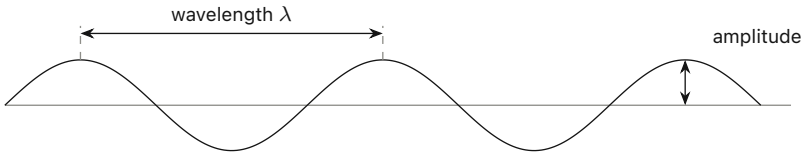
3 Electronic Structure

Helium was found on the Sun before it was found on Earth. In 1868 astronomers saw a yellow line in sunlight that matched no known element; it took another 27 years for anyone to isolate the gas here. This works because every element gives off its own set of colors, and the colors come from its electrons. Light is how you read where the electrons are, so the chapter starts there. The mock exam gives this chapter 9 of its 70 questions.

3.1 Light and the Electromagnetic Spectrum

Light is a wave. The **wavelength**, λ, is the distance from one crest to the next. The **frequency**, ν, is the number of crests that pass a point each second.

Frequency
Crests passing a point each second. One hertz is one cycle per second: $\mathrm{Hz} = \mathrm{s}^{-1}$.



All light travels at the same speed in a vacuum, $c = 2.998 \times 10^{8}\ \mathrm{m/s}$. That ties wavelength to frequency:

$$c = \lambda\nu$$

Wavelengths are usually given in nanometers. Convert to meters first, because c is in meters per second: $1\ \mathrm{nm} = 10^{-9}\ \mathrm{m}$.

EXAMPLE 3.1

A radio station broadcasts at a frequency of $98.1\ \mathrm{MHz}$. What is the wavelength of the waves, in meters?

What is asked Wavelength in meters, from frequency.

Frequency in Hz $\nu = 98.1\ \mathrm{MHz} = 9.81 \times 10^{7}\ \mathrm{s}^{-1}$

Wavelength
$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \mathrm{m/s}}{9.81 \times 10^{7}\ \mathrm{s}^{-1}} = 3.06\ \mathrm{m}$$

Check Radio waves are meters long, and a higher frequency would give a shorter wavelength.

Answer $3.06\ \mathrm{m}$

Light also acts as a stream of particles called **photons**. One photon of frequency ν carries the energy

$$E = h\nu = \frac{hc}{\lambda}$$

Photon
One packet of light. Light is absorbed and emitted only in whole photons.

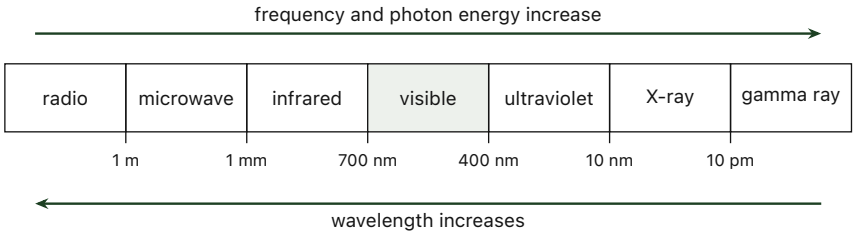
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where Planck's constant is $h = 6.626 \times 10^{-34}\,\mathrm{J\,s}$.

RULE A shorter wavelength means a higher frequency and a higher photon energy.

The **electromagnetic spectrum** lists the types of light from longest wavelength to shortest. Visible light runs from about $700\,\mathrm{nm}$ (red) to $400\,\mathrm{nm}$ (violet).

Spectrum
Every kind of light, ordered by wavelength. The boundaries are approximate.



The photoelectric effect

Light shining on a metal can knock electrons out of it. One photon gives all of its energy to one electron.

- Below a **threshold frequency**, no electrons leave, however bright the light.
- Above the threshold, brighter light of the same frequency ejects more electrons. The fastest electrons all have the same maximum kinetic energy.
- Higher frequency gives the fastest electrons more kinetic energy: $E_{k,\max} = h\nu - \Phi$.

Work function
The minimum energy needed to free one electron from a metal. Symbol Φ.

Brightness sets how many photons arrive. Frequency sets the energy of each one. Only the energy of a single photon decides whether an electron can escape.

EXAMPLE 3.2

Light of wavelength $250\,\mathrm{nm}$ strikes a metal with a work function of $3.85 \times 10^{-19}\,\mathrm{J}$. What is the maximum kinetic energy of an ejected electron?

What is asked The largest kinetic energy an electron can have, in joules.

Photon energy
$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\,\mathrm{J\,s})(2.998 \times 10^{8}\,\mathrm{m/s})}{2.50 \times 10^{-7}\,\mathrm{m}} = 7.95 \times 10^{-19}\,\mathrm{J}$$

Subtract Φ
$$E_{k,\max} = h\nu - \Phi = 7.95 \times 10^{-19}\,\mathrm{J} - 3.85 \times 10^{-19}\,\mathrm{J} = 4.10 \times 10^{-19}\,\mathrm{J}$$

Check The photon energy is larger than Φ, so electrons are ejected.

Answer $4.10 \times 10^{-19}\,\mathrm{J}$

Energy per mole of photons

$E = hc/\lambda$ gives joules for one photon. Multiply by Avogadro's number for one mole of photons, then divide by 1000 to report kilojoules.

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EXAMPLE 3.3

Yellow light has a wavelength of $589\,\text{nm}$. What is the energy of one mole of these photons, in kJ/mol?

What is asked	Energy per mole of photons, in kilojoules.
Wavelength in m	$\lambda = 589\,\text{nm} = 5.89 \times 10^{-7}\,\text{m}$
One photon	$E = \dfrac{hc}{\lambda} = \dfrac{(6.626 \times 10^{-34}\,\text{J s})(2.998 \times 10^{8}\,\text{m/s})}{5.89 \times 10^{-7}\,\text{m}} = 3.373 \times 10^{-19}\,\text{J}$
One mole	$(3.373 \times 10^{-19}\,\text{J})(6.022 \times 10^{23}\,\text{mol}^{-1}) = 2.031 \times 10^{5}\,\text{J/mol}$
To kJ	$2.031 \times 10^{5}\,\text{J/mol} \div 1000 = 203\,\text{kJ/mol}$
Check	Visible photons carry about 10^{-19} J, which is roughly 100 to $300\,\text{kJ/mol}$.
Answer	$203\,\text{kJ/mol}$

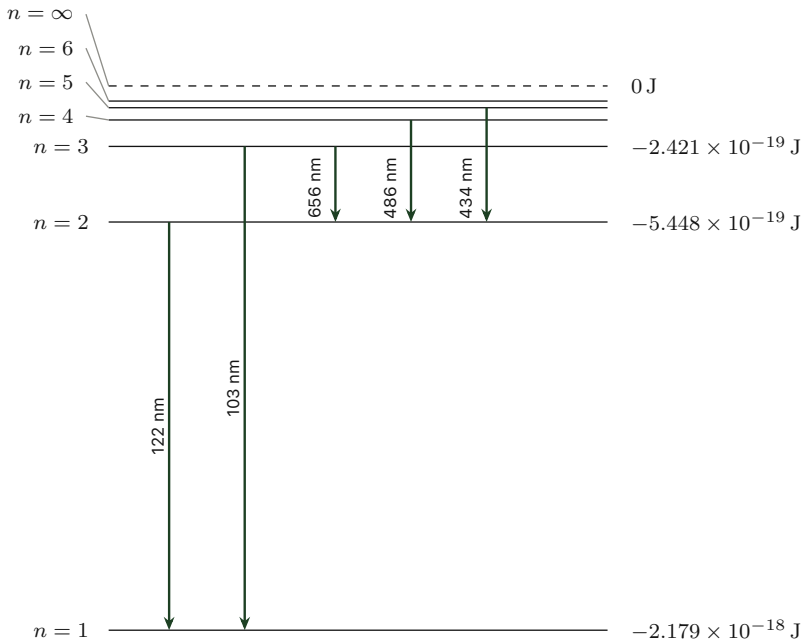
3.2 The Bohr Model of Hydrogen

A hydrogen atom emits light only at a few specific wavelengths. Bohr explained this by treating the electron's energy as **quantized**. The electron occupies a level labeled $n = 1, 2, 3, \ldots$ with energy

$$E_n = -\frac{2.179 \times 10^{-18}\,\text{J}}{n^2}$$

The energy is negative because the electron is bound to the nucleus. The level $n = 1$ is the ground state, the lowest energy the electron can have. Energy rises toward zero as n grows, and $n = \infty$ is the free electron at $E = 0$.

Quantized
Restricted to certain values. An electron in an atom cannot have just any energy.



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PRACTICE SET 3A 12 questions · 18 minutes · light and the hydrogen atom

1. Which list shows radiation in order of increasing photon energy?

(A) ultraviolet, visible, infrared, microwave
(B) microwave, infrared, visible, ultraviolet
(C) radio, visible, infrared, X-ray
(D) infrared, microwave, ultraviolet, visible

2. What is the frequency of light with a wavelength of $532\,\text{nm}$?

(A) $1.77 \times 10^{-15}\,\text{s}^{-1}$
(B) $5.64 \times 10^{5}\,\text{s}^{-1}$
(C) $5.64 \times 10^{8}\,\text{s}^{-1}$
(D) $5.64 \times 10^{14}\,\text{s}^{-1}$

3. Violet light of $400\,\text{nm}$ ejects electrons from a metal. Red light of $700\,\text{nm}$ ejects none. What happens if the red light is made much brighter?

(A) Electrons are ejected, with less kinetic energy than from violet light.
(B) No electrons are ejected, because each red photon is below the threshold energy.
(C) Electrons are ejected, because more photons add up to enough energy.
(D) No electrons are ejected, because red light has a higher frequency.

4. What is the energy of one photon of light with a wavelength of $450\,\text{nm}$?

(A) $4.41 \times 10^{-19}\,\text{J}$ **(B)** $4.41 \times 10^{-28}\,\text{J}$
(C) $8.94 \times 10^{-23}\,\text{J}$ **(D)** $9.95 \times 10^{-49}\,\text{J}$

5. Light X has a wavelength of $400\,\text{nm}$. Light Y has a wavelength of $650\,\text{nm}$. Which statement is correct?

(A) X has a lower frequency and a lower photon energy.
(B) X has a higher frequency and a lower photon energy.
(C) X has a higher frequency and a higher photon energy.
(D) X and Y have the same frequency, since both travel at c.

6. What is the energy of one mole of photons of $633\,\text{nm}$ light?

(A) $189\,\text{kJ/mol}$
(B) $1.89 \times 10^{5}\,\text{kJ/mol}$
(C) $3.14 \times 10^{-22}\,\text{kJ/mol}$
(D) $1.89 \times 10^{8}\,\text{kJ/mol}$

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