ELECTRONS IN ATOMS
• Visible light is a kind of electromagnetic radiation

• **Electromagnetic radiation**: a form of energy that exhibits wavelike behavior as it travels through space

• All forms of electromagnetic radiation form the *electromagnetic spectrum*
Visible light!
All forms of electromagnetic radiation move at a constant speed of $3.00 \times 10^8 \text{ m/s}$ – light’s approximate speed through air.

Significant features of wave motion is its repetitive nature.

Can be measured by frequency and wavelength.

- **Wavelength ($\lambda$)**: the distance between corresponding points on adjacent waves.
  - Units: nm, cm, or m
- **Frequency ($\nu$)**: the number of waves that pass a given point in a specific time, usually one second.
  - Units: waves/second $\rightarrow$ one wave/second = Hertz (Hz)
• Frequency and wavelength are mathematically related to each other

\[ c = \lambda \nu \]

• \( c \) = speed of light (3.00 \( \times \) 10\(^8\) m/s)
• \( \lambda \) = wavelength (m, nm, etc.)
• \( \nu \) = frequency (Hz)
SAMPLE PROBLEM

Find the frequency of a photon with a wavelength of 4.34 \times 10^{-7} \text{ m}.

- **Given:**
  - \( \lambda = 4.34 \times 10^{-7} \text{ m} \)
  - \( c = 3.00 \times 10^8 \text{ m/s} \)

- **Unknown:**
  - \( \nu = ? \)

- **Solve:**
  - \( c = \lambda \nu \)
  - \( \nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{4.34 \times 10^{-7} \text{ m}} \)
  - \( = 6.91 \times 10^{14} \text{ Hz} \)
Determine the frequency of light with a wavelength of $4.257 \times 10^{-7} \text{ m}$. 

- $7.05 \times 10^{14}$
• Speed of light is constant so $\lambda \nu$ is constant
• They are inversely proportional to each other
• ...meaning, as wavelength decreases, frequency increases & vice versa
Quantum Theory

• Early 1900s, scientists conducted experiments involving interactions of light and matter that could not be explained by the wave theory
  • One involved a phenomenon known as the *photoelectric effect*

*Photoelectric effect*: the emission of electrons from a metal when light shines on the metal

• EM radiation strikes the surface of a metal, ejecting electrons from the metal and creating an electric current
Max Planck (1900)

- German physicist
- Studied the emission of light by hot objects
- Suggested that a **hot object emits energy in small, specific amounts (quanta)**
  - **Quantum**: the minimum amount of energy that can be lost or gained by an atom
Planck proposed the following relationship between a quantum of energy and the frequency of radiation:

\[ E = h \nu \]

- \( E \) = energy (J, joules)
- \( \nu \) = frequency (Hz)
- \( h \) = Planck’s constant = \( 6.626 \times 10^{-34} \) J·s

Energy is directly proportional to frequency of radiation.

![Energy and Frequency Diagram](image)
Find the energy of a red photon with a frequency of $4.57 \times 10^{14}$ Hz.

- **Given:**
  - $\nu = 4.57 \times 10^{14}$ Hz
  - $h = 6.626 \times 10^{-34}$ J⋅s

- **Unknown:**
  - $E = ?$

- **Solve:**
  - $E = h\nu$
  
  
  $= (6.626 \times 10^{-34} \text{ J} \cdot \text{s})(4.57 \times 10^{14} \text{ Hz})$
  
  $= 3.03 \times 10^{-19} \text{ J}$
YOU TRY!

Determine the energy in joules of a photon whose frequency is $3.55 \times 10^{17}$ Hz.

- $2.35 \times 10^{-16}$
WAVE-PARTICLE DUALITY

Einstein (1905)

- Expanded on Plank’s theory by introducing that EM radiation has a dual wave-particle nature
  - *light has properties of both waves and particles*
- Each particle of light carries a quantum of energy
  - Einstein called these particles *photons*
- **Photon**: a particle of light having zero mass and carries a quantum of energy
  - Energy of a photon is proportional to its frequency
1. In the diagrams below, which wave has the higher frequency? Explain.

2. One of the line emission spectrum of sodium has a wavelength of $5.90 \times 10^7$ m. What is the frequency of this line?

3. A radio station broadcasts a frequency of $9.13 \times 10^7$ Hz. What is the wavelength of this EM wave?

4. Calculate the energy of a gamma ray photon with a frequency of $6.0 \times 10^{22}$ Hz.

5. Find the frequency of a photon with an energy level of $4.58 \times 10^{-19}$ J.
1. In the diagrams below, which wave has the higher frequency? Explain.

2. Use the formula \( c = \lambda \nu \) to solve the following problems:
   a) One of the line emission spectrum of sodium has a wavelength of \( 5.90 \times 10^7 \) m. What is the frequency of this line?
   b) A radio station broadcasts a frequency of \( 9.13 \times 10^7 \) Hz. What is the wavelength of this EM wave?

3. Use the formula \( E = h \nu \) to solve the following problems:
   a) Calculate the energy of a gamma ray photon with a frequency of \( 6.0 \times 10^{22} \) Hz.
   b) Find the frequency of a photon with an energy level of \( 4.58 \times 10^{-19} \) J.