Our Current Model of the Atom

\[ \text{He} \]
In a sense chemistry amounts to asking the following questions

How many electrons are present in a particular atom?

What energies do individual electrons possess?

Where in an atom can electrons be found?
From Classical Physics to Quantum Theory
The properties of atoms are not governed by the same laws of physics as larger objects.

Quantum Mechanics: the physics of the very small
The Players

Erwin Schrödinger
Werner Heisenberg
Louis Victor De Broglie
Neils Bohr
Albert Einstein
Max Planck

James Clerk Maxwell
James Clerk Maxwell

Proposed that visible light consists of electromagnetic waves.

waves

A vibrating disturbance by which energy is transmitted.
Electromagnetic radiation

is energy propagated at the speed of light

\[ c = 3 \times 10^8 \text{ m/sec} \]

Consists of electric and magnetic fields that simultaneously oscillate in planes mutually perpendicular to each other.
Electromagnetic radiation
Properties of Waves

Frequency $\nu = 1/s = \text{Hz} \ (\text{Hertz})$

wavelength, $\lambda = \text{m}$

$v = \nu \lambda$
Frequency and wavelength are inversely proportional

\[ c = \nu \lambda \]

high frequency-short wavelength

low frequency-long wavelength
Types of electromagnetic radiation

- High frequency: gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, radio waves
- Low frequency: short wavelength, long wavelength
practice problem 1

What is the frequency of green light, which has a wavelength $4.90 \times 10^{-7}$ m?

$c = \nu \lambda$

$\frac{c}{\lambda} = \nu$
What is the frequency of green light, which has a wavelength $4.90 \times 10^{-7}$ m?

$c = \nu \lambda$

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

$c = 3 \times 10^8$ m/sec

$\frac{3 \times 10^8 \text{ m/sec}}{4.90 \times 10^{-7} \text{ m}} = \nu$

$6.12 \times 10^{14} \text{ 1/s} = \nu$
practice problem 2

An X-ray has a wavelength of $1.15 \times 10^{-10}$ m. What is its frequency?

\[
c = \nu \lambda
\]

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

\[
c = 3 \times 10^8 \text{ m/sec}
\]

\[
\frac{3 \times 10^8 \text{ m/sec}}{1.15 \times 10^{-10} \text{ m}} = \nu
\]

\[
2.61 \times 10^{18} \text{ 1/s} = \nu
\]
practice problem 3

What is the speed of an electromagnetic wave that has a frequency of $7.8 \times 10^6$ Hz?

$$c = 3 \times 10^8 \text{ m/sec}$$
A popular radio station broadcasts with a frequency of 94.7 MHz. What is the wavelength of the broadcast? (1 MHz = 10^6 Hz)

\[
94.7 \text{ MHz} \times \frac{10^6 \text{ Hz}}{1 \text{ MHz}} = 9.47 \times 10^7 \text{ Hz}
\]
A popular radio station broadcasts with a frequency of 94.7 MHz. What is the wavelength of the broadcast? (1 MHz = $10^6$ Hz)

$$c = 3 \times 10^8 \text{ m/sec}$$

$$\begin{align*}
94.7 \text{ MHz} \times \frac{10^6 \text{ Hz}}{1 \text{ MHz}} &= 9.47 \times 10^7 \text{ 1/s} \\
\frac{c}{\nu} &= \lambda
\end{align*}$$
A popular radio station broadcasts with a frequency of 94.7 MHz. What is the wavelength of the broadcast? (1 MHz = 10^6 Hz)

\[
94.7 \text{ MHz} \times \frac{10^6 \text{ Hz}}{1 \text{ MHz}} = 9.47 \times 10^7 \text{ 1/s}
\]

\[
c = 3 \times 10^8 \text{ m/sec}
\]

\[
\frac{3 \times 10^8 \text{ m/sec}}{9.47 \times 10^7 \text{ 1/s}} = \lambda
\]

\[
3.17 \text{ m} = \lambda
\]
The Players

Erwin Schrödinger
Werner Heisenberg
Louis Victor De Broglie
Neils Bohr
Albert Einstein
Max Planck
James Clerk Maxwell
hot bodies radiate electromagnetic energy

classical physics assumed that radiating energy was continuous, due to its wavelike nature.
iron bar
Red Hot
White
Hot
Blue Hot

“Classical physics”

a continuous radiating energy, due to
cwavelike nature.

“an infinite amount of energy
could be released in a radiation
process!”
Max Planck

the energy of the emitted electromagnetic radiation is proportional to frequency

\[ \Delta E = h \nu \]

where \( h = 6.626 \times 10^{-34} \text{ J s} \)

\( h \) is called Planck’s constant
Max Planck

\[ \Delta E = n \hbar \nu \]

Energy is always emitted in multiples of \( \hbar \nu \).

\( n \) is a whole number (integer)
Max Planck

energy emitted as electromagnetic radiation by an object (such as a hot iron bar) can have only certain discrete values, not a continuous range of values.
Energy of electromagnetic radiation comes in $h\nu$-sized "packets" "bundles" "discrete units"

The energy of electromagnetic radiation is quantized.
The Players

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Neils Bohr
Albert Einstein
Max Planck
James Clerk Maxwell
Another Mystery in Physics: The Photoelectric Effect

Experiments showed that electrons were ejected from the surface of certain metals exposed to light at a minimum threshold frequency.
Accounted for the photoelectric effect by treating light as though it were a stream of particles -- photons.

quantization of electromagnetic radiation

\[ h \nu = \text{kinetic energy } e^- + \text{binding energy} \]
The Photoelectric Effect

 Photon = $h\nu$

“threshold” frequency for ejection of electrons
The Photoelectric Effect

\[ KE = h\nu - BE \]
The Photoelectric Effect

Kinetic energy of electron does not depend upon intensity of light.

It depends on the frequency.
\[ E_{\text{photon}} = h\nu \]

Potassium - 2.0 eV needed to eject electron

\[ v_{\text{max}} = 6.22 \times 10^5 \text{ m/s} \]

\[ v_{\text{max}} = 2.96 \times 10^5 \text{ m/s} \]

\[ v_{\text{max}} = 3.1 \text{ eV} \]

\[ 400 \text{ nm} \]

\[ 550 \text{ nm} \]

\[ 700 \text{ nm} \]

no electrons
Mass of a Photon

\[ E = h \nu \]

\[ E = mc^2 \]

\[ mc^2 = h \nu \]

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

\[ m = \frac{h}{c \lambda} \]

Mass of a Photon is relativistic.
Depending on the experiment:

light behaves either as a wave
or as a stream of particles
practice problem 5

What is the energy of each of the following types of radiation?

a. \( 6.32 \times 10^{20} \text{ 1/s} \)

\[ \Delta E = h \nu \]

\[ h = 6.626 \times 10^{-34} \text{ J s} \]

\[ \Delta E = 6.32 \times 10^{20} \text{ 1/s} \times 6.626 \times 10^{-34} \text{ J s} \]
What is the energy of each of the following types of radiation?

a. $6.32 \times 10^{20} \text{ } \text{1/s}$

$$\Delta E = h\nu$$

$$h = 6.626 \times 10^{-34} \text{ J s}$$

$$\Delta E = 6.32 \times 10^{20} \frac{1}{\text{s}} \times 6.626 \times 10^{-34} \text{ J s}$$

$$\Delta E = 4.19 \times 10^{-13} \text{ J}$$
What is the energy of each of the following types of radiation?

b. \(9.50 \times 10^{13} \text{ Hz}\)

\[\Delta E = h\nu\]

\(h = 6.626 \times 10^{-34} \text{ J s}\)

\[\Delta E = 9.50 \times 10^{13} \frac{1}{\text{s}} \times 6.626 \times 10^{-34} \text{ J s}\]

\[\Delta E = 6.29 \times 10^{-20} \text{ J}\]
What is the energy of an ultraviolet photon having a wavelength $1.18 \times 10^{-8}$ m?

$c = \nu \lambda$

$c = 3 \times 10^8$ m/sec

\[
\frac{c}{\lambda} = \nu \quad \frac{3 \times 10^8 \text{ m/s}}{1.18 \times 10^{-8} \text{ m}} = \nu
\]

$2.54 \times 10^{16}$ 1/s $= \nu$
What is the energy of an ultraviolet photon having a wavelength 1.18 x 10^{-8} m?

\[ \Delta E = h \nu \]

\[ h = 6.626 \times 10^{-34} \text{ J s} \]

\[ \nu = 2.54 \times 10^{16} \text{ 1/s} \]

\[ \Delta E = 2.24 \times 10^{16} \frac{\text{1}}{\text{s}} \times 6.626 \times 10^{-34} \text{ J s} \]

\[ \Delta E = 1.68 \times 10^{-17} \text{ J} \]