CHEM1011 LECTURE 7

Dr Shannan Maisey

PROPERTIES OF GASES

EFFUSION AND DIFFUSION

Concepts which concern the movement of gases

Allow us to answer questions such as:

There’s a pinhole in my spaceship – which gas will escape quickest?

There is a ‘gas leak’ across the other side of the room - how long before I can smell it?

RATE OF GAS MOVEMENT (BLACKMAN 6.3)

All gases, under the same conditions have the same amount of kinetic energy therefore:
The average speed of gas molecules is related to the temperature and molar mass of the gas.

Gas constant

Temperature

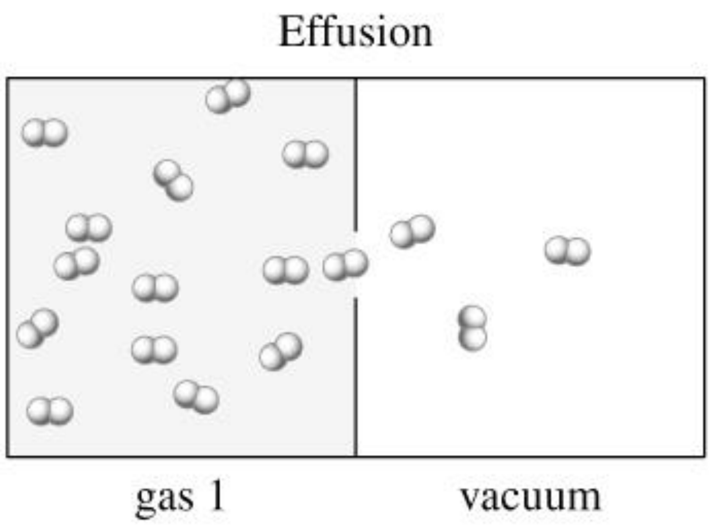
$$\boxed{v = \sqrt{\frac{3RT}{M}}}$$

Speed of molecule of gas

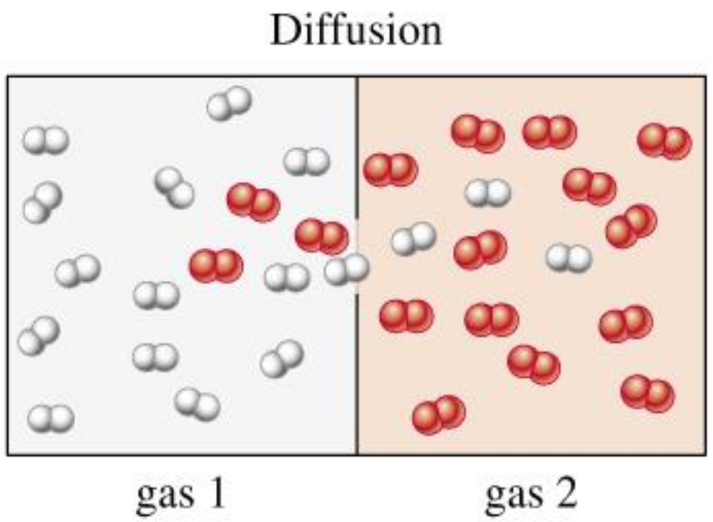
Molar mass of the gas in question

DIFFUSION AND EFFUSION

Effusion: the flow of molecules through an opening without collision by the molecules (escaping from a container into vacuum)

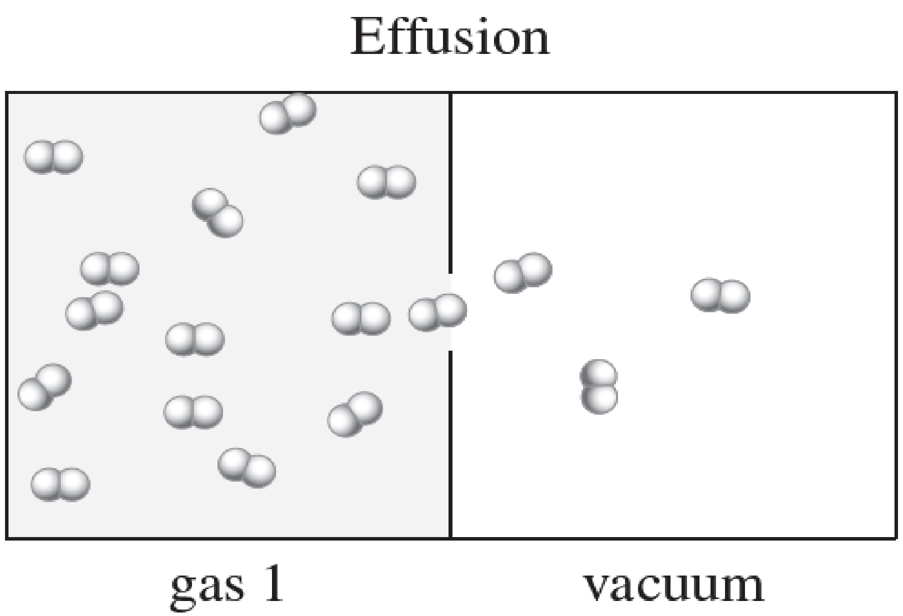


Diffusion: a mixing of gases until they are homogeneous (evenly mixed)



EFFUSION AND DIFFUSION

Effusion: process by which a gas escapes from its container through a tiny hole into an *evacuated* space;



$$\text{Rate of effusion}\ \mu\ \frac{1}{\sqrt{M_{\mathrm{r}}}}$$

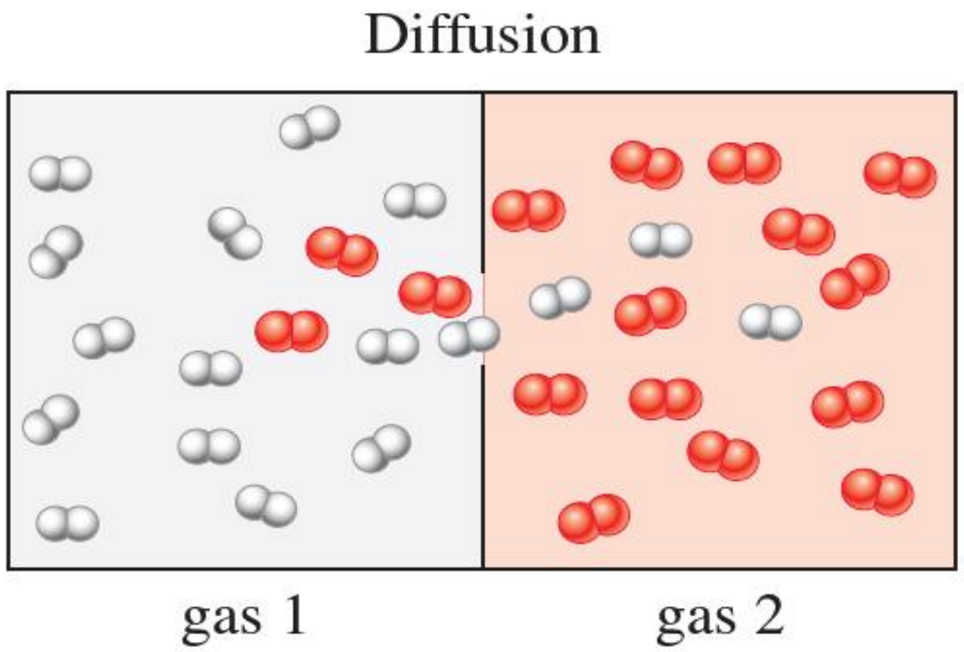
Graham's law of effusion: *the rate of effusion of a gas is inversely proportional to the square root of its molar mass*: Higher the molar mass the slower the gas will effuse

RATES OF DIFFUSION

Diffusion is the movement of one gas through another;

Graham's law is used to describe diffusion rates:

$$\text{Rate of diffusion} \propto \frac{1}{\sqrt{M_r}}$$



eg., for equal pressures of NH_3 and HCl through another gas or air:

$$\frac{\text{Rate}_{NH_3}}{\text{Rate}_{HCl}} = \frac{\sqrt{M_r(\text{HCl})}}{\sqrt{M_r(\text{NH}_3)}}$$

GRAHAM'S LAW

Mathematically: $\frac{\text{rate}_1}{\text{rate}_2} = \frac{\sqrt{r_2}}{\sqrt{r_1}}$ but $\rho = \frac{\text{PM}}{\text{RT}}$

So one can use: $$\boxed{\frac{\text{rate}_1}{\text{rate}_2} = \frac{\sqrt{\text{M}_2}}{\sqrt{\text{M}_1}}}$$

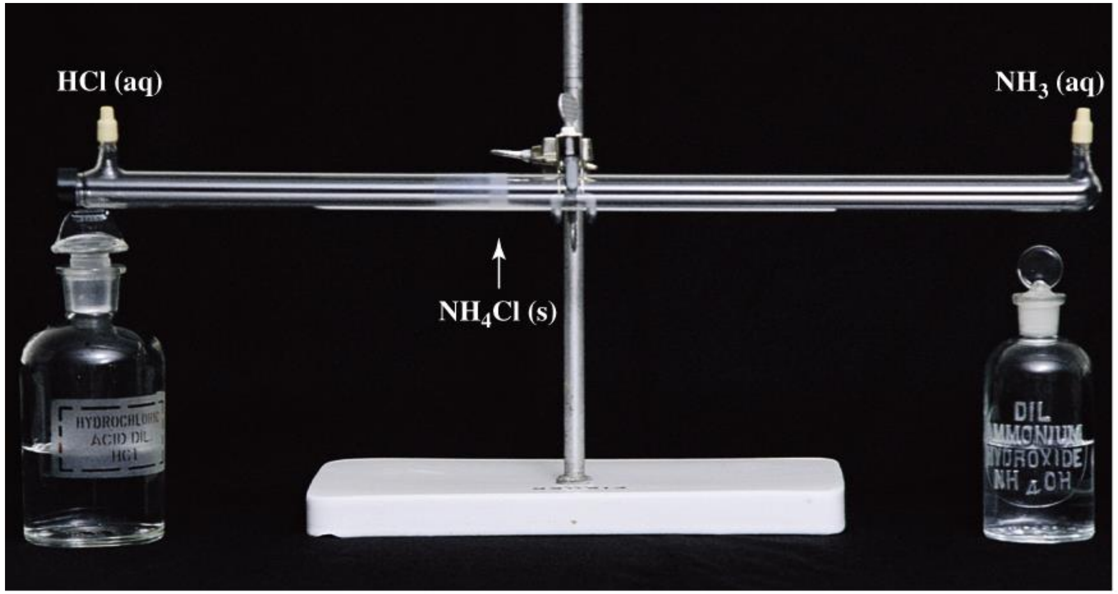
When the amount of each of gas is equal $$\boxed{\frac{\text{time}_1}{\text{time}_2} = \frac{\sqrt{\text{M}_1}}{\sqrt{\text{M}_2}}}$$

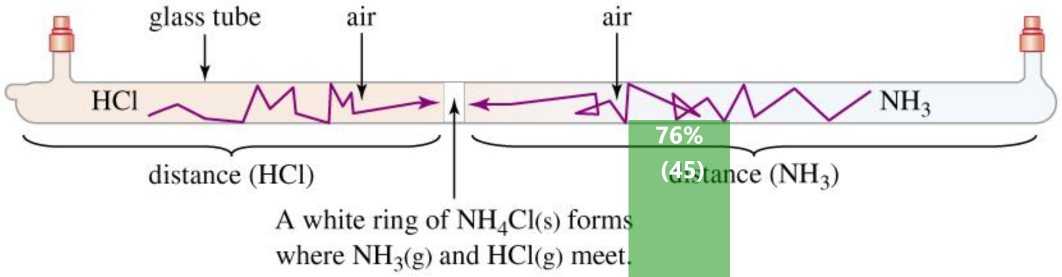
Thomas Graham
(20 December 1805[1] – 16 September 1869) was a British chemist who is best-remembered today for his pioneering work in dialysis and the diffusion of gases. He is regarded as the father of colloid chemistry.[2]

GRAHAM'S LAW

Concentrated vapours of HCl and NH_3 diffuse through the air in the glass tube. When they meet they react, forming NH_4Cl, a white solid.

$$\frac{rate_1}{rate_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$





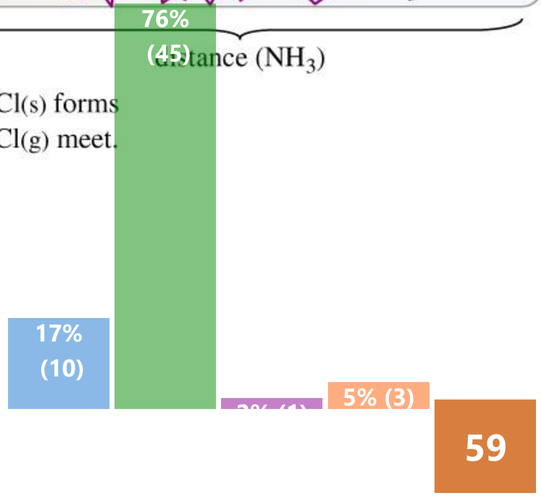
Which gas diffuses more rapidly? Why?

A HCl

B NH_3

C Air

D Don't know



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Example:

If it takes 1.25 minutes for 0.010 mol He to effuse, how long will it take the same amount of ethane (C_2H_6) to effuse?

$$\boxed{\frac{\text{time}_1}{\text{time}_2} = \frac{\sqrt{M_1}}{\sqrt{M_2}}}$$

Example:

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$$\frac{\text{time}_1}{\text{time}_2} = \frac{\sqrt{M_1}}{\sqrt{M_2}}$$

Lets make ethane gas 1 (because it makes rearranging the formula easier)

M_{He} = 4.002 g/mol
M_{ethane} = 30.07g/mol

$\text{time1} = \frac{\sqrt{M_1}}{\sqrt{M_2}} \times \text{time 2} = (5.48/2) \times 1.25 =$ <u>3.43 minutes</u>

ATOMIC STRUCTURE

LEARNING OUTCOMES – WEEK 4

- ❑Calculate wavelength from frequency and *vice versa* for electromagnetic radiation.
- ❑Use the Rydberg equation to calculate the wavelengths emitted or absorbed by a H atom.
- ❑Calculate photon energy for EM radiation from its frequency.
- ❑List the allowed values of the quantum numbers for orbitals in hydrogen–like atoms.
- ❑Sketch the shapes of *s*, *p*, and *d* orbitals.

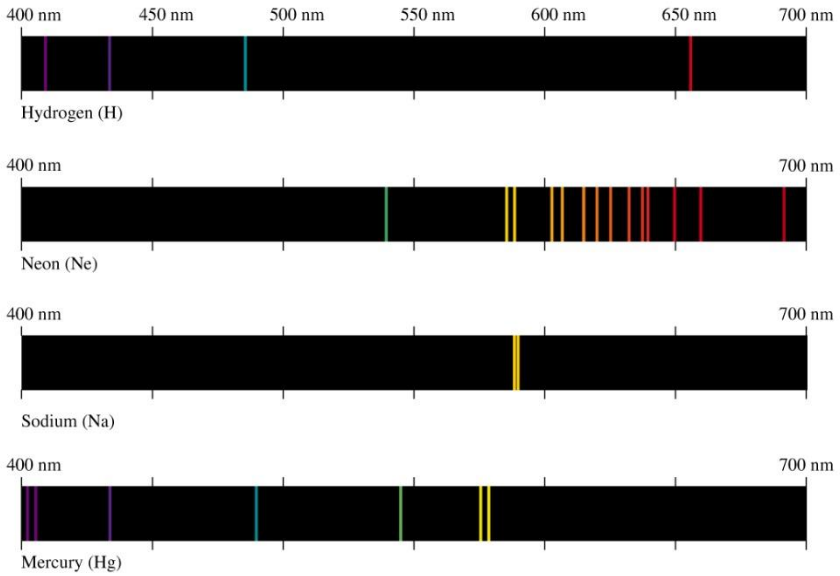
Note for tutorials : We will not cover the material from set 2 qu.8 onwards this week. You can cover these questions at the beginning of your tutorial in week 5. Your tutor knows this.

EXTRA RESOURCES

Check out Khan Academy:
https://www.khanacademy.org/science/chemistry/electronic-structure-of-atoms

INTRODUCTION

- We will discuss the properties of atoms, light and the interactions between them.
- Light interacts with electrons in atoms — and has been an important tool to probe atomic properties.
- From such study has come the theory of quantum mechanics, which explains the electronic structure of atoms, orbital energy levels and patterns of chemical behaviour in the periodic table.
- Electrons on the surface of an atom determine its chemical properties (isotopes of an element have nearly identical chemical properties).

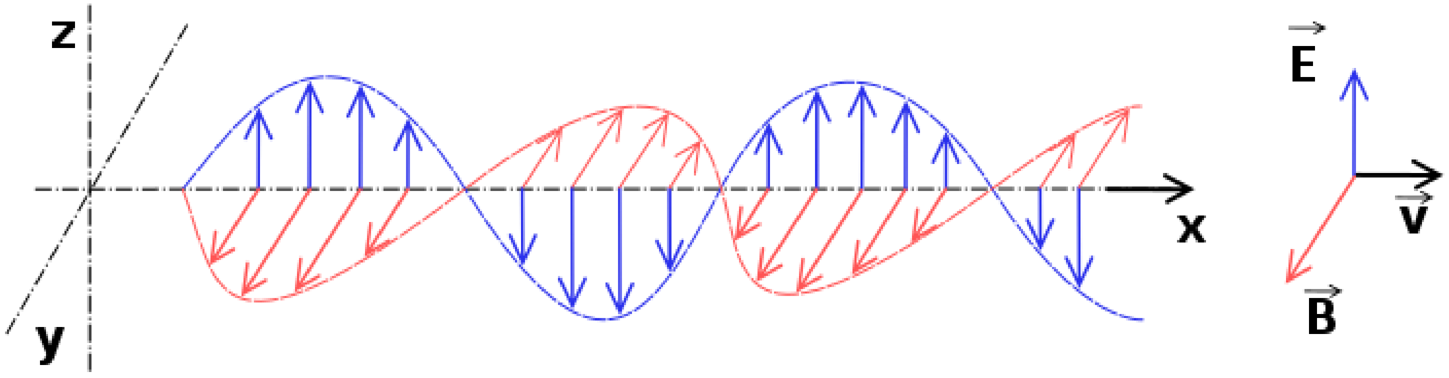


ELECTROMAGNETIC RADIATION (EMR)

EMR is used to **study structure** – how it **interacts** with atoms tells us a lot about the properties of the atoms.

What is EMR?

- Electric and magnetic fields at right angles to each other, propagating through space-time

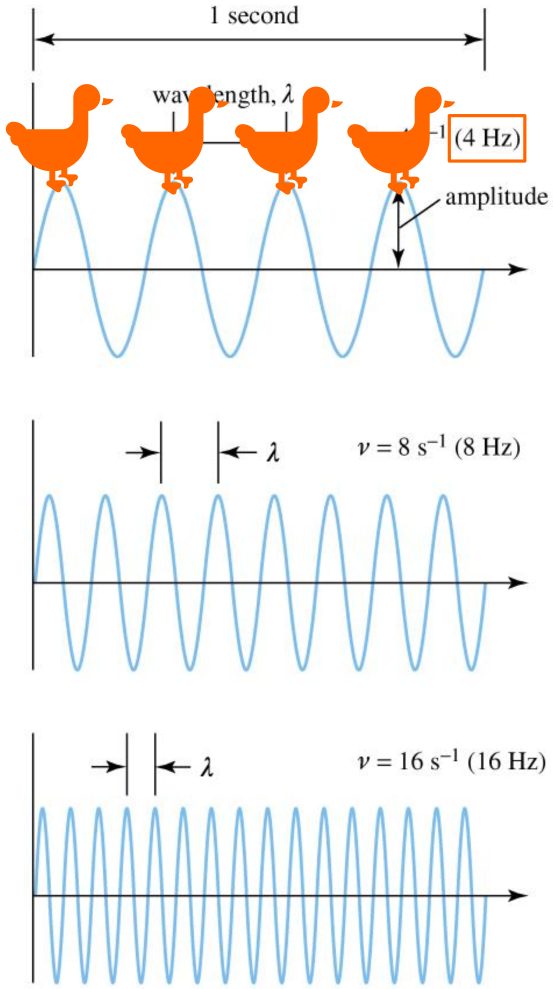


PROPERTIES OF LIGHT

- Wave-like:
  - Regular oscillation e.g. *position of duck on surface*
  - Light waves vary with *time* (snapshot)

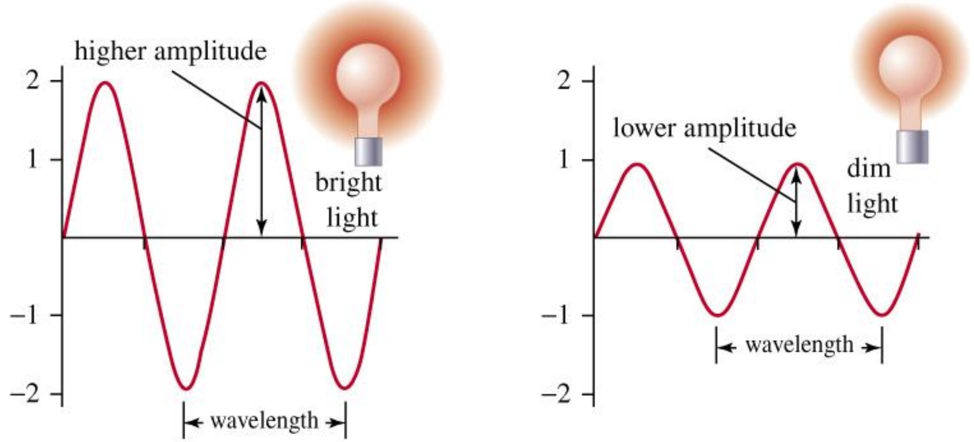
Frequency ν is the number of wave crests (or troughs) per second. The **wavelength** λ is the distance between successive wave crests (or troughs).

- The duck will bob at the top of the wave 4 times in 1 second, so the frequency is $= 4\ s^{-1}$ (or Hz).
- The wavelength of the wave decreases as the frequency increases (figures from top to bottom) i.e. frequency and wavelength are *inversely proportional*.

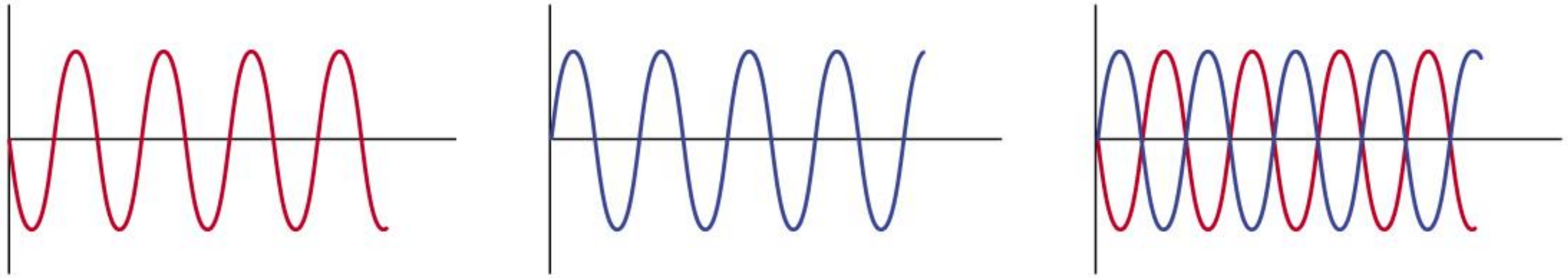


PROPERTIES OF LIGHT

Amplitude determines intensity:



Phase refers to the starting position of the wave:

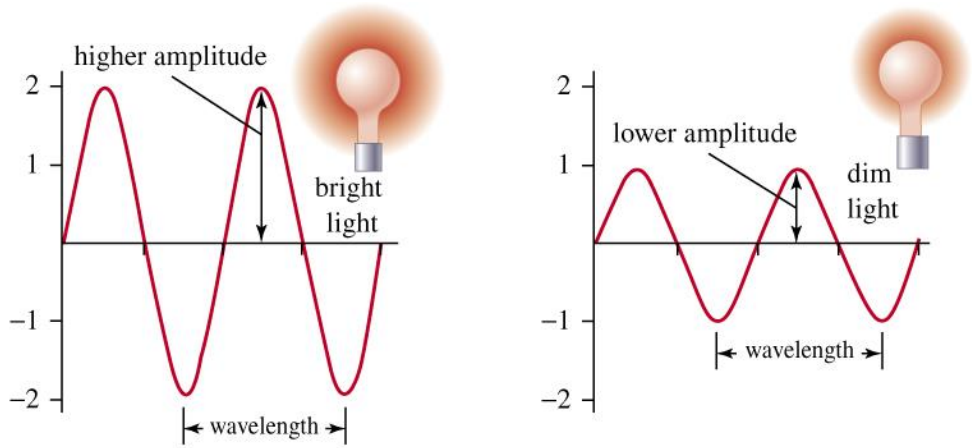


(a) (b) (c)

When waves have the same phase (and amplitude and wavelength) they will look exactly the same when superimposed (layered over each other). Since (b) is exactly the opposite phase of (a) the result would be (c).

PROPERTIES OF LIGHT

Amplitude determines intensity:



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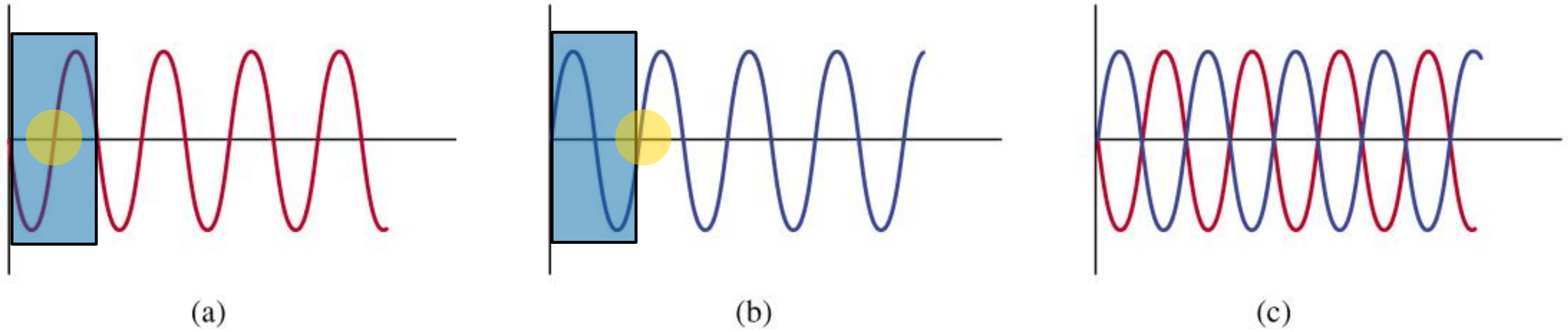


In the shaded region there is exactly 1 wavelength. The yellow spot highlights the same position of the wave – in (a) it is at ½ λ, however in (b) it is at 1 λ. These two waves are out of phase by half a wavelength.

THE SPEED OF LIGHT

Light waves, and all other types of EMR, always move through a vacuum at the same speed.

In a vacuum c = **2.998 x 10^{8} m s^{-1}**

$$\lambda v = c$$

Wavelength (distance) × Frequency (time) = Speed of light (velocity)

m × s^{-1} = m s^{-1}

$$\lambda\nu = c$$

WORKED EXAMPLE

An FM radio station transmits its signal at 88.1 MHz. What is the wavelength of the signal?

c = 2.998 x 10^8 m s^{-1}

ν = 88.1 MHz (= 88.1 x 10^6 Hz)

Rearrange for wavelength: $\lambda = \frac{c}{\nu}$

$$\lambda = \frac{2.998 \times 10^8\ m\ s^{-1}}{88.1 \times 10^6\ Hz} = 3.40\ m$$

Radio waves are in the order of m so this checks out!

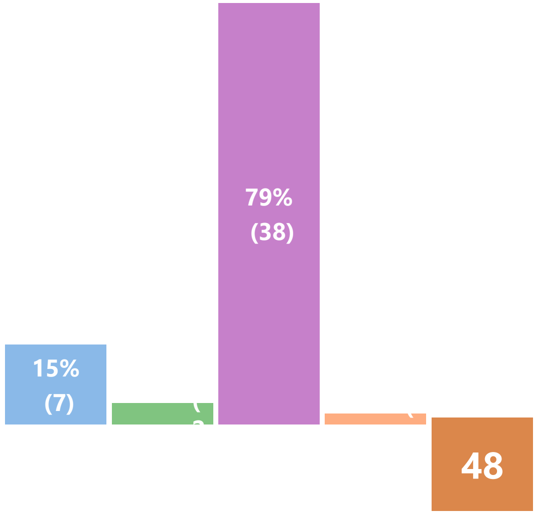
THINK CRITICALLY!

What is the frequency of X-rays that have a wavelength of 5 nm?

Assume the x-rays are in a vacuum, so use c = 2.998 x 10^{8} ms^{-1}

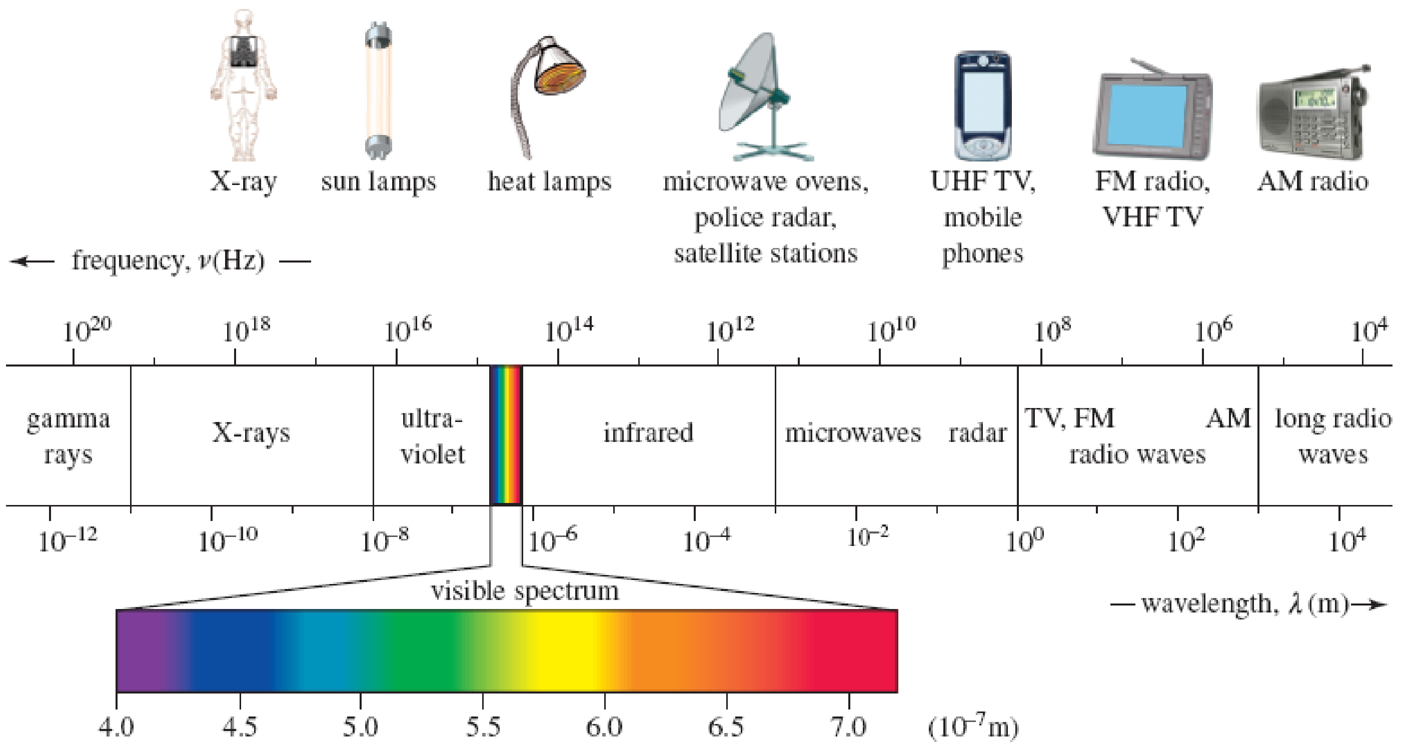
- **A** 17 aHz (10^{-18})
- **B** 1.5 Hz
- **C** 60 PHz (10^{15})
- **D** Don't know

Wilhelm Rontgen took this radiograph of his wife's left hand on December 22, 1895, shortly after his discovery of X-rays



CHARACTERISTICS OF LIGHT

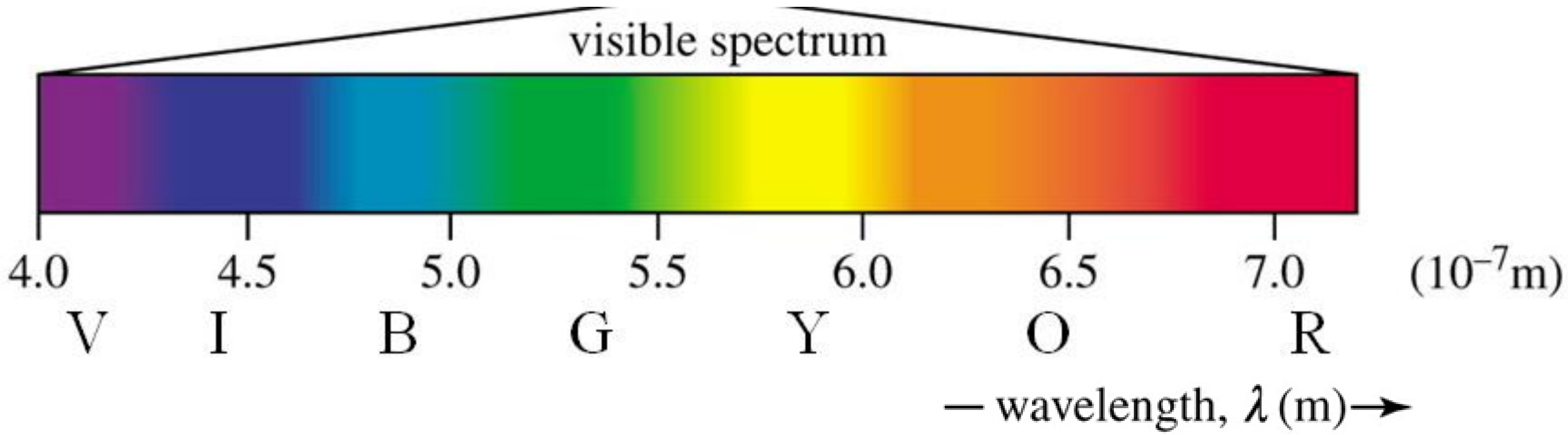
The electromagnetic spectrum



What we perceive as white light actually consists of a range of wavelengths (400-800 nm).

VISIBLE LIGHT

Only a small part of the electromagnetic spectrum



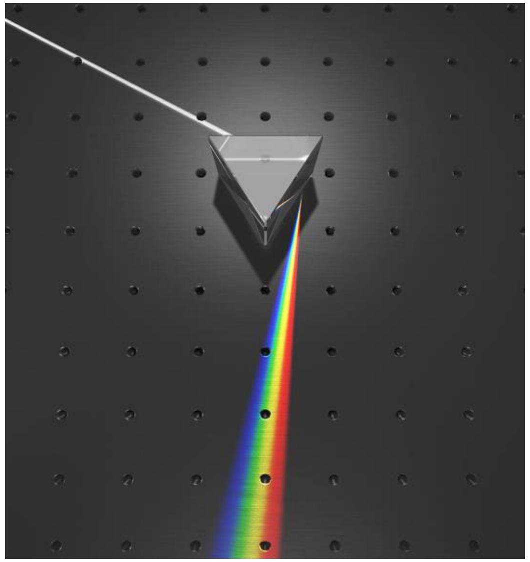
Visible spectrum mnemonic = "ROYGBIV" - Red, Orange, Yellow, Green, Blue, Indigo, Violet

Monochromatic e.m. radiation/light: a selection of one frequency of e.m. radiation – can be used for various scientific measurements etc

Polychromatic e.m. radiation/light: consists of many frequencies - such as the light we receive from the sun.

WAVE LIKE PROPERTIES OF LIGHT - REFRACTION

Its path bends when passed at an angle through an interface between different phases of matter.



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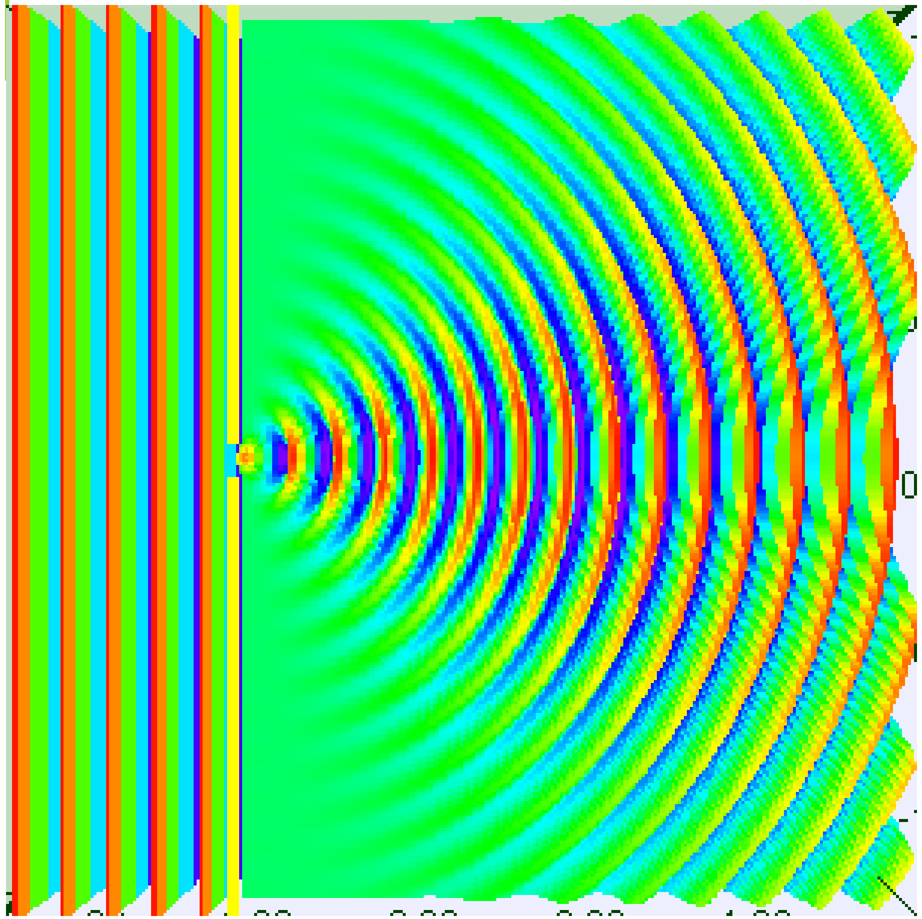
WAVE LIKE PROPERTIES OF LIGHT -DIFFRACTION



Upon passage through a slit, it expands into radiating circular wave fronts.

Spectrum of fluorescent lamp by diffraction in a CD (Photo: Tim Jones)

Numerical approximation of diffraction pattern from a slit of width equal to wavelength of an incident plane wave in 3D spectrum visualization.

WAVE LIKE PROPERTIES OF LIGHT - INTERFERENCE

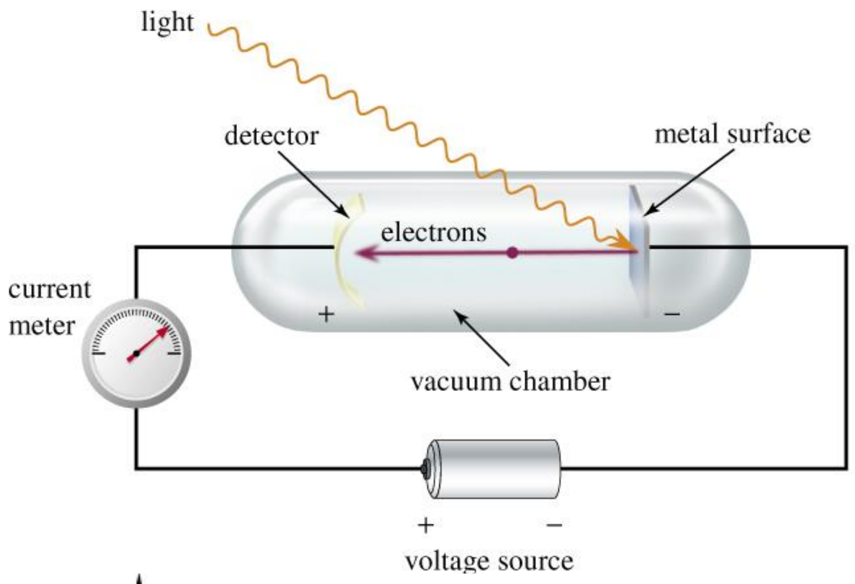
Two light waves can combine constructively or destructively, depending upon how their peaks and troughs coincide.

Interference of left traveling (green) and right traveling (blue) waves in one dimension, resulting in final (red) wave

THIS IS WHERE THINGS GET WEIRD...

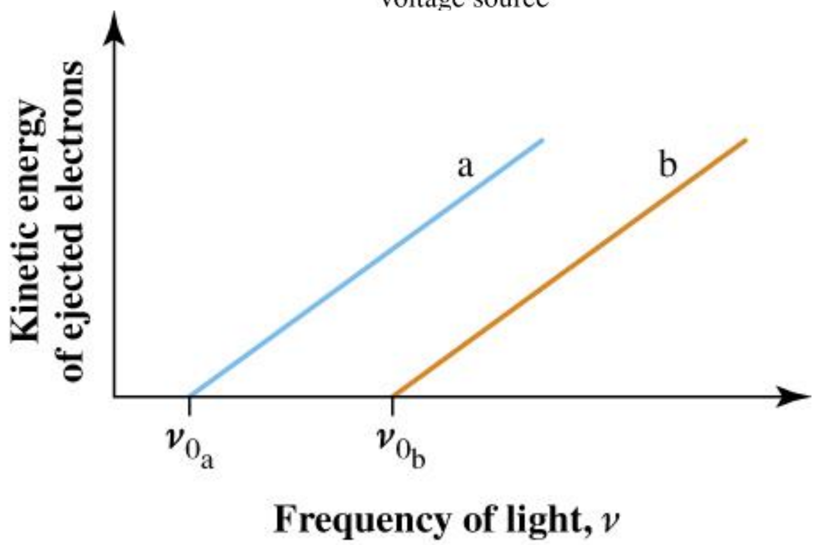
PHOTOELECTRIC EFFECT

Heinrich Hertz in 1887: shining light (of a high enough frequency) onto the surface of a metal would eject electrons.



Further experiments showed:

1. Current would flow if the light had a **frequency above a certain threshold value**, ν_{0a} and ν_{0b}, that was characteristic of the metal used (a or b)
2. No current would flow using light below the threshold frequency - *no matter how intense it was*
3. The current measured when the frequency used was **greater than the threshold frequency** **depended upon the intensity** of the light.
4. The **energy of the electrons** ejected from the metal depended upon the **frequency** of the light.



Threshold frequency indicates a certain amount of energy is required to remove an electron from an atom of the metal(s).

LIGHT BEHAVES AS A PARTICLE?

e.m. radiation also shows properties that cannot be explained by wave theory

Wave theory implied it should be possible to provide enough energy to eject electrons (at any light frequency) by making the light intense enough (with a big enough wave amplitude).

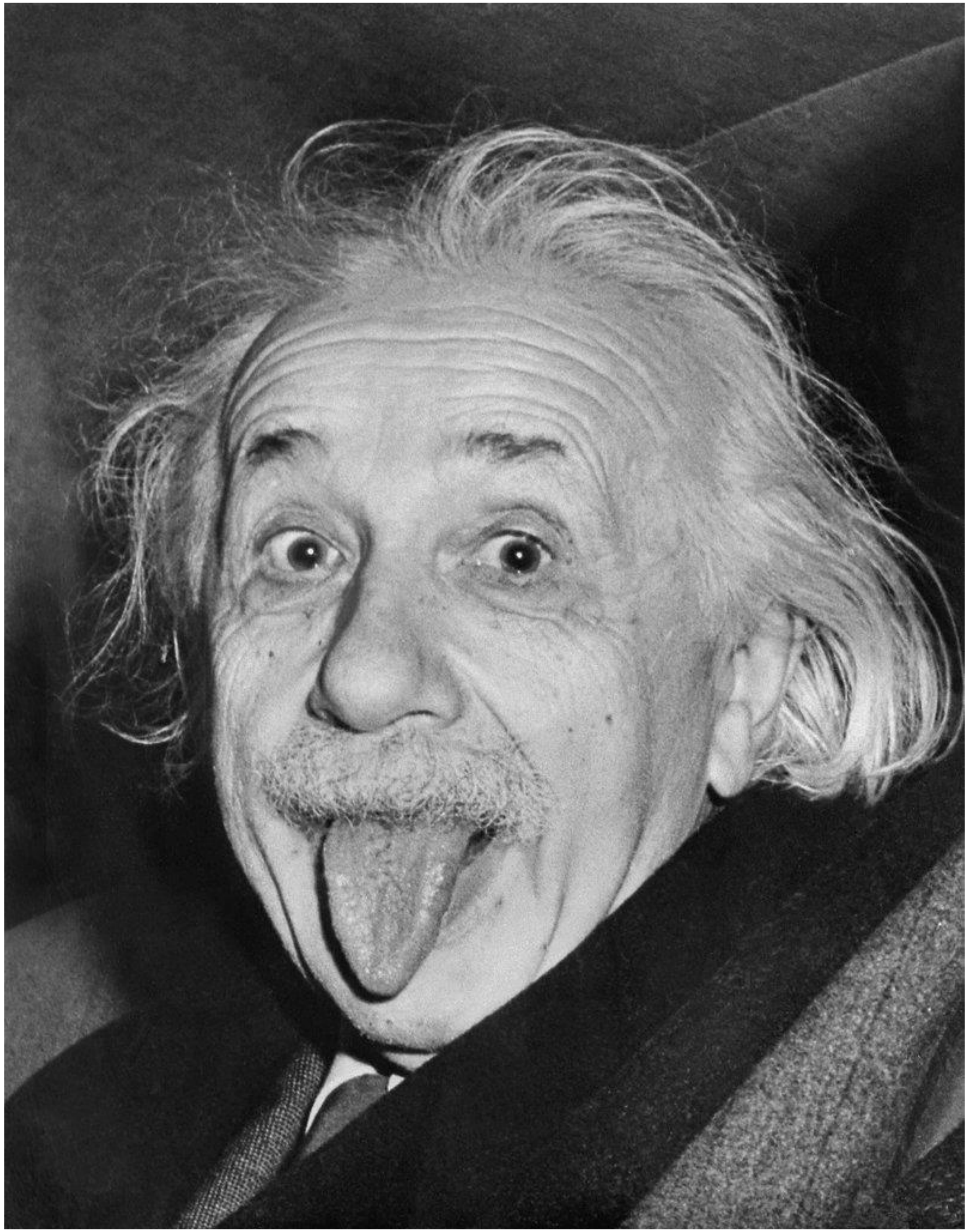
…NOT OBSERVED

Instead, Einstein (1905) proposed light consisted of packets of energy (**photons**), which is dictated by the frequency of the light.

EXPLAINS OBSERVATIONS (Nobel prize 1921).

HUGE! :Light can behave not only as waves, but also as particles. This is known as:

wave-particle duality



LIGHT BEHAVES AS A PARTICLE?

$$E = h\nu$$

The energy of photons are directly proportional to their frequency:

Where:

E = energy (J)

ν = frequency (s^{-1} = Hz)

h = Planck's constant = 6.626 x 10^{-34} J s

[Wikipedia] From left to right: W. Nernst, A. Einstein, M. Planck, R.A. Millikan and von Laue at a dinner given by von Laue in Berlin on 11 November 1931

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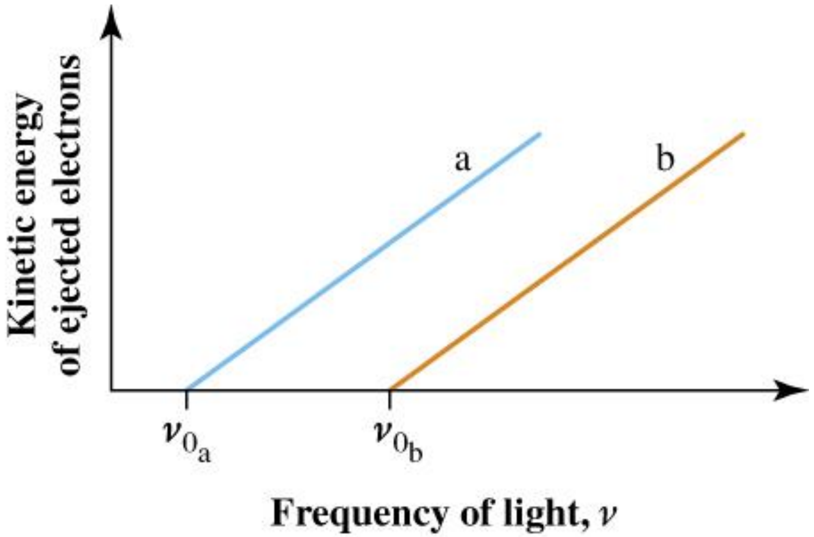
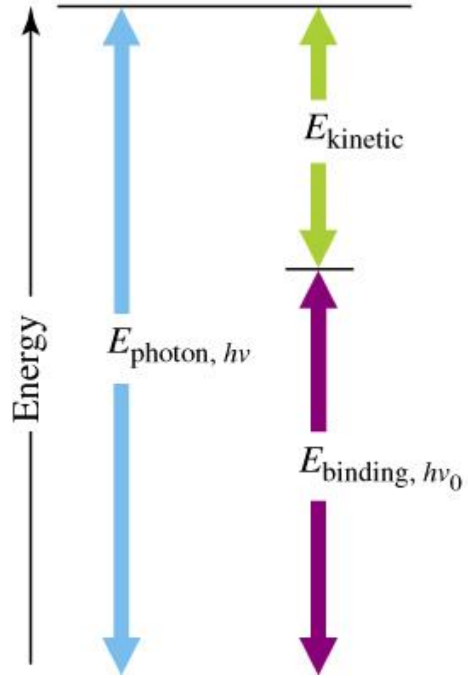




Therefore only photons with enough energy can allow electrons to break free from the attraction of the metal nuclei. *(Threshold frequency)*

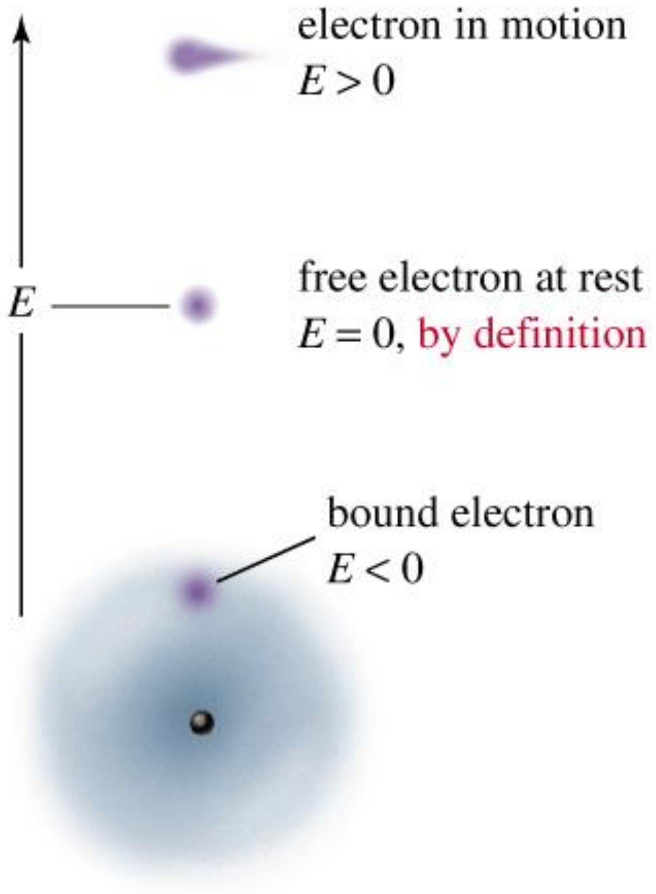
Any excess energy from the photon (greater than the binding energy) is converted to kinetic energy once the electron is ejected.

LIGHT BEHAVES AS A PARTICLE?

$$E = h\nu$$

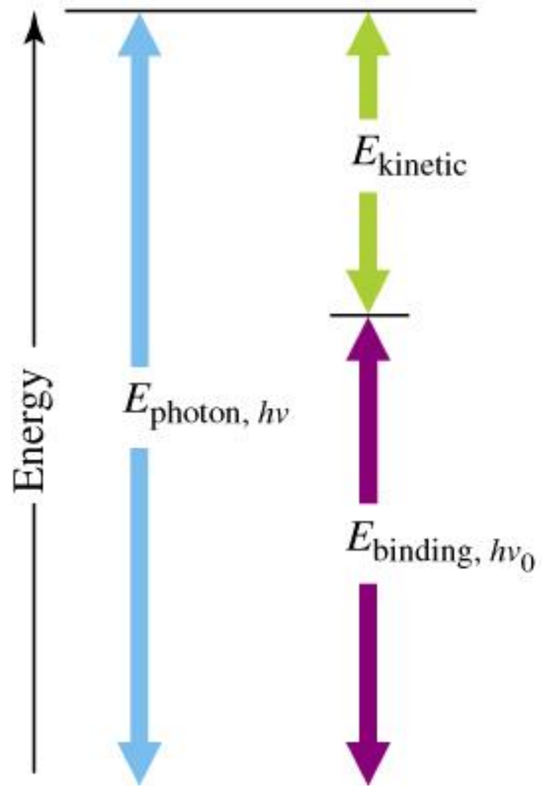
Positive energy

Once free, any electron that is moving has positive kinetic energy



Negative energy when bound

Because energy is required to free a bound electron



WORKED EXAMPLE

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

What is the energy of red light that has a wavelength of 655 nm?

1. Convert red wavelength to frequency using c = νλ

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\, ms^{-1}}{655 \times 10^{-9}\, m} = 4.58 \times 10^{14}\, s^{-1}$$

2. Determine energy using E = hν

$$E = h\nu = (6.626 \times 10^{-34} J\, s) \times (4.58 \times 10^{14}\, s^{-1})$$
$$= 3.03 \times 10^{-19}\, J$$

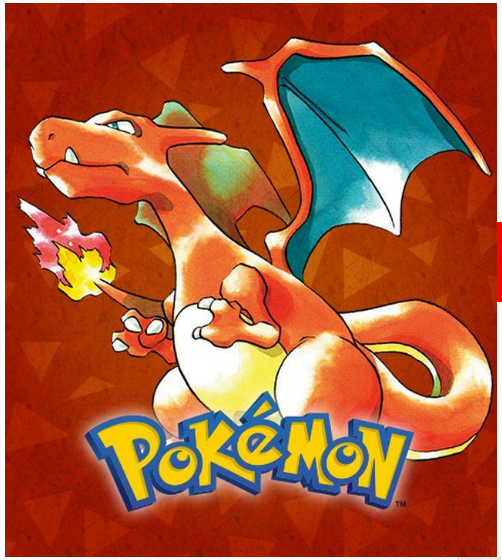
THINK CRITICALLY!

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

Does red light or blue light have more energy? Use the following wavelengths:

Red = 700 nm

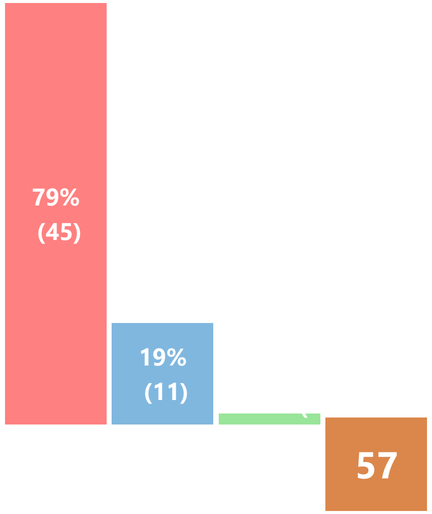
Blue = 470 nm



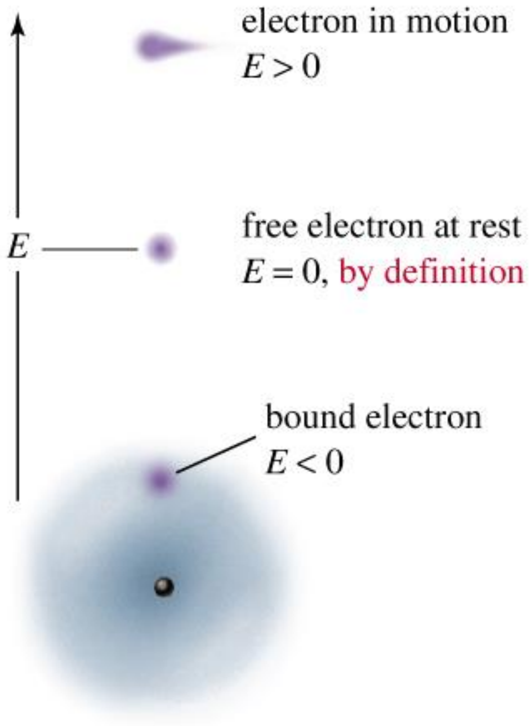
RED

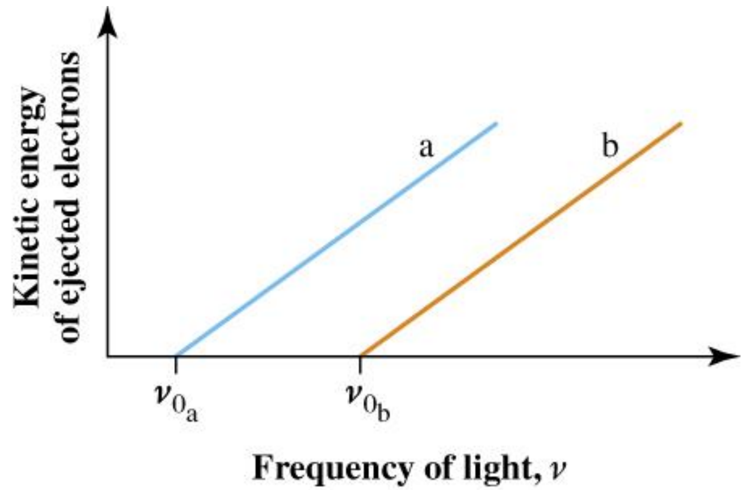
BLUE

DON'T KNOW



ELECTRON ENERGIES





Free, moving electrons have kinetic energy. The energies these electrons can have are continuous, as seen from the photoelectric effect experiment.

Classical mechanics

What about the energies of electrons that are bound in atoms?

Why was a 'threshold' frequency required in the photoelectric experiment?

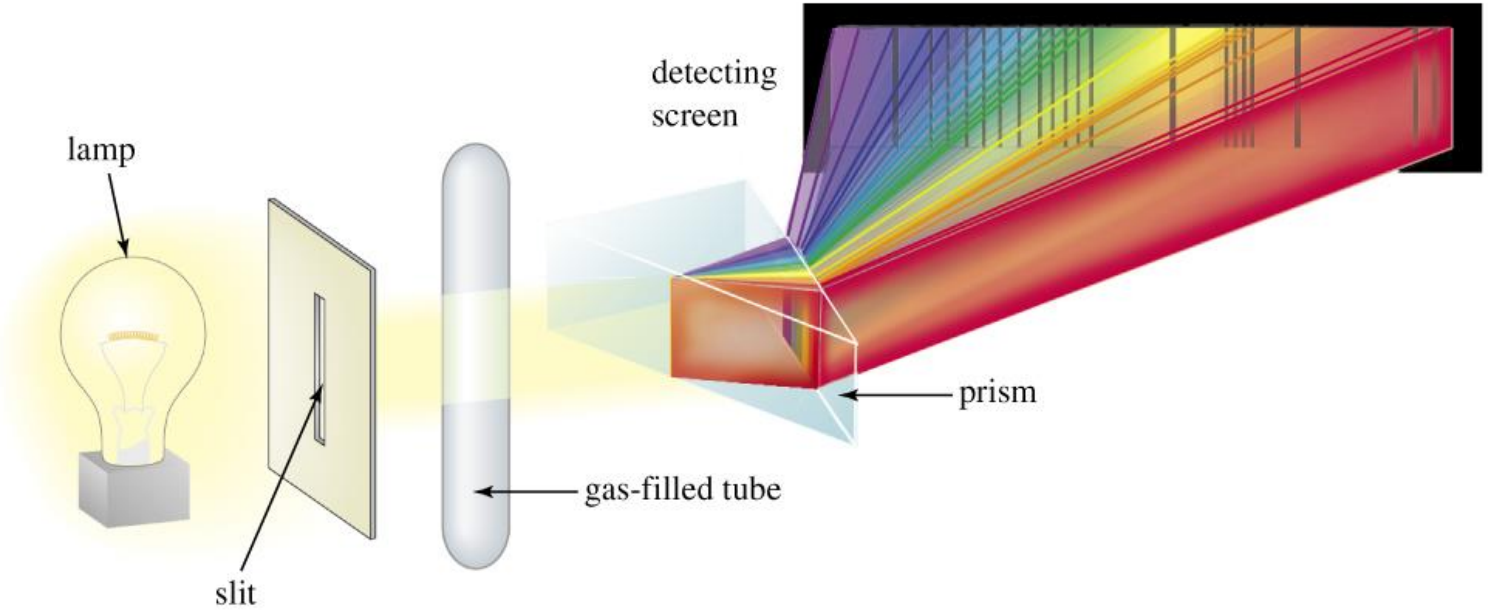
Quantum mechanics

INTERACTION OF LIGHT AND MATTER

White (polychromatic) light passing through a gas composed of single atoms of one element (e.g. H) will show a spectrum with a range of wavelengths, like below.

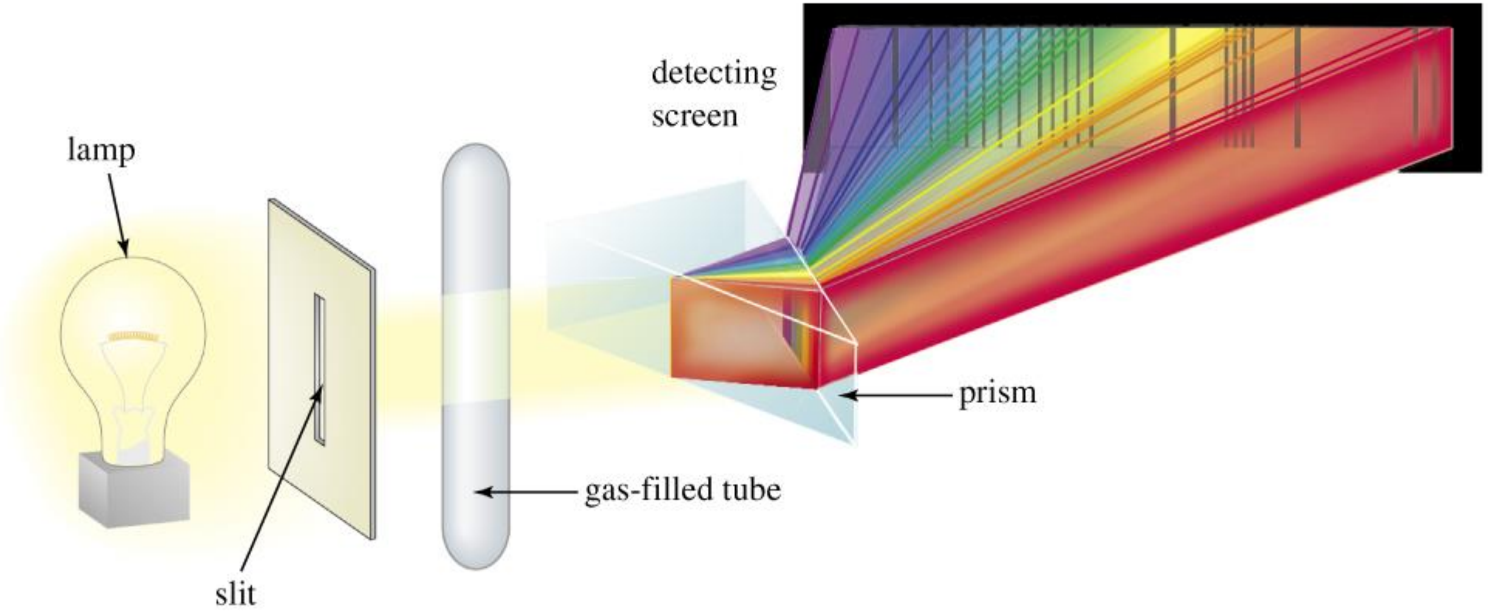
Why are there thin black lines in the spectrum?

What do the lines correspond to?



INTERACTION OF LIGHT AND MATTER

White light has photons with a range of wavelengths (polychromatic). When they pass through the gaseous atoms some of the photons' energies (i.e. specific frequencies) *exactly match* the difference between energy levels of an atom. These photons are consequently **absorbed,** leading to no light of that frequency/wavelength showing on the detector (i.e. the black lines).



QUANTISATION

This pattern is known as an absorption spectrum; **light of specific frequencies has been absorbed by atoms**, causing the black lines. But being below the threshold frequency: the electron is not lost from the atom….

Specific frequencies/energies are being absorbed by the atom. This indicates **the energies available in an atom are non-continuous**. Rather, there are **discrete** 'steps' of energy available, like rungs on a ladder. The energy is restricted to certain levels, known as **quantisation**.

When an atom absorbs energy from photons, its only those photons with complimentary *frequency/energy* to the energy levels the atom contains (taking a step).