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VCE Physics Unit 4

Area Of Study 2, Interactions Of Light And Matter, Study Notes 3

Matter Waves

The diffraction of light through a double slit to form an interference pattern demonstrates it to be a wave. The photoelectric effect demonstrates it to be a particle. So light, and electromagnetic radiation, are waves that act like particles, and can be shown to have momentum by the formula:

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

As long as waves can act like particles, **particles can act like waves**. This was first shown by Taylor's experiment, in which single photons one at a time formed an interference pattern by diffracting through a double slit. Since then, electrons, whole atoms and small molecules have been shown to have wave-like characteristics by diffracting through a double slit to form an interference pattern.

De Broglie Wavelengths

A de Broglie wavelength is the **wavelength of a particle**. Particles have mass, and moving particles have velocity. Moving particles therefore have momentum, such that:

$$p = mv$$

By re-arranging the formula for photon momentum to make λ the subject, the above formula for momentum ($p=mv$) can be substituted for p, creating a formula for the wavelength (the "de Broglie wavelength") of a particle:

$$p = \frac{h}{\lambda} \rightarrow \lambda = \frac{h}{p} \rightarrow \lambda = \frac{h}{mv}$$

Remembering that diffraction is proportional to wavelength, so short wavelengths diffract less: particles with tangible mass, or even particles with mass greater than subatomic particles, have wavelengths so short that while diffraction and interference probably occur, with current technology interference patterns are not observable and therefore not measurable.

For small particles, such as electrons, the kinetic energy is often easier to measure than the velocity (for example, in a photoelectric effect experiment, $V_0=E_K$ [in eV]). The mass of subatomic particles has been determined and referenced; the **mass of an electron is 9.11×10^{-31}kg**. Using a re-arrangement of the formula known for kinetic energy, velocity can be determined:

$$E_K = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2E_K}{m}}$$

This formula can be substituted for v into the de Broglie wavelength formula.

Energy Levels Of Atomic Electrons

Electrons around the nucleus of an atom occupy a set of discrete energy levels specific to the element. As energy is absorbed into an atom, the electrons "jump" to higher energy levels.

- **Ground state**; the lowest energy level (labelled as "n=1"), closest to the atom's nucleus.
- **Excited state**; any level higher than the ground state (labelled as "n=2", "n= 3", "n=4" and so on).

- **Excitation energy**; energy required for an electron to "jump" from ground state to any other energy level.
- **Ionisation energy**; energy required for an electron to be removed from its association with an atomic nucleus and be ejected.

Energy can be supplied to an atom in three main ways:

1. Heating the atom.
2. "Bombarding" the atom with other electrons. Incident electrons with energy greater than an excitation energy will cause atomic electrons to jump to higher energy levels, and the incident electrons will be left with the energy difference.
3. "Bombarding" the atom with photons. Only photons with energy equal to an excitation energy will cause atomic electrons to jump to higher energy levels. Photons with energy less or greater than excitation energies will pass through the atom with no effect.

The de Broglie wavelengths of electrons explain why they occupy particular energy levels around the nuclei of atoms, rather than being capable of having energies between the levels. **The circumference of an electron's path around the nucleus of an atom is always a whole number multiple of the electron's wavelength**. Electrons will not "fit" into circumferences not corresponding to the atom's energy levels, because their wavelengths will not divide into those circumferences to result in a whole number.

Where Photons Come From

As already described, absorption of energy into an atom causes the electrons to "jump" to higher energy levels. Without being constantly "topped up" with more energy, the electrons will lose energy, and "drop" back down to lower energy levels. **Every time an electron drops to a lower energy level, the energy it loses is released as a photon**.

Energy Of Emitted Photons

The energy of a photon emitted as an electron drops to a lower energy level is equal to the difference between the energy level the electron dropped from, and the energy level the electron dropped to. This is also equal to the energy that would be required to move the electron back up to the higher energy level.

$$E_{\text{photon}} = E_{\text{electron\_at\_higher\_energy\_level}} - E_{\text{electron\_at\_lower\_energy\_level}}$$

Emission Spectra

The set of electromagnetic wavelengths of the photons emitted (observable as colours of light) as atomic electrons drop from excited states down to less excited states and ground state.

The observed colours of light are directly attributable to electromagnetic wavelengths, which are directly attributable electromagnetic frequencies, which are directly attributable to photon energies, which are directly attributable to the energy levels of the electrons in an element's atoms.

Each element has its own unique emission spectrum, allowing its distinction from all other elements.

Absorption Spectra

Basically, these are the inverse of emission spectra. An absorption spectrum for a particular element will have black lines on a coloured background where the emission spectrum for the same element would have coloured lines on a black background.

White light (electromagnetic radiation consisting of all visible wavelengths and hence frequencies) is shone into the vapour of an element.

Photons with energy corresponding to the excitation energies of the electrons in the element's atoms are absorbed, causing the electrons to jump to higher energy levels. All other photons pass through the vapour with no effect on any electrons.

A spectrum can be observed with black lines indicating wavelengths associated with photon energies corresponding to energy levels of electrons in the element's atoms.