Light, Electrons, and Energy

Pre-AP
Light Waves!

Electromagnetic Frequency

Amplitude

Wavelength, $\lambda$

Electric vector

Magnetic vector

Nodes

Direction of propagation

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Light Phenomenon

- Light can act as a wave or as a particle, but most light-electron interactions use wave physics.

\[ \lambda = \text{greek letter lambda} \]
\[ \lambda = \text{wavelength} \]
Electromagnetic Radiation

- Waves have a frequency
- Use the Greek letter “nu”, $\nu$, for frequency, and units are “cycles per sec”

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

where $c =$ velocity of light $= 3.00 \times 10^8$ m/sec

- Long wavelength $\rightarrow$ small frequency
- Short wavelength $\rightarrow$ high frequency
Electromagnetic Radiation

Long wavelength  ----->  small frequency
Short wavelength  ----->  high frequency

See Figure 7.3
Relationships with Energy

Long wavelength  ---->  small frequency
Short wavelength  ---->  high frequency
The Electromagnetic Spectrum

The electromagnetic spectrum represents the range of energy from low energy, low frequency radio waves with long wavelengths up to high energy, high frequency gamma waves with small wavelengths.
Frequency Ranges of Visible Light

- **Red light** has a frequency of roughly $4.3 \times 10^{14}$ Hz, and a wavelength of about $7.0 \times 10^{-7}$ m (700nm).

- **Violet light**, at the other end of the visible range, has nearly double the frequency—$7.5 \times 10^{14}$ Hz—and (since the speed of light is the same in either case) just over half the wavelength—$4.0 \times 10^{-7}$ m (400nm).
Multiplication Rule

\[ x^n \cdot x^m = x^{n+m} \]

In order to use this rule the base numbers being multiplied must be the same.

Example: \( x^3 \cdot x^4 \)

Written in multiplication form

\[ x \cdot x \cdot x \cdot x \cdot x \cdot x \cdot x \cdot x = x^7 \]

Using Rule

\[ x^{3+4} = x^7 \]
Division Rule:

If the bases are the same subtract the exponents

\[ \frac{x^m}{x^n} = x^{m-n} \]

\[ \frac{x^5}{x^3} = \frac{x \cdot x \cdot x \cdot x \cdot x}{x \cdot x \cdot x} = x^2 \]

OR

\[ \frac{x^5}{x^3} = x^{5-3} = x^2 \]

Always do top exponent minus bottom exponent
Special Cases (zero power):

Any base raised to a power of zero equals 1

\[ x^0 = 1 \]

Here is why, when the number in the numerator is the same as the number in the denominator, the quotient is always 1.

\[ \frac{10^4}{10^4} = \frac{10 \times 10 \times 10 \times 10}{10 \times 10 \times 10 \times 10} = 1 \]

So it makes sense that \[ \frac{10^4}{10^4} = 10^{4-4} = 10^0 = 1 \]
Let us take our previous problem; red light has a certain wavelength ($\lambda$) and frequency ($\nu$), do they work out to be $C = \lambda \nu$?

\[ C = \lambda \nu \]

\[ C = (7.0 \times 10^{-7} \text{ m}) \times (4.3 \times 10^{14} \text{ Hz}) \]

We have the same base numbers under the exponent, so we can separate the problem easily. Do a little math and then put the pieces together.

\[ 30.1 \times 10^7 \]

Our first answer isn’t neat, though. Move the decimal over to the left, adding +1 to the power of ten in the process. There, neat scientific notation with the right units.

\[ 3.01 \times 10^8 \text{ m/s} \]
The frequency \( v \) of a wave is the number of waves to cross a point in 1 second (units are Hertz – cycles/sec or sec\(^{-1}\))

\( \lambda \) is the wavelength - the distance from crest to crest on a wave
Simple Math

- The product of wavelength and frequency always equals the speed of light.
  \[ C = \lambda \nu \]

- Why does this work?

- NOTE: \( c \) is a constant value= \( 3.00 \times 10^8 \) m/s
Calculate the wavelength of yellow light emitted from a sodium lamp if the frequency is $5.10 \times 10^{14} \text{ Hz (5.10 x 10^{14} s^{-1})}$

List the known info
- $c = 3.00 \times 10^8 \text{ m/s}$
- Frequency ($v$) = $5.10 \times 10^{14} \text{ s}^{-1}$

List the unknown
- Wavelength ($\lambda$) = ? m

Solve:

$$C = \lambda v$$

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

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{5.10 \times 10^{14} \text{ s}^{-1}} = 5.88 \times 10^{-7} \text{ m}$$
Red light has $\lambda = 700$ nm. Calculate the frequency.

\[
\text{Freq} = \frac{3.00 \times 10^8 \text{ m/s}}{7.00 \times 10^{-7} \text{ m}} = 4.29 \times 10^{14} \text{ sec}^{-1}
\]
1. What is the wavelength of radiation with a frequency of $1.50 \times 10^{13} \text{ s}^{-1}$?

2. What frequency is radiation with a wavelength of $5.00 \times 10^{-8} \text{ m}$? In what region of the electromagnetic spectrum is this radiation?
Math Example 4 Two

- We start with $C = \lambda \nu$ as our equation, but it needs to be rearranged.

  $C = \lambda \times \nu$

  \[
  \frac{C}{\nu} = \lambda
  \]

- To get $\lambda$ by itself we divide $C$ by $\nu$. They cancel out and viola, ready to math!

  $\lambda = \frac{C}{\nu}$

  $\lambda = \frac{(3.00 \times 10^8 \text{ m})}{(1.50 \times 10^{13} \text{ Hz})}$

  \[
  \lambda = 2.00 \times 10^{-5}
  \]

  We have the same base numbers under the exponent, so we can separate the problem easily. Do a little math and then put the pieces together.

  Our first answer isn’t complete unless we put the right units on there.

  $2.00 \times 10^{-5} \text{ m}$
The movement of electrons inside of atoms produces light and other electromagnetic radiation thanks to quantum mechanics.

Each element gives off only certain frequencies of light, called **spectral lines**.

In effect each element has its own **signature** of spectral lines allowing us to identify which element we have or what stars are made of.
Below is a picture of the spectral lines given off by hydrogen. Note there are 3 different frequencies.
More Spectra

- The emission spectra makes it possible to identify inaccessible substances. Most of our knowledge of the universe comes from studying the emission spectra of stars.
- Below is the spectra of a few more elements.

Helium
More Spectra

- Neon

- Argon
Particle Wave Duality

- The photoelectric effect – When light shines on metals, electrons (photoelectrons) are ejected from their surface.
  - A certain frequency has to be achieved or the effect does not work!

Red light will not cause electrons to eject!
Quantization of Energy

- Energy of electro-magnetic radiation is proportional to frequency.

\[ E_p = h \cdot \nu \]

- \( h = \text{Planck's constant} = 6.6262 \times 10^{-34} \text{ J} \cdot \text{s} \)
Sample Problem

Calculate the frequency of light having a wavelength of $1 \times 10^{-7}$ m.

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

$$1 \times 10^{-7} \text{m} \cdot \nu = 3.00 \times 10^8 \text{ m/s}$$

$$\nu = 3 \times 10^{15} / \text{s}$$
Sample Problem

Calculate the wavelength of light having a frequency of $1.5 \times 10^8$ hz.

\[ \lambda \cdot \nu = c \]

\[ \lambda \cdot 1.5 \times 10^8 \text{/s} = 3.00 \times 10^8 \text{m/s} \]

\[ \lambda = 2.0 \text{ m} \]
Sample Problem

3. Calculate the frequency of light having a wavelength of $1 \times 10^3$nm.

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

$$1 \times 10^{-6}m \cdot \nu = 3.00 \times 10^8 \text{ m/s}$$

$$\nu = 3 \times 10^{14} / \text{s}$$
Sample Problem

1. Calculate the energy of a photon having a frequency of $3 \times 10^{15}$/s.

\[
E_p = h \cdot \nu
\]

\[
E_p = 6.63 \times 10^{-34} \text{ Js} \cdot 3 \times 10^{15}/\text{s}
\]

\[
= 2 \times 10^{-18} \text{ J}
\]
Sample Problem

Calculate the energy of a photon with a wavelength of 575 nm.

\[ \lambda \cdot \nu = c \]

\[ 5.75 \times 10^{-7} \text{ m} \cdot \nu = 3.00 \times 10^8 \text{ m/s} \]

\[ \nu = 5.22 \times 10^{14}/\text{s} \]

\[ E_p = h \cdot \nu \]

\[ E_p = 6.63 \times 10^{-34} \text{ Js} \cdot 5.22 \times 10^{14}/\text{s} \]

\[ = 3.46 \times 10^{-19} \text{ J} \]
Sample Problem

Calculate the energy of the photon:
Photon wavelength = 2.35 x 10^{-7} m

\[ \lambda \cdot \nu = c \]

\[ 2.35 \times 10^{-7} \text{ m} \cdot \nu = 3.00 \times 10^8 \text{ m/s} \]
\[ \nu = 1.28 \times 10^{15}/\text{s} \]

\[ E_p = h \cdot \nu \]
\[ E_p = 6.63 \times 10^{-34} \text{ Js} \cdot 1.28 \times 10^{15}/\text{s} \]

\[ = 8.49 \times 10^{-19} \text{ J} \]