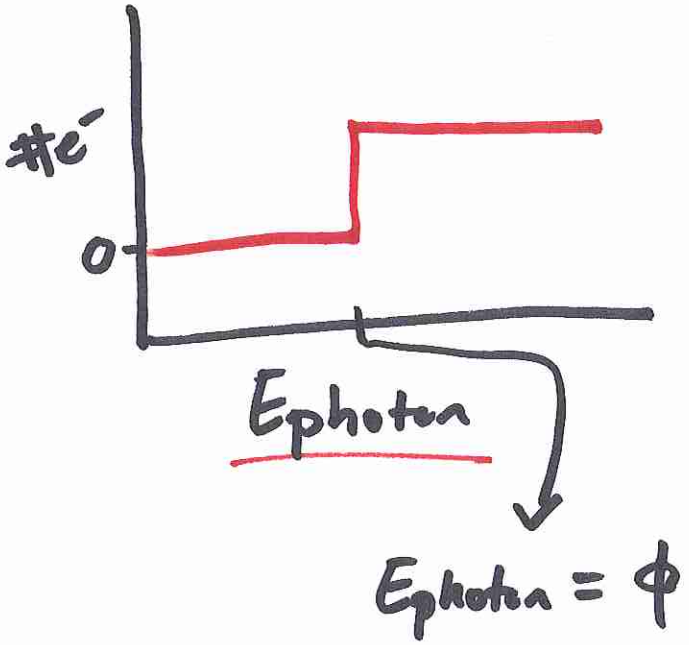
$$E_k = E_{photon} - \Phi$$

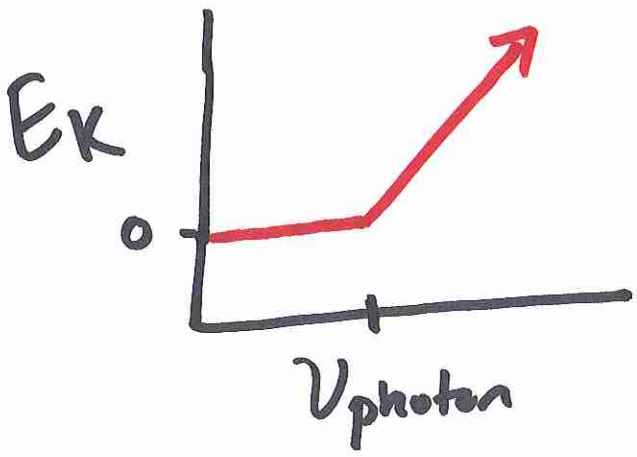
$$E_k = \frac{1}{2}mv^2$$

Metal (Al, $\Phi = 4.08 eV$)

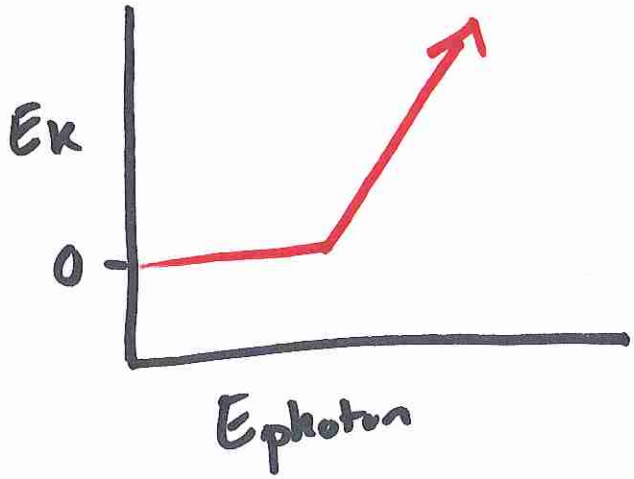


,



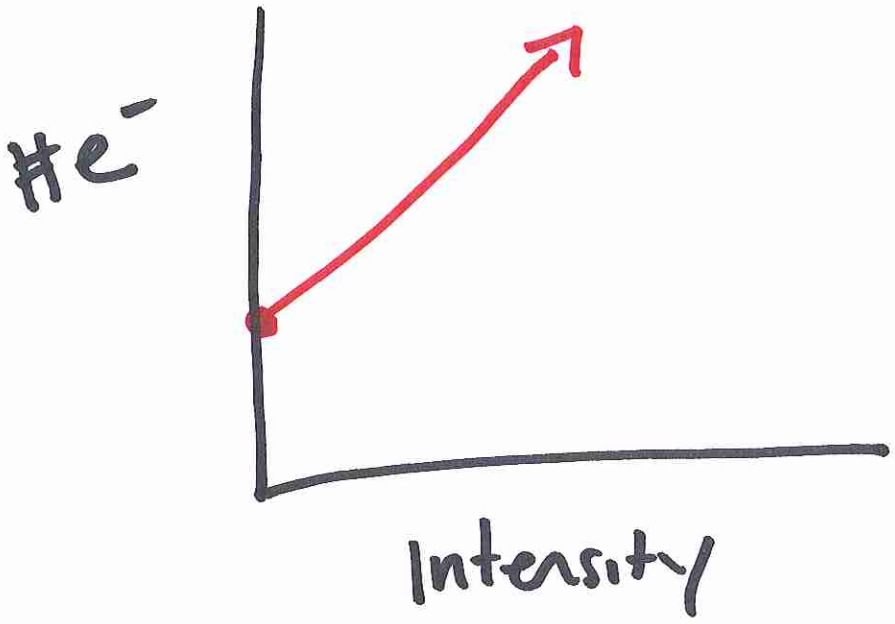


,



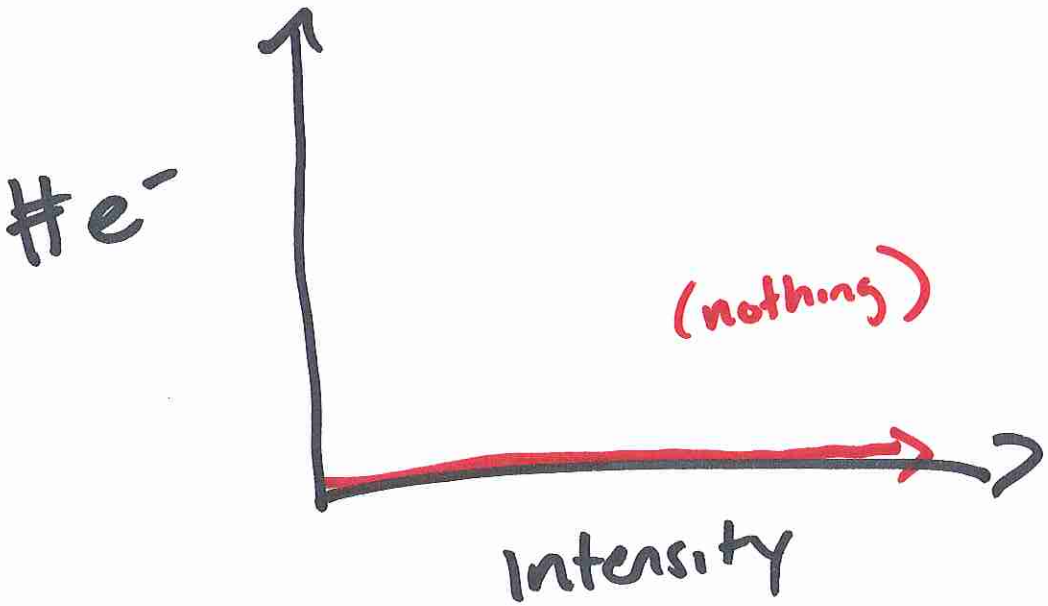
Suppose $E_{photon} = 5eV$

$E_{photon} > \Phi$



Suppose $E_{photon} = 2eV$

$E_{photon} < \Phi$



Photoelectric Effect Question

The work function for chromium metal is 7.0×10^{-19} J (4.37 eV). What wavelength of radiation must be used to eject electrons with a velocity of 2300 km/s? Please answer in units of nm.

The mass of an electron is 9.10939×10^{-31} kg.

$J = \frac{Kg \cdot m^2}{s^2}$

$E_{photon} = \phi + E_K \rightarrow \frac{1}{2}mv^2$

(J) (J) (J)

$E = h\nu$

$c = \lambda \cdot \nu$

$\phi = 4.37 eV = 7 \times 10^{-19} J$

$m = 9.10938 \times 10^{-31} Kg$

$v = 2300 \frac{Km}{s} = 2.3 \times 10^6 \frac{m}{s}$

squared

1) $E_{photon} = 7 \times 10^{-19} J + \frac{1}{2}(9.11 \times 10^{-31} kg)(2.3 \times 10^6 \frac{m}{s})^2$

$= 3.11 \times 10^{-18} J$

2) $\frac{3.11 \times 10^{-18} J}{6.626 \times 10^{-34} J \cdot s} = \frac{E}{h} = \nu = 4.69 \times 10^{15} s^{-1}$

3) $\frac{c}{\nu} = \lambda = \frac{3 \times 10^8 m/s}{4.69 \times 10^{15} s^{-1}} = 6.4 \times 10^{-8} m$

$\times 10^9$

64 nm

Photoelectric Effect Question

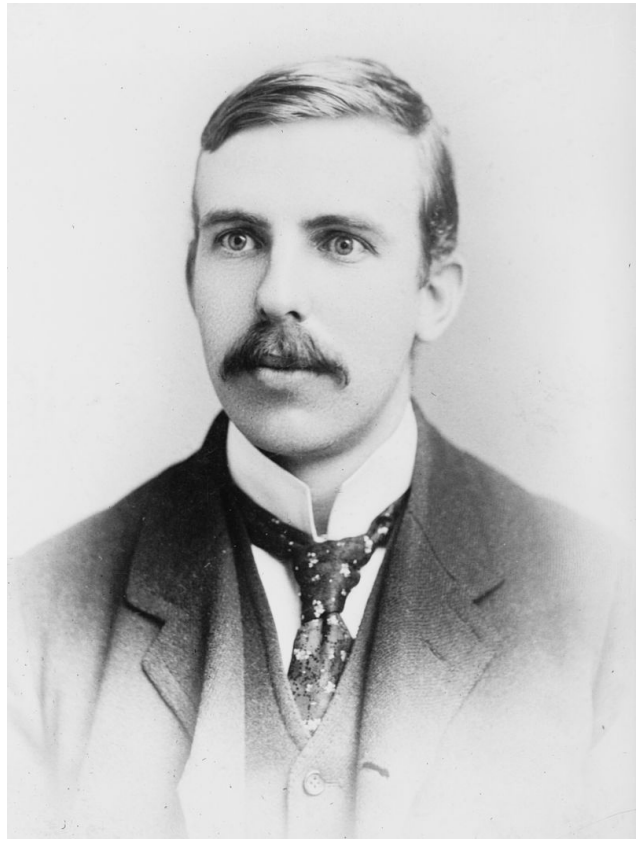
The work function for chromium metal is 7.0×10^{-19} J (4.37 eV). What wavelength of radiation must be used to eject electrons with a velocity of 2300 km/s? Please answer in units of nm.

The mass of an electron is 9.10939×10^{-31} kg.

Answer: 64nm

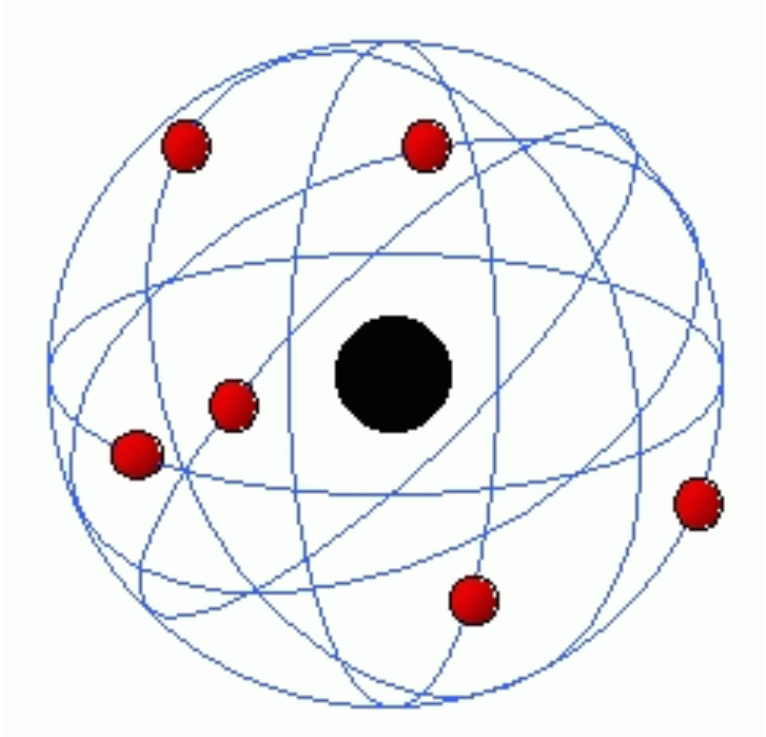
Classical Atomic Theory

- The classical theory of an atom is an important contribution to science that is still taught today even though it is extremely wrong.
- The following points are the main pillars of classical atomic theory
  1. The atom consists of three fundamental particles: protons, neutrons, and electrons
  2. Electrons whirl around the nucleus like planets around the sun, and (like all things in the universe) are governed by Newtonian laws of motion
  3. Light is a wave and exhibits only wave-like behavior

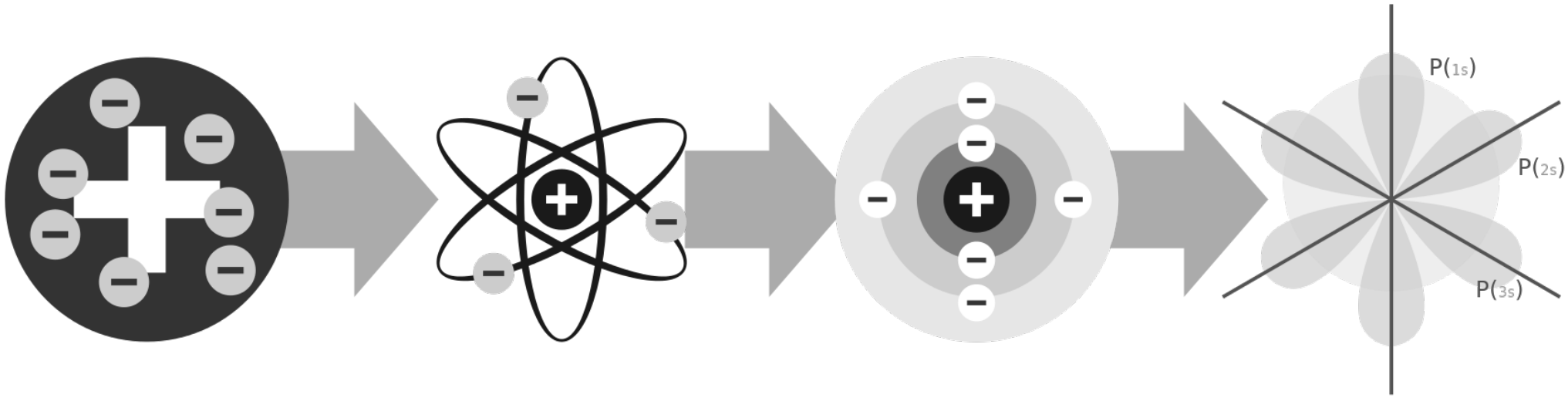


Classical Atomic Theory

- However, there were known failures in these models that, until technology caught up to theoretical physics, could not be explained:
  1. If electrons truly abided by the laws of classical motion, they would lose their energy and collapse in on the nucleus – this would happen on a human time-scale in the blink of an eye
  2. The UV catastrophe showed that blackbodies emit characteristic wavelengths at low wavelengths, whereas the current laws predicted that the absorption would approach infinity before the visible spectrum-range
  3. The spectrum of hydrogen absorption and emission showed indescribable patterns that conflicted with the idea that light and electrons could not interact



The History of the Modern Atomic Model



Classical Theory

Quantum Theory

What is Quantum Mechanics?

- Quantum mechanics helps us explain the currently accepted model of the atom using the following empirically derived postulates:
  1. Electrons exist in **discrete, quantifiable energy states**.
  2. Electrons and light (photons) exhibit **wave-particle duality**.
  3. The motion of electrons can be described only with **probabilities**. That is, only the position or momentum can be known with certainty at any given time.
     - Furthermore, this demonstrates that electrons exist in “clouds” and not circular orbits

- Quantum mechanics is the mathematical model for subatomic motion. QM is therefore the model of a particle traveling from point A to point B, and the understanding that the path between these two points is not as simple as you might think.

Classical Vs. Quantum Mechanics

Classical Mechanics

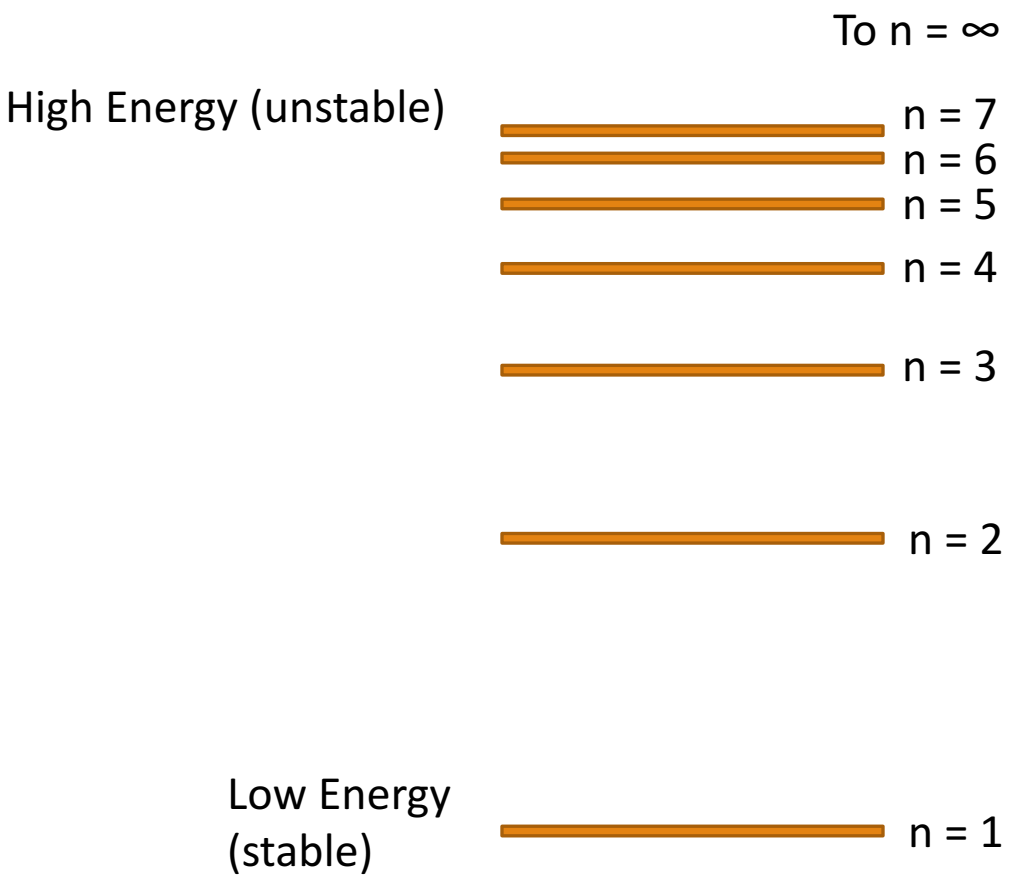
- Three fundamental particles: protons, neutrons, and electrons
- Light is a wave
- Electrons and light do not interact
- Electrons orbit the nucleus
- Position and momentum are predictable

Quantum Mechanics

- Many subatomic particles and growing
- Light exists as tiny packets of energy called photons. Photons exhibit particle-like behavior.
- Electrons and light interact
- Electrons exist in a “cloud” outside the nucleus and are confined to energy levels (n) of various shapes (l)
- Position and momentum are not simultaneously predictable
- Everything with momentum has a quantifiable wavelength

Quantum Mechanics: Emission vs. Absorption

- A second hallmark experiment of Quantum Mechanics revealed that electrons of the hydrogen atom exist in "energy states," which were later designated with the letter "n."
- You can understand n values by adhering to the following rules:
  1. n values begin at 1 (closest to the nucleus) and go to infinity (completely out of the influence of the nucleus/ free in space)
  2. The lower n value means
  3. The greatest energy difference between two consecutive numbers is 1 and 2.



RYDBERG EQUATION: EMISSION

$$\Delta E = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

R = 2.18 X 10^{-18}J

- THIS EQUATION SHOWS THE ENERGY CHANGE BETWEEN TWO ENERGY LEVELS WITH THE CONDITION THAT YOU ARE UNDERGOING EMISSION
- IN OTHER WORDS, THIS EQUATION ONLY WORKS AS WRITTEN IF YOUR ELECTRON IS FALLING FROM A HIGH ENERGY STATE TO A LOWER ONE (IN OTHER WORDS $N_F < N_I$)
- YOU WILL GET A NEGATIVE ENERGY CHANGE.

RYDBERG EQUATION: EMISSION

$$\Delta E = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

R = 2.18 X 10^{-18}J

- THIS EQUATION SHOWS THE ENERGY CHANGE BETWEEN TWO ENERGY LEVELS WITH THE CONDITION THAT YOU ARE UNDERGOING ABSORPTION
- IN OTHER WORDS, THIS EQUATION ONLY WORKS AS WRITTEN IF YOUR ELECTRON IS JUMPING FROM A LOW ENERGY STATE TO A HIGHER ONE (IN OTHER WORDS $N_F > N_I$)
- YOU WILL GET A **POSITIVE** ENERGY CHANGE.

RYDBERG EQUATION TO WAVELENGTH, FREQUENCY

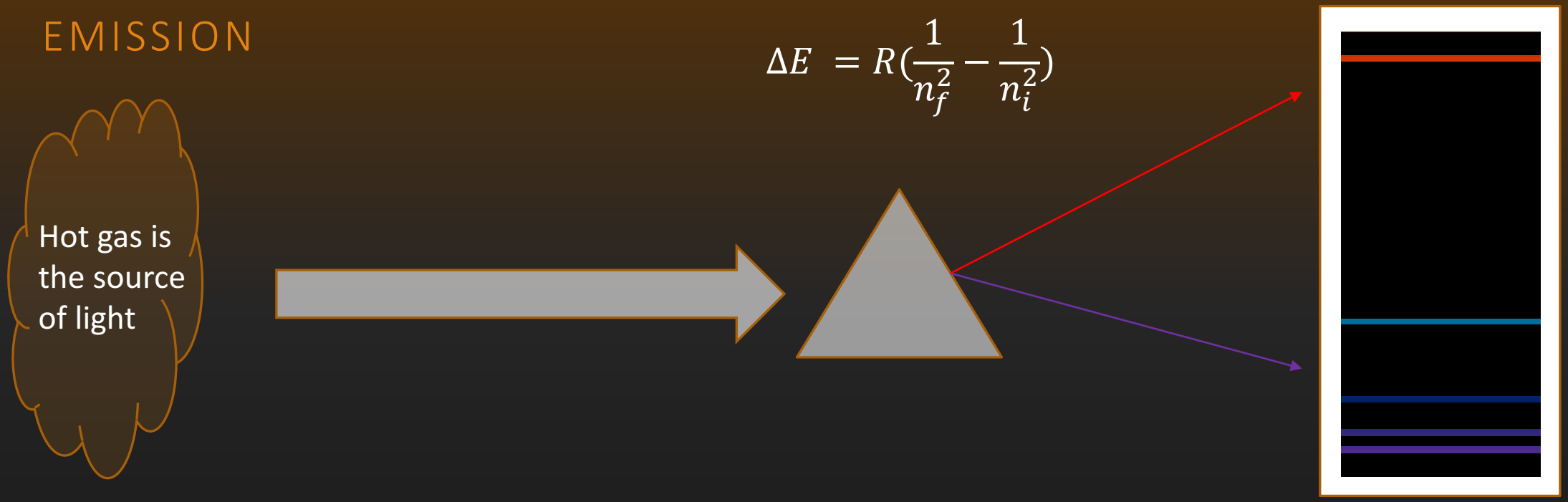
$$|\Delta E| = E_{photon} = h\nu$$
$$c = \lambda\nu$$

R = 2.18 X 10^{-18}J

- YOU CAN CALCULATE THE WAVELENGTH OR FREQUENCY USING THE ABSOLUTE VALUE OF THE ENERGY CHANGE
- THIS IS THE WAVELENGTH OF LIGHT ABSORBED OR EMITTED GIVEN ANY ENERGY DIFFERENCE BETWEEN TWO N VALUES

EMISSION

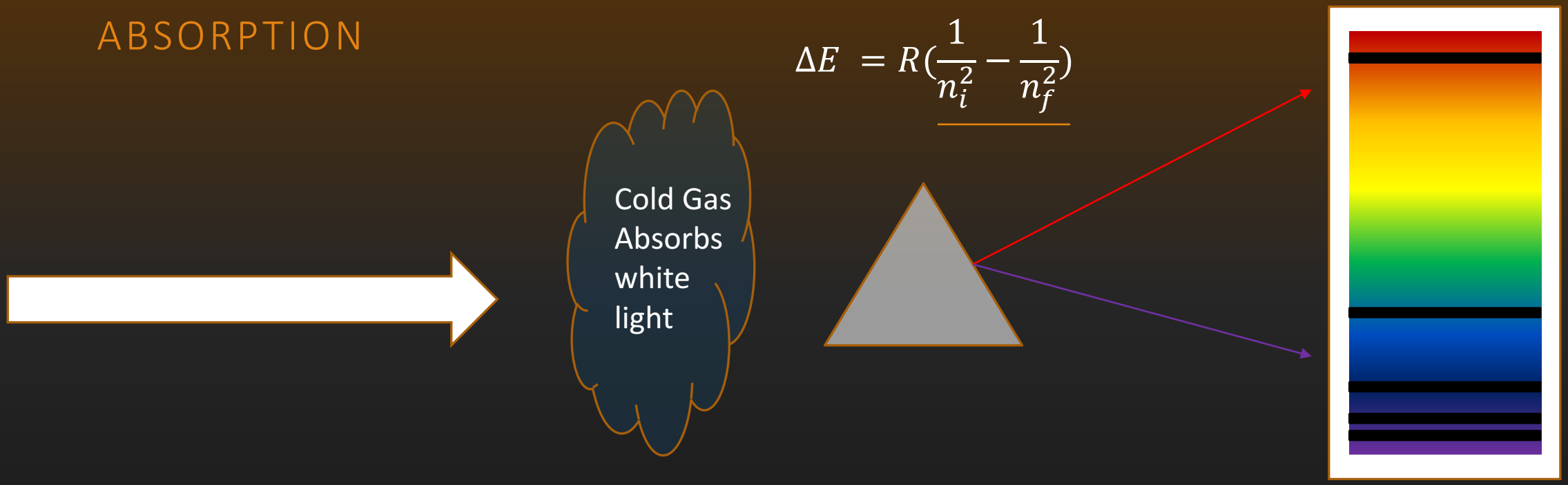
$$\Delta E = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$



- YOU SEE ONLY THE CHARACTERISTIC FREQUENCIES OF HYDROGEN EMISSION
- THE LIGHT EMITTED HAS THE ENERGY OF THE FREQUENCIES SEEN IN THE COLORED LINES. THIS CORRESPONDS TO ELECTRONS FALLING FROM A HIGH N TO A LOWER N

ABSORPTION

$$\Delta E = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$



- YOU WILL SEE THE CONTINUOUS (“WHITE LIGHT”) SPECTRUM MINUS THE CHARACTERISTIC FREQUENCIES OF HYDROGEN
- THE LIGHT ABSORBED IS “LAUNCHING” THE ELECTRONS FROM A LOW N VALUE TO A HIGHER N VALUE. THIS ABSORPTION REQUIRES ENERGY THAT CORRESPONDS TO THE FREQUENCIES OF LIGHT THAT ARE MISSING

Calculations with the Rydberg Equation

- Two equations you should know:
  - $\Delta E = R(\frac{1}{n_f^2} - \frac{1}{n_i^2})$
  - The change in energy is proportional to the difference of the inverse square of "n" values
  - $E_n = -R(\frac{1}{n^2})$
  - The potential energy of a given energy level is proportional to the inverse square of its "n" value

Remember, if you have the energy change, you can also solve for the wavelength of the light emitted using E = hv