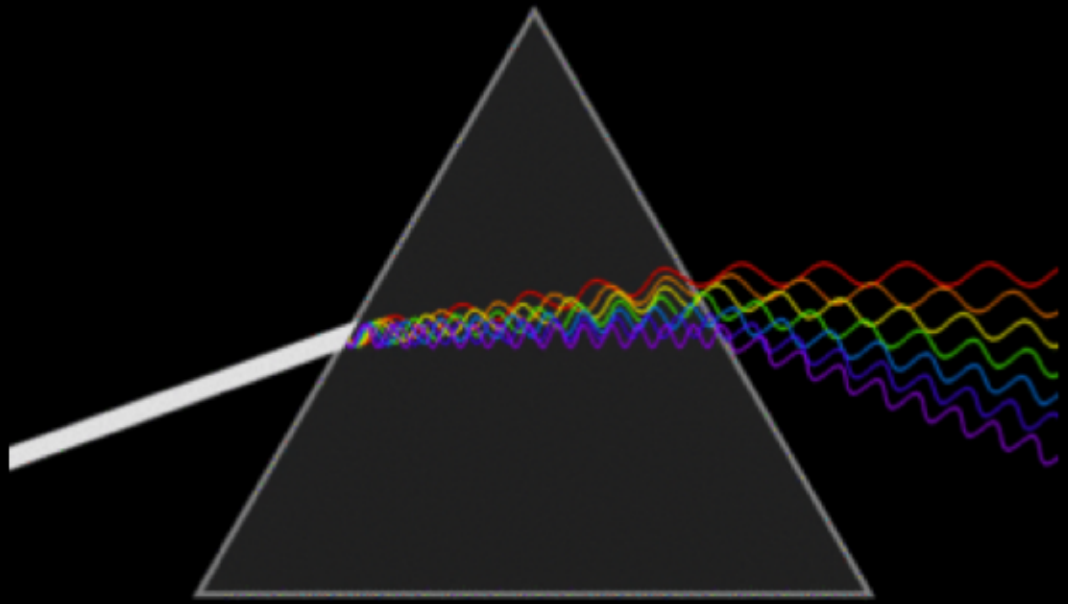
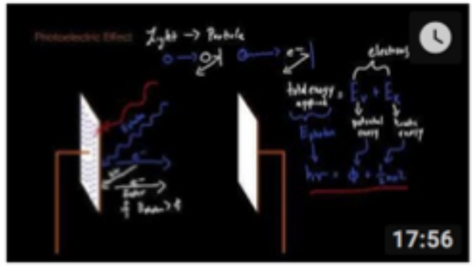


CH301 Unit 2

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
- YouTube videos:



Atomic Theory - Photoelectric Effect - Theory and Application

8 views • 1 day ago

In this lesson, we will discuss the fundamentals of the photoelectric effect for general chemistry. The photoelectric effect demonstrates that light can behave like a particle when interacting wi...

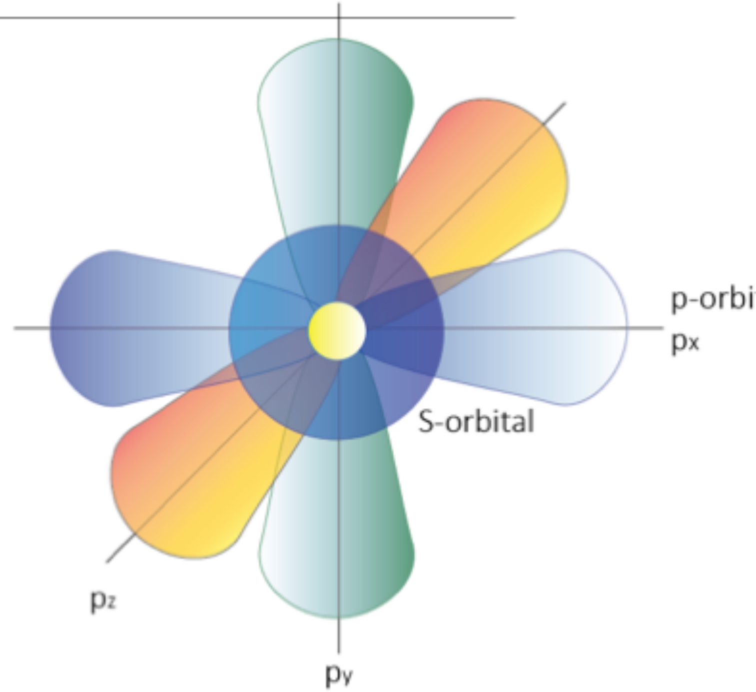
Lesson Two: Quantum Numbers (Atomic Theory)

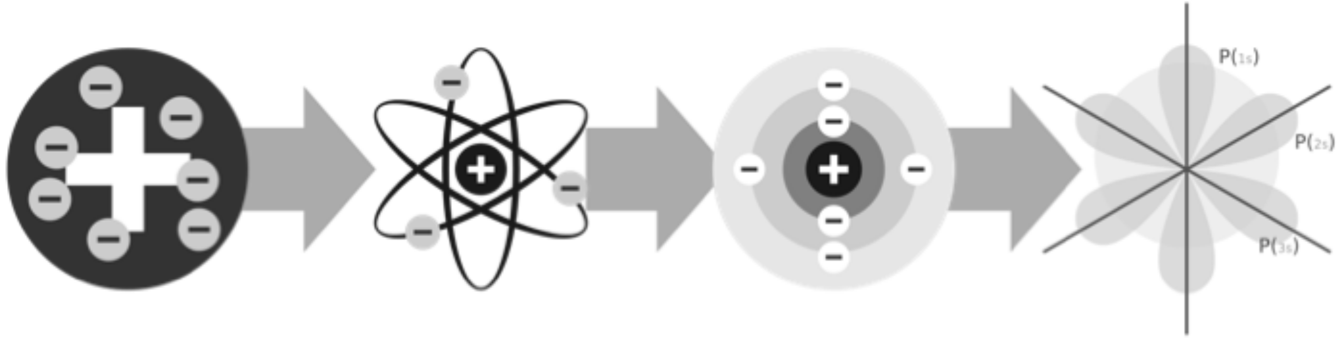
Jimmy Wadman • 91 views • 2 months ago

In this lesson, we will discuss the quantum numbers and how they relate to the modern atomic model.

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
  - De Broglie Wavelengths
  - Wave function ✓

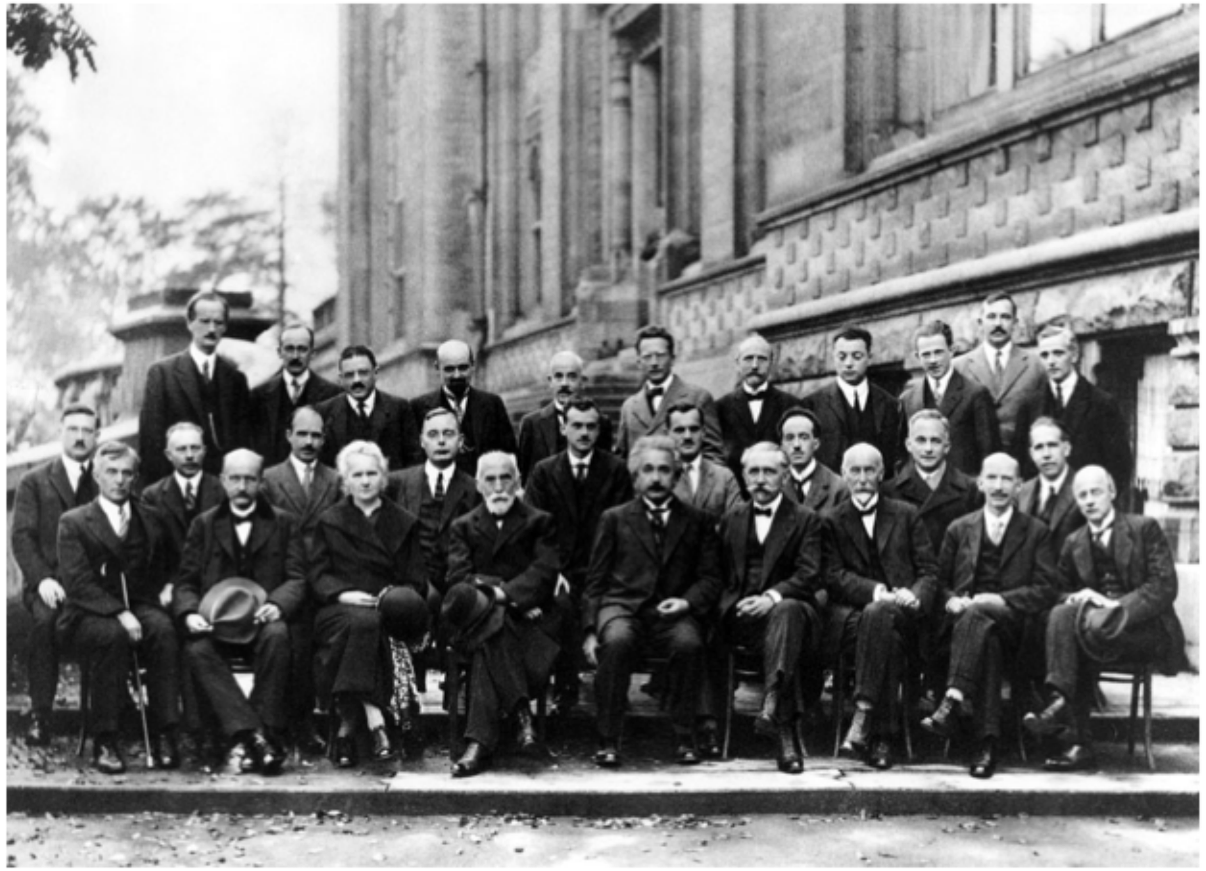




What is Quantum Mechanics?

- 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**.
    - Absorption/Emission spectra: The line spectra for a given gas has characteristic wavelengths
2. Electrons and light (photons) exhibit **wave-particle duality**.
    - Photoelectric effect: Light can act like particles
    - X-Ray diffraction: Small particles (electrons) can act like waves
3. The position and momentum of electrons can only be described with statistical **probabilities** when electron orbitals are quantified as wave functions
    - The Schrödinger Equation: Uses an understanding of probabilities and uncertainty to give us useful information about the electrons of an atom, such as the 4 quantum numbers (n, l, m_l, and m_s)
    - Uncertainty principle: only the position or momentum can be known with certainty at any given time.



(The Lads*, 1927)

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:

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

  - This equation states that the **energy of a photon** (E) is equal to the **frequency** (ν) times the **Planck's constant** (h = 6.626 x 10^{-34} J s)
  - **Energy and frequency are directly proportional**
  - **Energy and wavelength are inversely proportional**

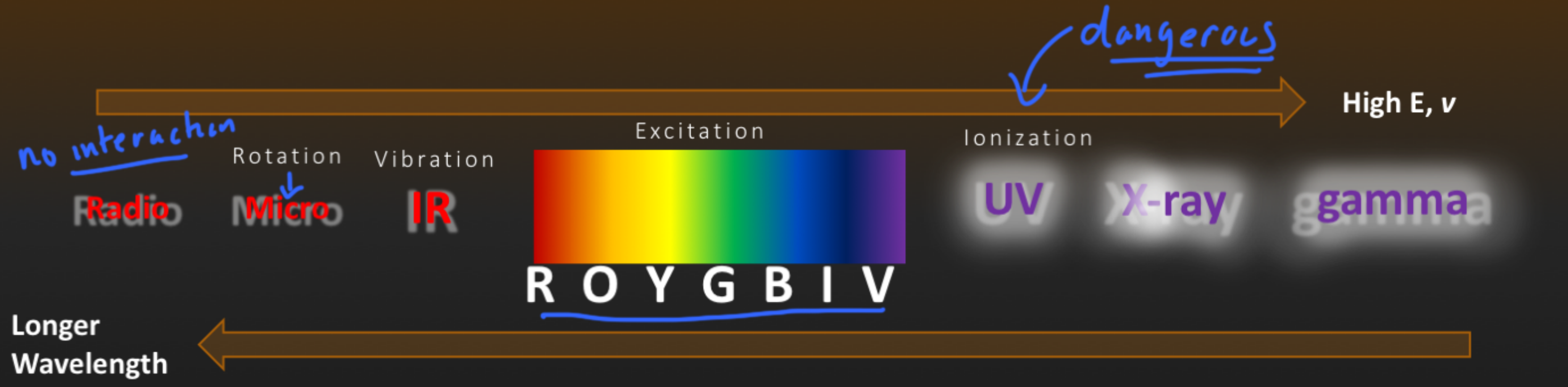
THE SPEED OF LIGHT AS A CONSTANT

$$c = \lambda \nu$$

- 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: 630 nm  $\lambda\uparrow, \nu\downarrow, E\downarrow$

Light B: 430 nm 

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: 630 nm

Light B: 430 nm

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 $6.20 \times 10^{14}\ s^{-1}$.

1. What is the wavelength of the light in nanometers?
2. What is the energy of a photon in Joules?

$Hz = \frac{1}{s}$

$c = \lambda \nu$

$\frac{m}{s} = m \cdot \frac{1}{s}$

$E = h\nu$

$(6.626 \times 10^{-34}\ J \cdot s)(6.20 \times 10^{14}\ \frac{1}{s})$

$= 4.11 \times 10^{-19}\ J$

$\frac{c}{\nu} = \lambda = \frac{3 \times 10^8}{6.20 \times 10^{14}}$

$= 4.8387\ldots \times 10^{-7}\ m \times \frac{10^9\ nm}{1\ m}$

$= 484\ nm$

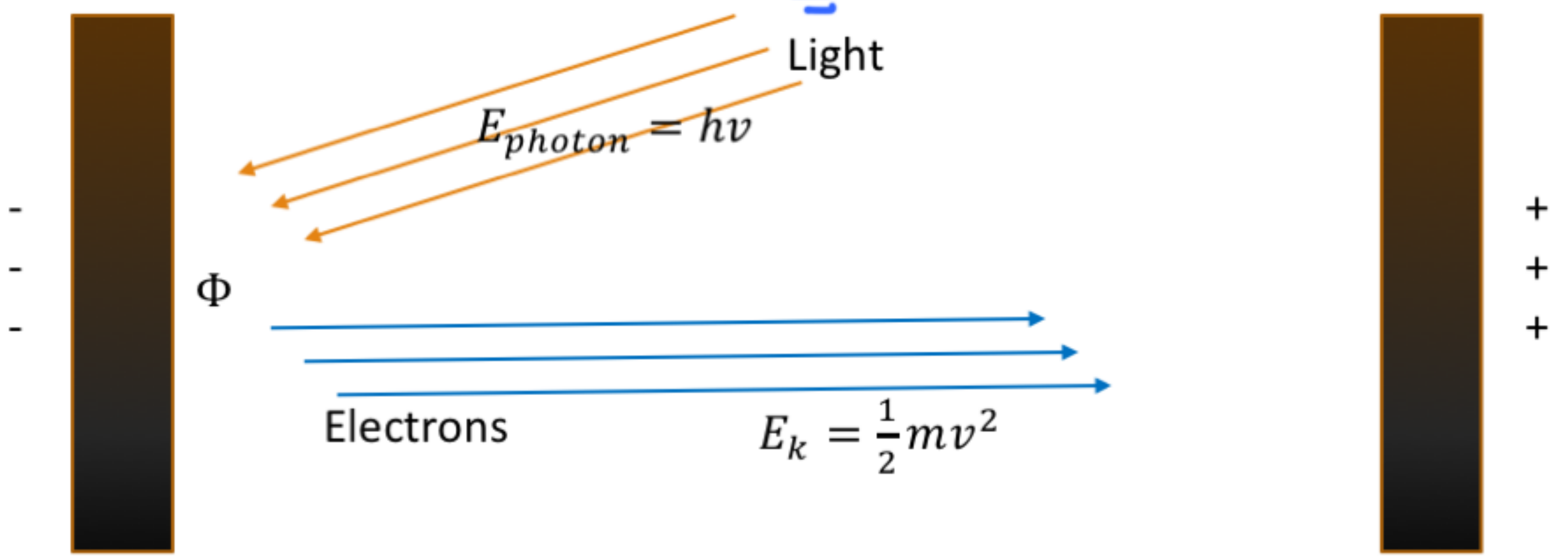
macro
intensity, brightness, # of photons

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:

total E in = P.E. + K.E.

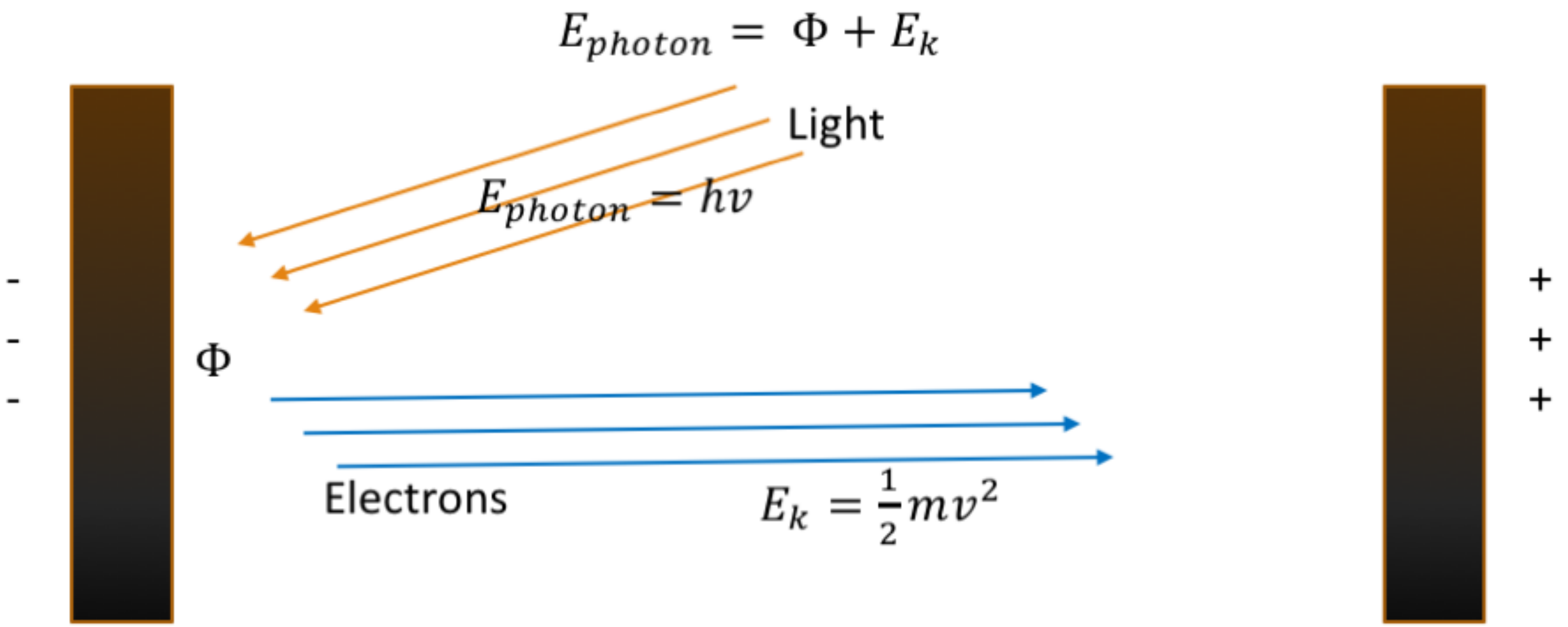
$$E_{photon} = \Phi + E_k$$



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



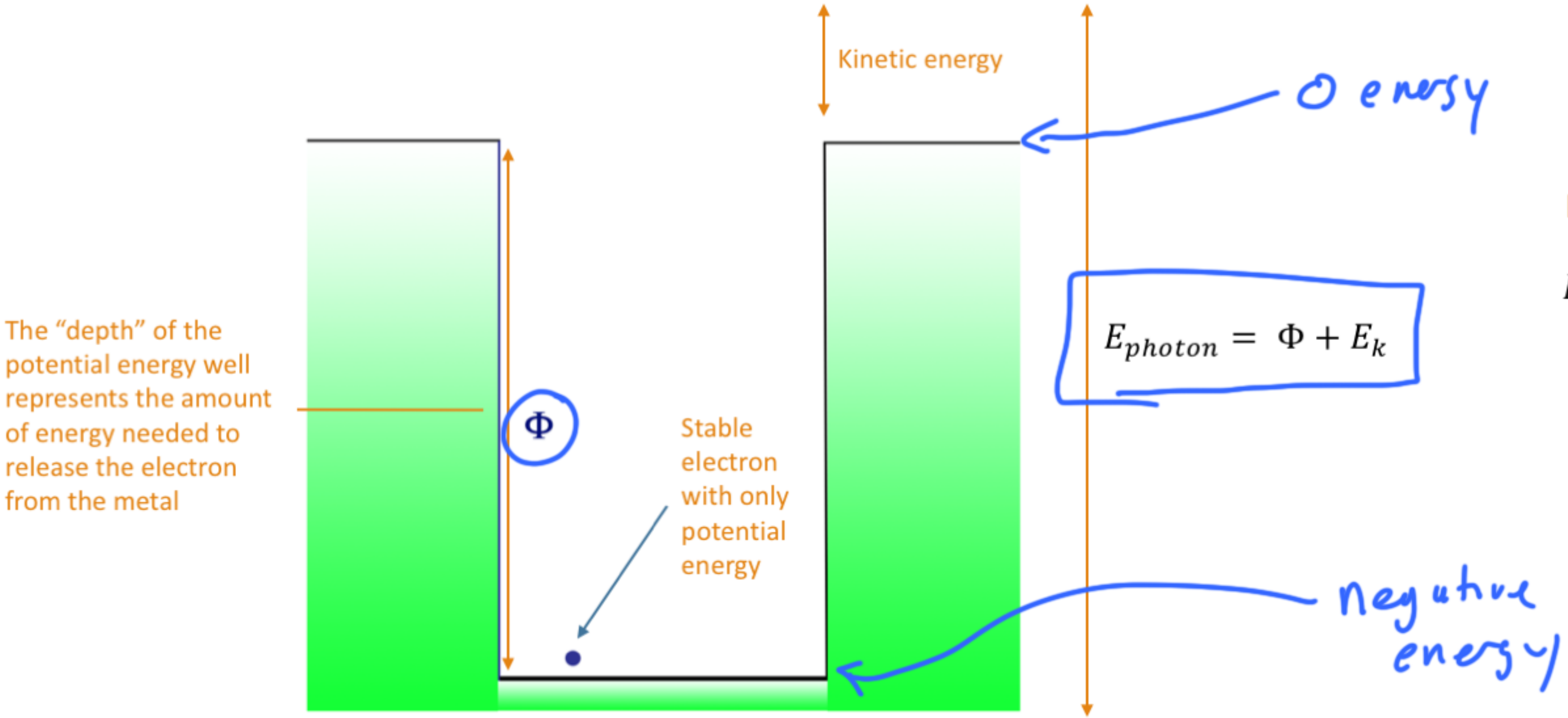
IF THE WORK FUNCTION IS REACHED:

- Increasing intensity:
  1. Increases the number of emitted electrons
  2. 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):
  1. Increases the kinetic energy of the emitted electrons
  2. Increases the velocity of the emitted electrons
  3. 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 2.5 eV photons does NOT equal 5 eV overall. ✓

Potential Energy Well



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

If threshold is met:

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

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

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

Photoelectric Effect Question (Homework)

A particular metal has a work function of 1.05 eV. A light is shined onto this metal with a corresponding wavelength of 324 nm. What is the maximum velocity of the photoelectrons produced? (Hint: 1eV = 1.6022 x 10^{-19} J, mass of an electron = 9.11 x 10^{-31} kg)

E_{photon}

$\rightarrow E_K$

$$\frac{hc}{\lambda} = \phi + \frac{1}{2}mv^2$$

nm → m   eV → J

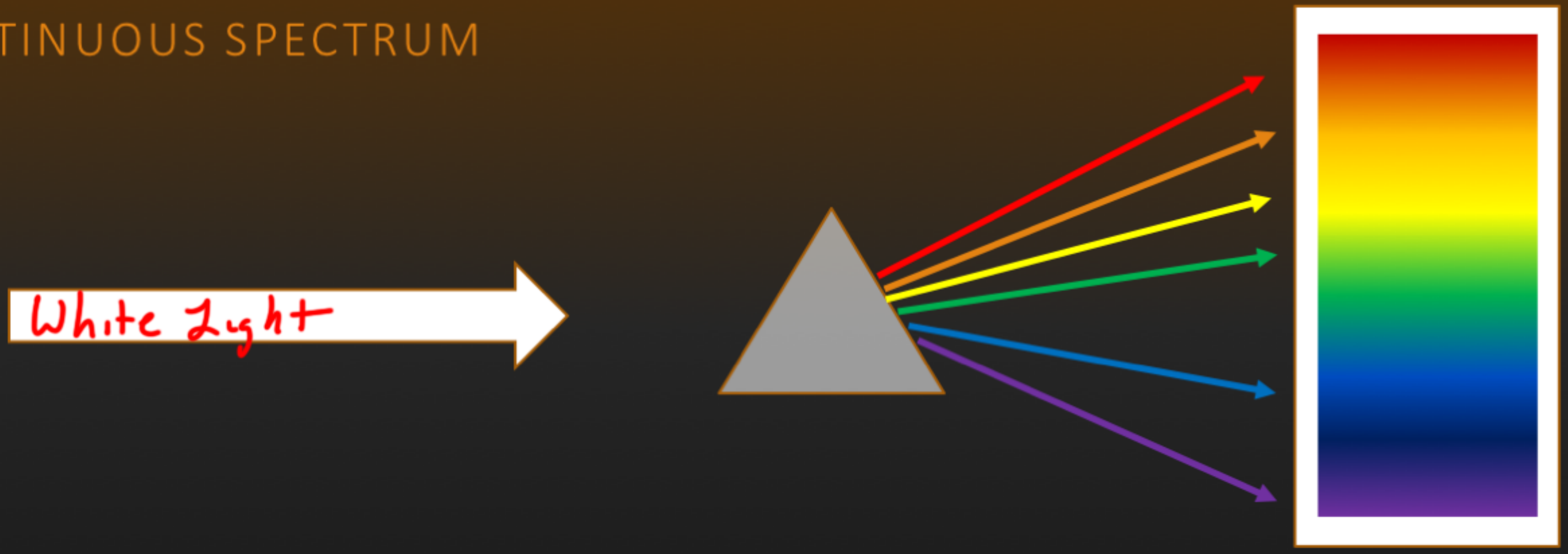
$$E_{photon} = \phi + E_K$$

1) $E_K = E_{photon} - \phi$

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

2) $v = \sqrt{\frac{2 \cdot E_K}{m}}$

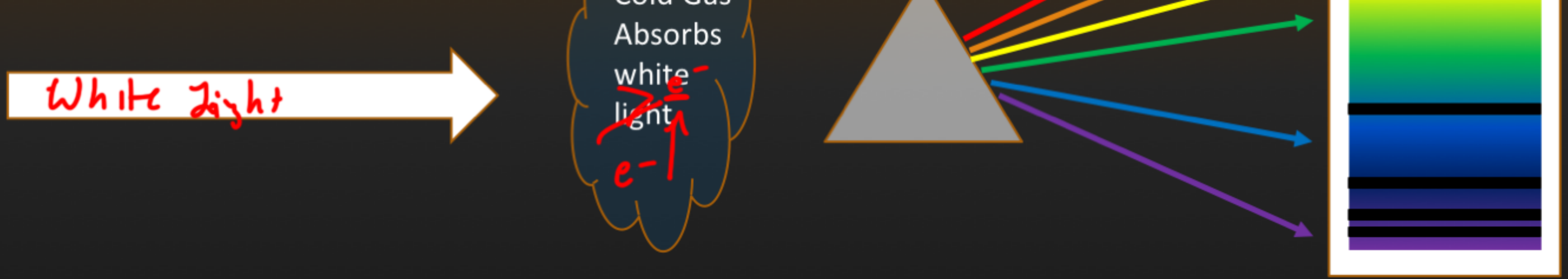
CONTINUOUS SPECTRUM



- WHITE LIGHT ENTERS THE PRISM AND DISPERSES INTO INDIVIDUAL COLORS (ROYGBIV)
- NOTHING SPECIAL IS HAPPENING HERE, EXCEPT TO GIVE US A FRAME OF REFERENCE FOR THE ABSORPTION AND EMISSION SPECTRUM.

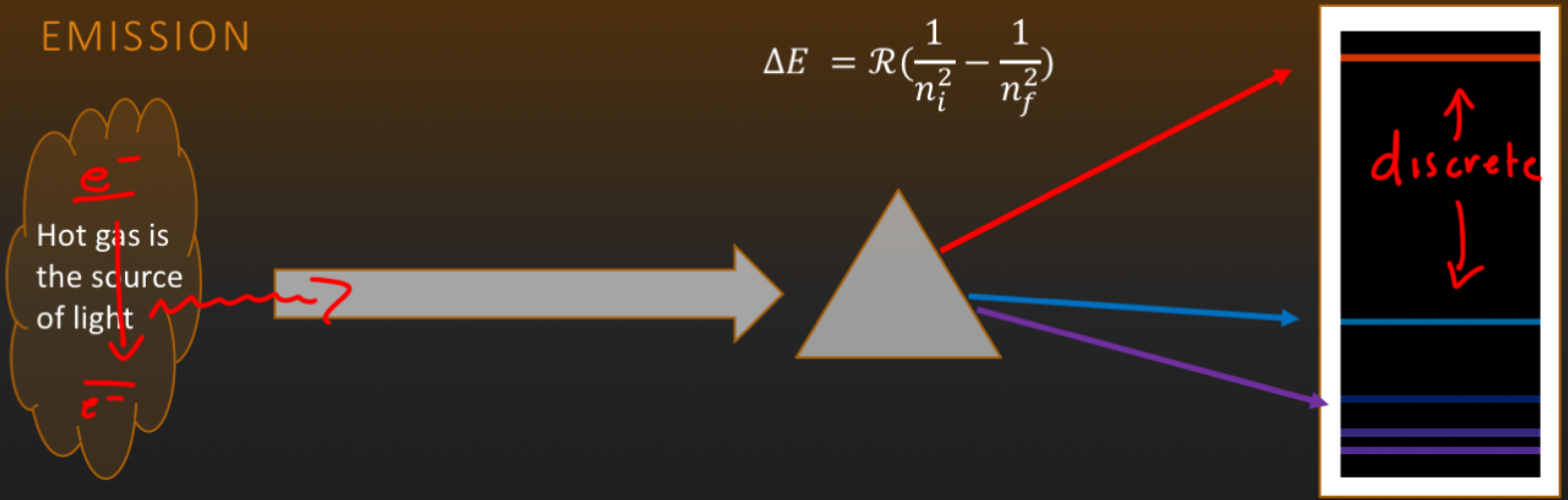
ABSORPTION

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



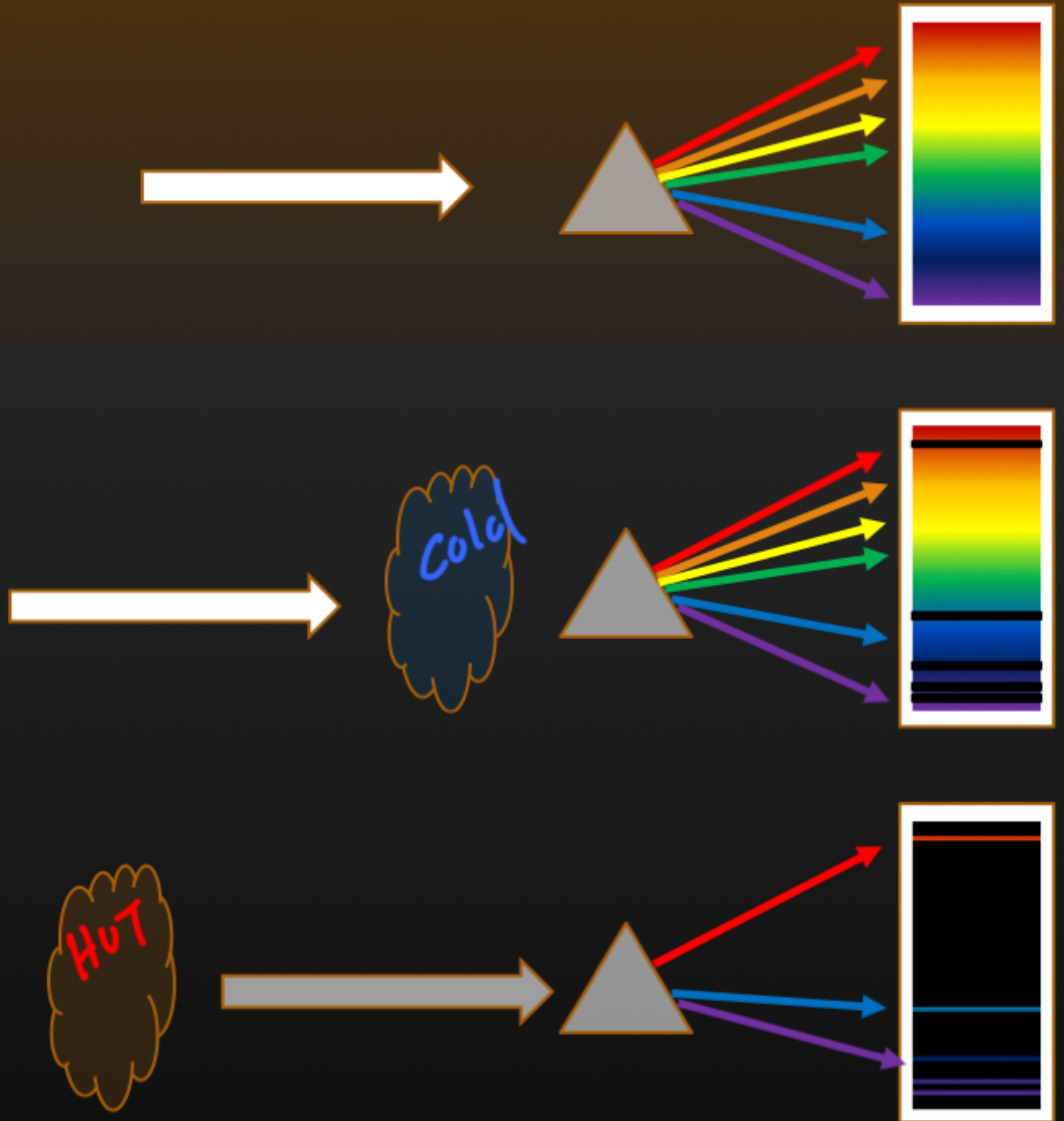
- YOU WILL SEE THE CONTINUOUS ("WHITE LIGHT") SPECTRUM MINUS THE CHARACTERISTIC FREQUENCIES OF HYDROGEN
- THE LIGHT ABSORBED IS "LAUNCHING" THE ELECTRONS FROM A LOW N VALUE TO A HIGHER N VALUE. THIS ABSORPTION REQUIRES ENERGY THAT CORRESPONDS TO THE FREQUENCIES OF LIGHT THAT ARE MISSING

EMISSION



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

- 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



CONTINUOUS

ABSORPTION

EMISSION

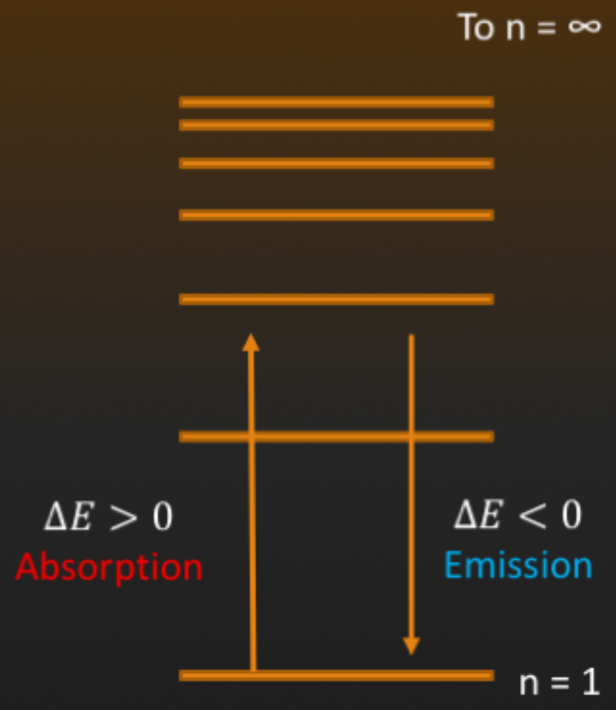
NOTICE HOW THESE ARE OPPOSITES FOR ANY GIVEN GAS. THIS IS EVIDENCE OF THE DISCRETE ENERGY LEVELS OF ELECTRONS

RYDBERG EQUATION

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

R = 2.18 X 10^{-18}J

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



- This equation calculates the energy difference of an electron going from n_i to n_f
- This equation will always work so long as you follow one conceptual trick: The value for photon energy will always be positive.
- If you are undergoing absorption, ΔE is positive. If you are undergoing emission ΔE is negative. Either way, your photon energy is the absolute value of these energy transitions.

RYDBERG EQUATION: ENERGY

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

R = 2.18 X 10^{-18}J

Electron energy level transition	Sign of ΔE	Absorption/Emission ($\lvert\Delta E\rvert$) (Cause/Effect)
Low n to high n	Positive (increasing energy)	Light absorbed
High n to low n	Negative (decreasing energy)	Light emitted

Quantum Mechanics: Emission vs. Absorption

An excited hydrogen electron emits a photon in the Balmer series when it falls from n = 4.

1. What is the change in energy of the electron?
2. What is the photon energy associated with this energy change?

$n_i = 4$

$n_f = 2$

$$\Delta E = R\left(\frac{1}{4^2} - \frac{1}{2^2}\right)$$

$$2.18 \times 10^{-18} J\left(\frac{1}{16} - \frac{1}{4}\right) = -4.09 \times 10^{-19} J$$

$$E_{photon} = 4.09 \times 10^{-19} J$$

Rydberg Equation Question: on your own

A hydrogen electron emits a photon in the Lyman Series when it falls from n = 3.

a. What is the difference in energy for the electron in this process? Answer in Joules
b. What is the wavelength of the photon emitted? Answer in nm
c. What is the color of light emitted?

$R = 2.18 \times 10^{-18} J$

(Provided)

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

(Memorize)

Rydberg Conceptual Question

Which of the following represents the greatest (in magnitude) energy transition?

a. n = 3 to n=1
b. n = 5 to n=2
c. n = 2 to n = 1
d. n = 3 to n = 2
e. n = 5 to n = 1

2->1 biggest consecutive

Which of the following represents the greatest (in magnitude) energy transition between consecutive energy levels?

a. n = 3 to n = 2
b. n = 5 to n = 6
c. n = 10 to n = 9
d. n = 4 to n = 3

Rydberg Conceptual Question

Which of the following represents the greatest (in magnitude) energy transition?

a. n = 3 to n=1
b. n = 5 to n=2
c. n = 2 to n = 1
d. n = 3 to n = 2
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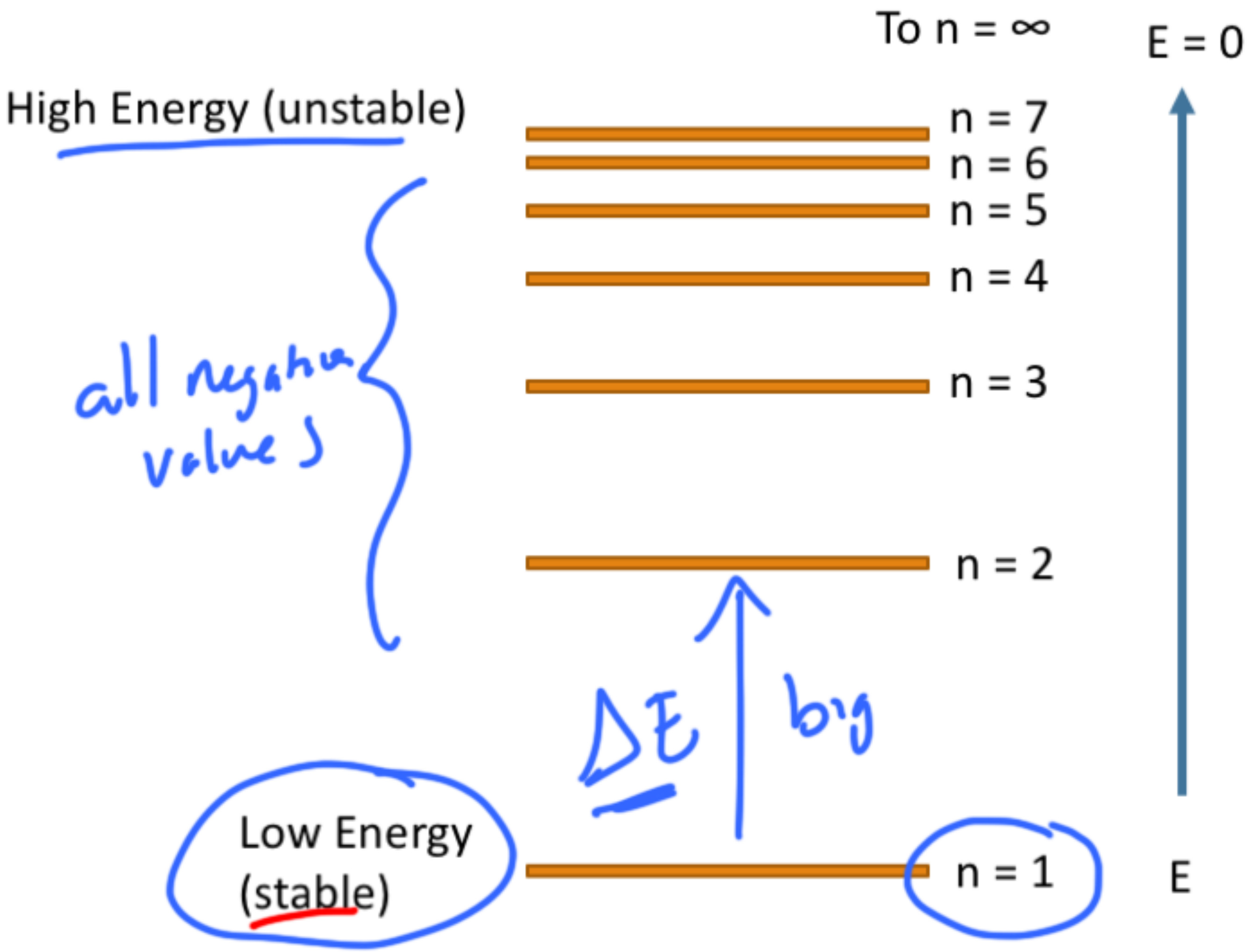
Which of the following represents the greatest (in magnitude) energy transition between consecutive energy levels?

a. n = 3 to n = 2
b. n = 5 to n = 6
c. n = 10 to n = 9
d. n = 4 to n = 3

Quantum Mechanics: Emission vs. Absorption

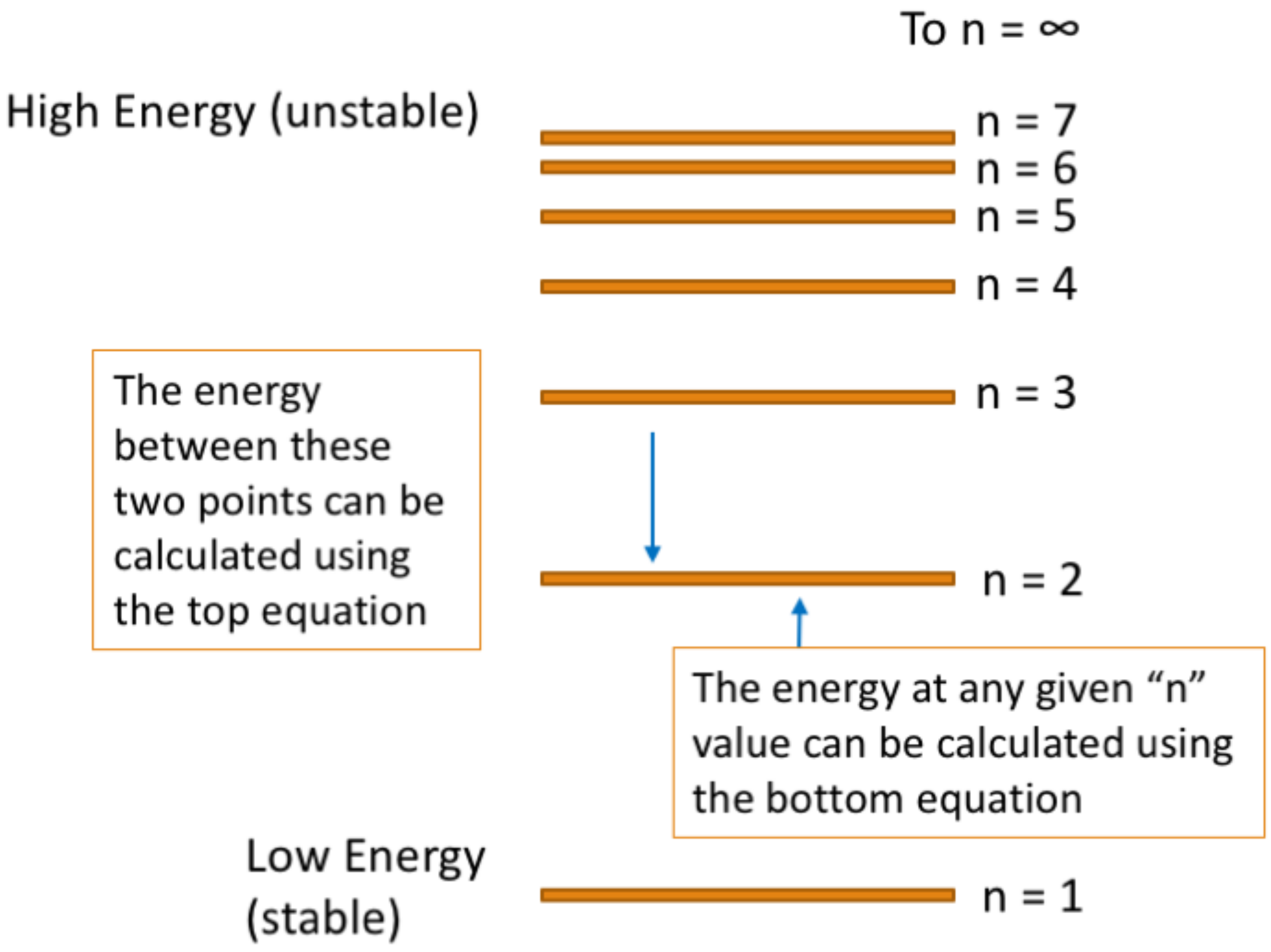
- The Bohr Model of the atom explained that electrons exist in "energy states," which we now designate the letter "n."
- You can understand n values by following these rules:
  1. n values begin at 1 (closest to the nucleus) and go to infinity (completely out of the influence of the nucleus/ free in space)
  2. The lower n value means more stable (most negative potential energy)
  3. The greatest energy difference between two **consecutive** numbers is 1 and 2.



Calculations with the Rydberg Equation

- Two equations you should know:
  - $\Delta E = \mathcal{R}(\frac{1}{n_i^2} - \frac{1}{n_f^2})$
  - The change in energy is proportional to the difference of the inverse square of "n" values
  - $E_n = -\mathcal{R}(\frac{1}{n^2})$
  - 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 and $c = \lambda v$



Summary: 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**.
    - Absorption/Emission spectra: **The line spectra for a given gas has characteristic wavelengths**
2. Electrons and light (photons) exhibit **wave-particle duality**.
    - Photoelectric effect: **Light can act like particles**
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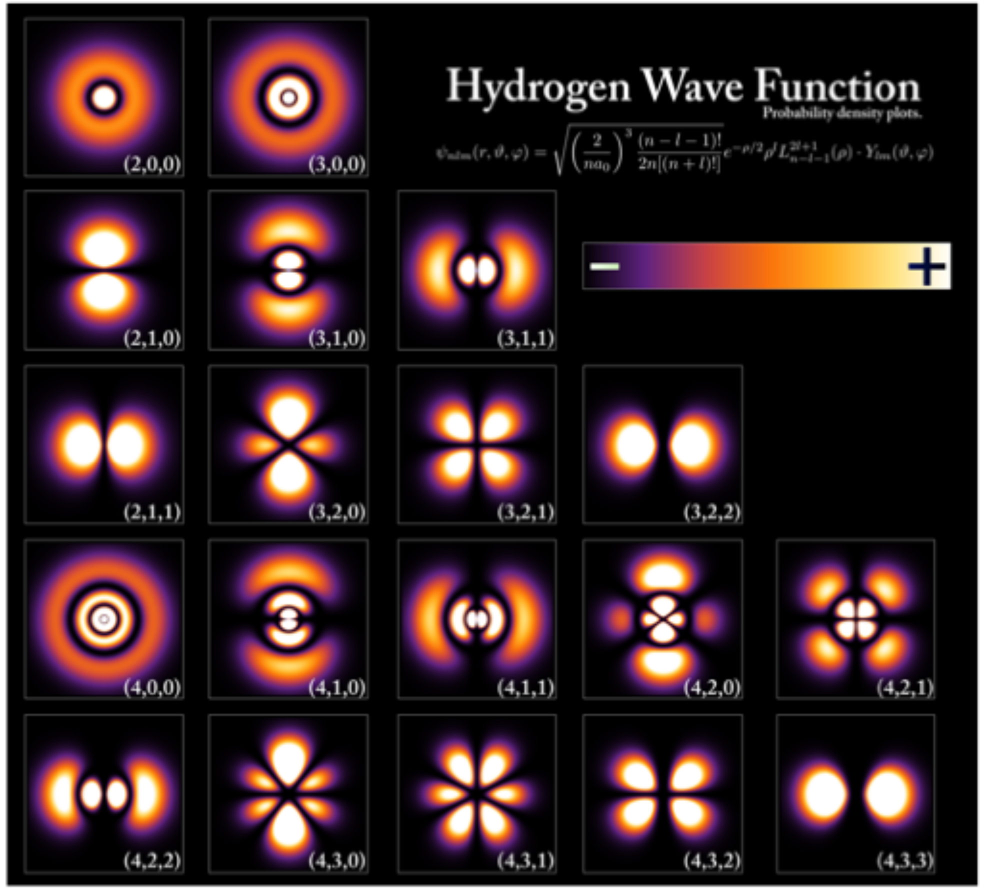
3. The position and momentum of electrons can only be described with statistical **probabilities** when electron orbitals are quantified as wave functions.
    - The Schrödinger Equation: Uses an understanding of probabilities and uncertainty to give us useful information about the electrons of an atom, such as the 4 quantum numbers (n, l, m_l, and m_s)
    - Uncertainty principle: only the position or momentum can be known with certainty at any given time.

Conceptual look into the Schrödinger Equation

$$\underbrace{-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2}}_{\text{kinetic energy}} + \underbrace{V(x)\psi}_{\text{potential energy}} = \underbrace{E\psi}_{\text{total energy}}$$

- The Schrödinger Equation gives us infinite wave functions (solutions) for the Hydrogen atom.
- The wave functions are classified by the quantum numbers:
  - Principle Quantum Number, n (Energy)
  - Angular Momentum Quantum Number, l (Shape)
  - Magnetic Quantum Number, m_l (Orientation)
- **This ultimately tells us the energy of an electron and the probable location of that electron in three dimensional space.**



Particle in a Box

- The Schrödinger Equation gives us insight to the **energy of an electron** and the **probability of finding that electron** (location, correlates with shape) in a given range of three dimensional space.

- Particle in a Box is useful because it conceptualizes the simplest solutions to the Schrödinger equation (1 particle, 1 dimension, no potential energy):
  - Given any n-value, where can I find the particle? Where is there zero probability of finding the particle?

- The Radial Distribution Function helps bring it all together in three-dimensional space by answering:
  - Where are my electrons most likely to be found?

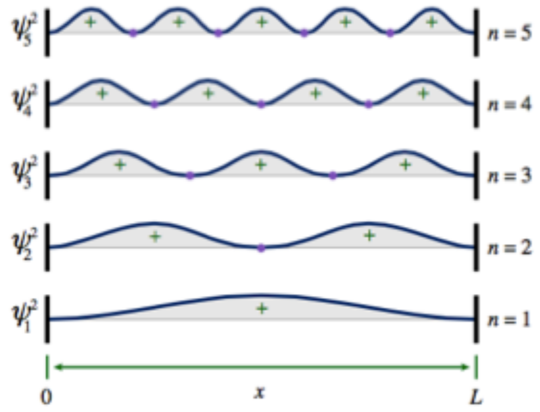
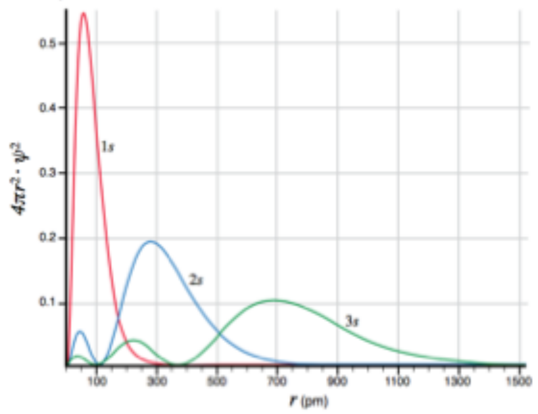


figure 2



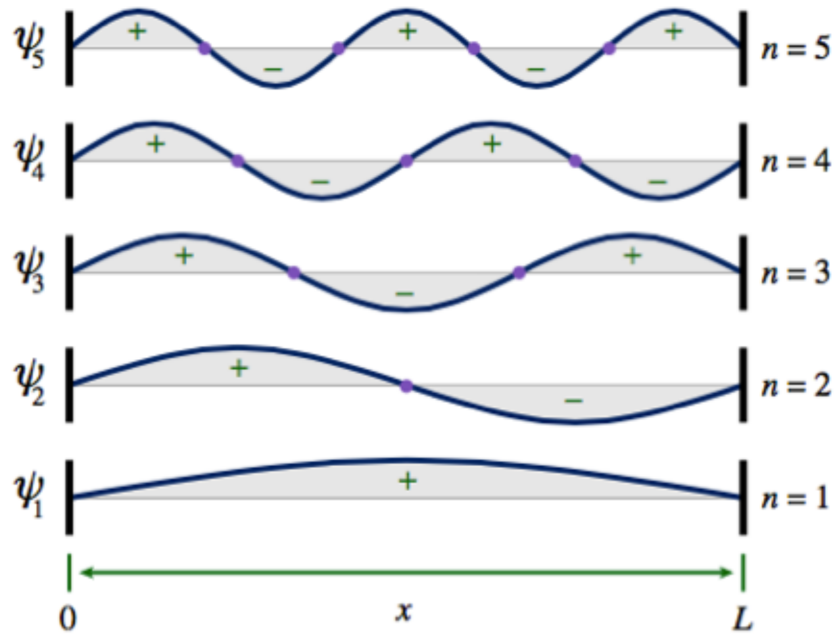
Particle in a Box

Some helpful rules:

- # of full wavelengths = n/2
- # of distributions (“humps”) = n
- # of nodes = n-1

- Given any n-value, where can I find the electrons?
  - Where the graph gives you a non-zero value
- Where is there zero probability of finding an electron?
  - At the nodes (y=0)

$$\psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi}{L}\right)x$$



Multiply by Ψ to get all positive values

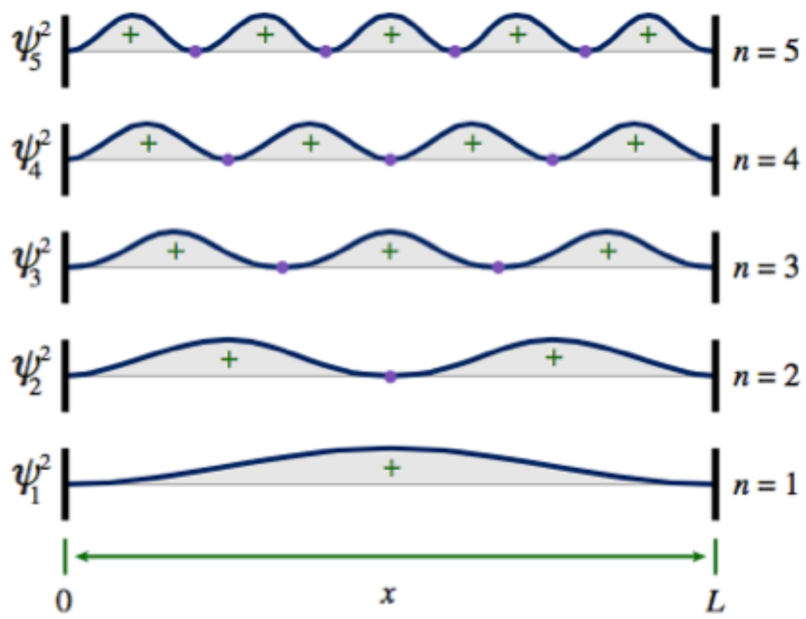
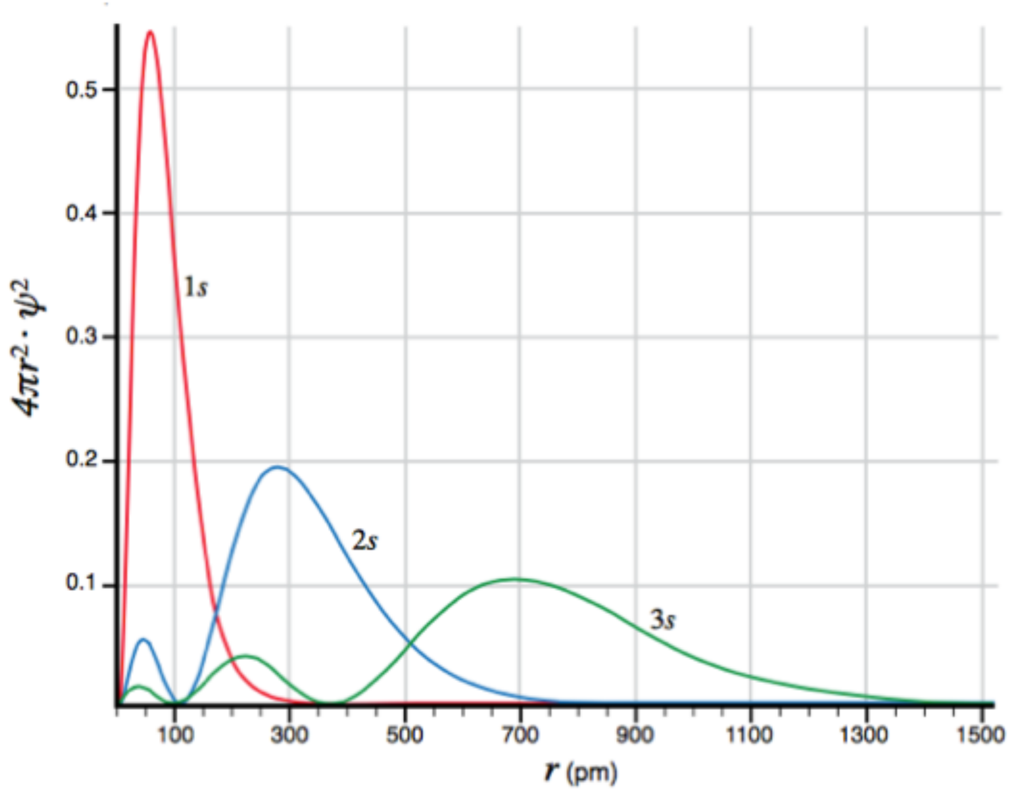


figure 2

Node: any time the sinusoidal function crosses from (-) to (+) or (+) to (-)

Radial Distribution

- If we further apply this concept, we can answer the more specific question: where are the electrons **most likely** to be found?



- Radial distribution curves show the same number of nodes as particle in a box, but they also show the actual probability of finding an electron in **three-dimensional space**.
- The number of distributions is equal to the n-value. It is always most probably that electrons are found in the furthest hump from the nucleus (r=0)

PIB to Radial Distribution Example

Suppose you have a single particle confined to a one-dimensional "box" of length 360 pm.

1. At what distances are you most likely to find the particle if n = 4?
2. At what distances do you have zero probability of finding this particle?
3. How many wavelengths are in the box?
4. Lastly, if this particle is a hydrogen atom electron in the 4s orbital, what does the radial distribution function tell you about the location of the electrons?