Weds: HW by 5pm
Read

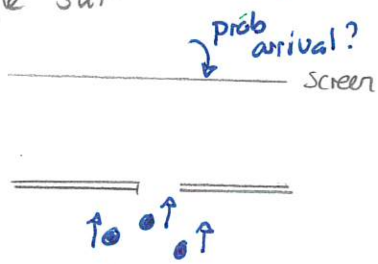
Fri: Review Test 3
Waves + Quantum Physics
2022 Test 3 Q1 → Q9, Q11 – Q13
2021 Test 3 Q1 → Q11

Particle wavelength

We have seen that particles (electrons, neutrons, atoms, molecules) display wave behavior when passing through a single slit.

Physical

Particles fired toward a single slit



same mass
same speed

↓

Requires wavelength of associated wave.

$$\text{wavelength} = \frac{6.63 \times 10^{-34}\ \text{J}\cdot\text{s}}{\text{mass particle} \times \text{velocity particle}}$$

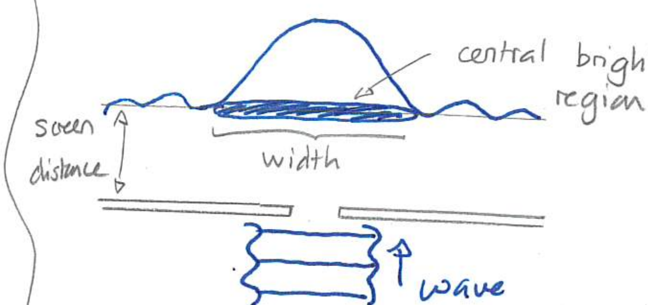
$$\text{wavelength} = \frac{h}{m \times v}$$

Mathematical Description

Associate a wave with particles

↓

Use physics of wave propagation / wave interference to predict intensity on screen.



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Intensity profile gives probability (of arrival) distribution

$$\text{width central max} = \frac{2 \times \text{wavelength} \times \text{screen distance}}{\text{slit width}}$$

Slide: Different width slits

Demo: Zeilinger article - different slit widths

1 Wavelengths of neutrons

Neutrons, each with mass 1.67×10^{-27} kg, are fired from a neutron gun.

a) In the famous experiment by Zeilinger and his collaborators, neutrons were fired with speed 206 m/s (this is about 460 mph). Determine the wavelength of these neutrons.

b) How does this compare (similar, smaller, much smaller, ...) to the wavelength of red laser light, 6.5×10^{-7} m?

c) Suppose that the neutrons were fired at a higher speed. Will this increase or decrease the wavelength of the associated wave? Explain your answer.

d) Suppose that neutrons are fired toward a single slit, whose width can be varied. As the neutron speed is increased, will the region where they are most likely to arrive beyond the slit become wider, narrower or stay the same? Explain your answer.

Answer: a)

$$\text{wavelength} = \frac{6.63 \times 10^{-34}\,\text{J}\cdot\text{s}}{\text{mass} \times \text{speed}}$$

$$= \frac{6.63 \times 10^{-34}\,\text{J}\cdot\text{s}}{1.67 \times 10^{-27}\,\text{kg} \times 206\,\text{m/s}} = 1.93 \times 10^{-9}\,\text{m}$$

b) much smaller

c) speed increases ⇒ divide by larger number
⇒ wavelength decreases.

d)

$$\text{width most likely region} = \frac{2 \times \text{wavelength} \times \text{screen distance}}{\text{slit width}}$$

⇒ multiply by smaller wavelength
⇒ width most likely region decreases
⇒ narrower.

Quiz 1

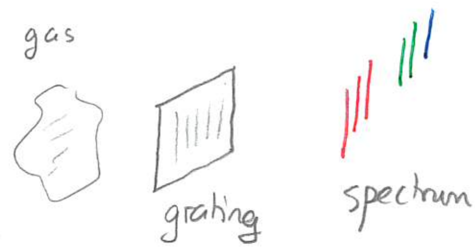
Atomic spectra

Atoms and molecules, can, under the right circumstances emit and absorb electromagnetic radiation such as light. The emitted light can be broken into constituent colors, each with a very specific wavelength. The resulting pattern is called the <u>emission spectrum</u>

DEMO: Discharge tube + spectrum glasses.

Observed facts are:

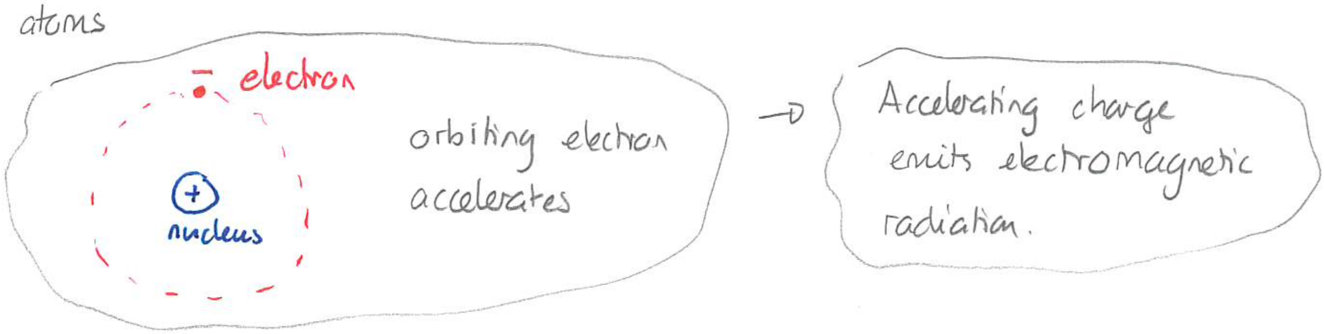
1) the emission spectrum only depends on the type of molecule/atom
2) the emission spectra of different types of atoms and molecules are distinct



3) the emission spectrum can be used to identify the atom/molecule

Explanations for emission spectra

Classical physics could use electromagnetic interactions between the positive nucleus and negative electrons to try to explain emission by atoms



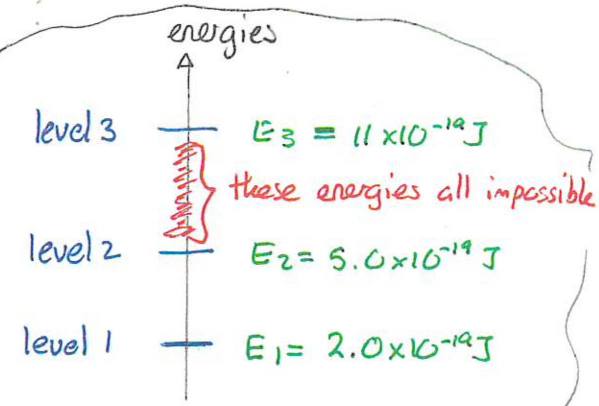
However, it cannot get the details correct.

Quantum physics, developed in the 1920s, uses a very different framework The details can be worked out exactly for the hydrogen atom and correctly predict the hydrogen spectrum.

The picture that emerges from quantum physics is :

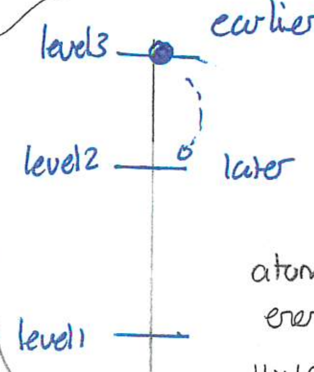
The electron in any atom or molecule can only occupy one of many discrete energy states. (called energy levels).

The exact arrangement of the states depends on the atom / molecule and will vary among different types



A system can emit one photon if it jumps from a higher to a lower energy level. Then

energy emitted photon = energy change system



atom loses energy

11×10^{-19} J $- 5 \times 10^{-19}$ J

$= 6 \times 10^{-19}$ J

Quiz1 40% -

The frequency of any emitted photon is given by using $E = h \times f$

$$\text{frequency} = \frac{\text{energy photon}}{6.63 \times 10^{-34}\ \text{J}\cdot\text{s}}$$

$$= \frac{\text{decrease in atom energy}}{6.63 \times 10^{-34}\ \text{J}\cdot\text{s}}$$

decrease in atom energy $= 6 \times 10^{-19}$ J

$$\text{frequency} = \frac{6 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J}}$$

$= 9.1 \times 10^{14}$ Hz

The important fact is that

There are only certain discrete energy change possibilities $\Rightarrow$ only certain discrete frequency possibilities

2 Artificial atom emission spectrum

An artificial atom has three energy levels as illustrated. The atom is initially in the level 3 and it then makes a jump to level 1.

Level 3 —— 11.0×10^{-19} J

Level 2 —— 7.0×10^{-19} J

Level 1 —— 2.0×10^{-19} J

a) Determine the decrease in the atom's energy.

b) Determine the frequency of the emitted light.

c) Determine the wavelength of the emitted light.

Answer:

a) energy decrease = energy initial − energy final

$= 11.0 \times 10^{-19}\,\text{J} - 2.0 \times 10^{-19}\,\text{J}$

$= 9.0 \times 10^{-19}\,\text{J}$

b) energy photon = $9.0 \times 10^{-19}\,\text{J}$

$$\text{frequency} = \frac{\text{energy photon}}{6.63 \times 10^{-34}\,\text{J·s}} = 1.4 \times 10^{15}\,\text{Hz}$$

c) speed light = wavelength × freq.

$$\text{wavelength} = \frac{\text{speed}}{\text{frequency}}$$

$$= \frac{3.0 \times 10^{8}\,\text{m/s}}{1.4 \times 10^{15}\,\text{Hz}}$$

$= 2.21 \times 10^{-7}\,\text{m}$ $= 221\,\text{nm}$

Quiz 3