Ngā Whetū Resources

**Physics Year 13 (Level 8)**

# Summary Modern Physics

*Revise notation of nuclear reactions*. Example: $^{238}_{92}U \Rightarrow ^{234}_{90}Th + ^{4}_{2}He + \gamma$

Top index: **Mass Number** (number of nucleons)
Bottom index: **Atomic Number** (number of protons or positive charge of nucleus)
Sum of indices left and right must match:
Top index *Conservation of mass*, Bottom index *Conservation of charge*.

**Radiation:**

Alpha particle: $^{4}_{2}He$ (helium nucleus, positively charged)
Beta particle: $^{0}_{-1}e$ (electron, negatively charged)
Gamma waves: $\gamma$ (high energy electromagnetic waves, no charge)

**Equivalence of mass and energy** $E = mc^2$

**Binding Energy, Fission and Fusion reactions** (see Handout "*Binding Energy and the Release of energy from nuclear reactions (fission and fusion)*")

**Nuclear Fission** is the decay of a large heavy nucleus in smaller nuclei with the release of energy.
*Natural Radioactivity* is natural decay of radioactive material (see Handout: "*Half-life of Radioactive elements"*)
*Artificial nuclear fission* occurs when a heavy nucleus is bombarded with neutrons.
When the reaction produces more neutrons than used, a **chain reaction** may occur.
A *Fission Power station* involves *Cadmium* rods to absorb neutrons (control system) and *Graphite* rods to slow neutrons down to increase the change of a collision with a large nucleus.

**Nuclear Fusion** is the fusion of smaller light nuclei into one larger nucleus with the release of energy. It produces no radioactive radiation. Technically it is very complicated because of the high temperatures involved.

Nuclear collisions are governed by the law of Conservation of Momentum:

$$\sum mv_{before} = \sum mv_{after}$$

**Photoelectric Effect**
Emission of electrons by a metal if hit by electromagnetic waves. Some characteristics of this effect cannot be explained by wave feature of light. In particular the **Threshold frequency** below which no photo emission occurs. This led to **Quantum Theory** where electromagnetic energy is quantised (**photon**).
**Energy of a photon** is expressed by $E = hf$ where *h* is Planck's constant and $f$ the frequency of the light. Energy in Nuclear Physics is frequently expressed in eV, see Handout: "*The Electronvolt (eV) as a unit of energy*").
**Work function** $(\Phi)$ is energy needed to release an electron of a material. Remaining photon energy is converted to Kinetic energy of the electron: $hf = \Phi + E_k$.
At threshold frequency the photon energy is just equal to the work function: $hf_0 = \Phi$.

In the **Photoelectric Experiment** a voltage is applied to stop the flow of photoelectrons in the circuit. The work done by the **Stopping Voltage** on one electron is $e \times V_s$ where *e* is the charge of the electron and $V_s$ the Stopping Voltage.

Thus the energy equation is now: $hf = eV_s + \Phi$ or $eV_s = hf - \Phi$. Dividing by *e* gives

$V_s = \frac{h}{e} f - \frac{\Phi}{e}$ where $eV_s$ and $V_s$ are expressed as a linear function of the frequency:

Because *h* and $\frac{h}{e}$ are constant, different materials will have *parallel lines* in the eV/f or V/f graphs.

Electromagnetic radiation has both wave and particle properties (**Wave Particle Duality**).

**Atomic Spectra**

Atoms can emit electromagnetic radiation when given energy. This comes from the electrons which absorb incoming energy by jumping to a higher energy level ("orbit") and then fall down to a lower level while radiating a specific amount of energy. Different materials thus have their own specific **emission spectrum** of frequencies, relating to specific energy levels of the electrons.

**Atomic Model**

By studying atomic spectra energy levels of electrons can be deduced. For the simplest atom (Hydrogen) the possible energies are given by the **Reidberg formula**: $E = hcR(\frac{1}{S^2} - \frac{1}{n^2})$ where R is Reidberg's constant. E is the amount of energy released when the electron moves from level n to level S. Note that for positive energies, when the electron "falls down", *n* must be larger than *S*. For $S \to \infty$ the formula gives the amount of energy *released* to bring the electron from level n to level $"\infty"$ or the **ionisation level** : $E = -\frac{hcR}{n^2}$. This is negative energy so it is the energy *needed* to release the electron from its nucleus.

With $E = hf$ and $f = \frac{c}{\lambda}$ Reidberg's formula becomes: $\frac{1}{\lambda} = R(\frac{1}{S^2} - \frac{1}{n^2})$.

Different values of *S* give different series called after their discoverers, Lyman (*S*=1), Balmer (*S*=2), Paschen (*S*=3), Brackett (*S*=4), Pfund (*S*=5).

Reidberg's formula is in agreement with **Bohr's model** for the atom in which the **Angular Momentum** of the electron can only have the discrete values:

$L = mvr = \frac{nh}{2\pi}$ where n is a positive integer.

With DeBroglie's assumption that the **Linear Momentum** of the electron must satisfy the relationship: $p = mv = \frac{h}{\lambda}$ it can be shown that the circumference of the (circular) electron orbit equals integer multiples of the wavelength, $2\pi r = n\lambda$.

These orbits can be considered as **harmonics of the standing wave** of the electron.

The electron thus can be considered to have wave properties!