Physics AS90184 Demonstrate understanding of heat transfer & nuclear physics

Part 2: Nuclear Physics

The **atomic number** (Z) is the number of protons. The **mass number** (A) is the number of protons PLUS neutrons. The mass number is also sometimes known as the **nucleon number**. The neutron number (N) = mass number (A) - atomic number (Z).

particle	*relative mass*	*electric charge*	*location*
proton (p)	1	+	nucleus
neutron (n)	1	zero	nucleus
electron (e)	approx 1/2000	-	in energy levels

$^{A}_{Z}\mathbf{X}$. Eg. $^{7}_{3}\mathrm{Li}$ means an atomic no. of 3 (3 protons) & a mass no. of 7 (3 protons + 4 neutrons).

Isotopes: Natural uranium is mainly $^{238}_{92}\mathrm{U}$. About 0.7% of natural uranium is $^{235}_{92}\mathrm{U}$. These two atoms are known as isotopes. **Isotopes** are atoms with the same number of protons but a different number of neutrons or mass number.

Radioactivity results from the **random and spontaneous breakdown of the unstable nucleus** of an atom. In the breakdown of the unstable nucleus, energy is released by the emission of alpha, beta and gamma radiation.

Particle	Symbol	Description	Penetration power
Alpha particle α	$^{4}_{2}\mathrm{He}$	Helium nucleus made up of 2 protons & 2 neutrons	Stopped by a few cm of air or thin sheet of paper
Beta particle β	$^{0}_{-1}\mathrm{e}$	High energy electron	Stopped by a few mm of most metals eg aluminium.
Gamma radiation γ	$^{0}_{0}\gamma$	electromagnetic radiation / wave	"stopped" by several cm of steel or metres of concrete.

Nuclear equations

Balancing: The changes can be represented as nuclear equations and *they must balance in atomic number and mass number*. When α or β particles are emitted, a new element is formed.

- When alpha decay occurs, mass no. decreases by 4 and atomic no. decreases by 2.
- For beta decay, the mass number does not change, but atomic number increases by 1.
- Gamma decay does not change the mass or atomic number.

Two **conservation laws** are the "law of conservation of atomic number" & the "law of conservation of mass number" (or nucleon number)

Alpha: $^{235}_{92}U \rightarrow ^{231}_{90}Th + ^{4}_{2}He$

- Law of conservation of atomic number: Here 92 (LHS) = 90 + 2 (RHS).

  Sum of atomic numbers before the reaction equals sum of atomic numbers after the reaction.
- Law of conservation of mass number: Here 235 (LHS) = 231 + 4 (RHS).

  Sum of mass numbers before the reaction equals sum of mass numbers after the reaction.

Beta: $^{238}_{92}U \rightarrow ^{238}_{93}Np + ^{0}_{-1}e$ (92 = 93 + -1; 238 = 238 + 0)

A neutron in the nucleus changes into a proton and an electron – the beta particle. *Since the proton and neutron have a mass of 1 and the electrons mass is negligible, the mass number stays the same, the atomic number rises by 1.*

To “make” radioisotopes for use in industry and medicine, stable isotopes are bombarded with neutrons in a nuclear reactor. *You might be asked to complete one of these equations.*

$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co + \gamma.$ $^{16}_{8}O + ^{1}_{0}n \rightarrow ^{13}_{6}C + ^{4}_{2}He$

There is a low level of natural radioactivity, known as the background radiation. Natural sources include: radiation from space (cosmic rays from Sun), from naturally occurring radioisotopes in rocks eg granite, and radiation due to human activity - atomic weapons testing & emissions from nuclear power stations. Any radioactivity is dangerous to living organisms. When radioactivity hits living cells, alpha, beta and gamma radiation collides with neutral atoms or molecules, knocking off electrons and turning them into charged/ionised particles (ions). These may be very reactive and cause other chemical changes in the cell molecules. Ionisation can kill cells directly or cause genetic damage (damages DNA).

How long does material remain radioactive? Some atomic nuclei are very unstable, existing for a few minutes or seconds. Others are very stable and take millions of years to decay to form another atom. Used radioisotopes and nuclear fuel most be processed into a safer form and the waste stored in long-term leak-proof containers which could be buried in a deep and well shielded storage area underground. Nuclear reactor/weapon waste is dangerously radioactive initially so it is stored in containers under water until it has 'cooled off' and is safer to handle.

Nuclear Fission

Fission: Splitting/breaking apart of nucleus with the release of a large amount of energy.

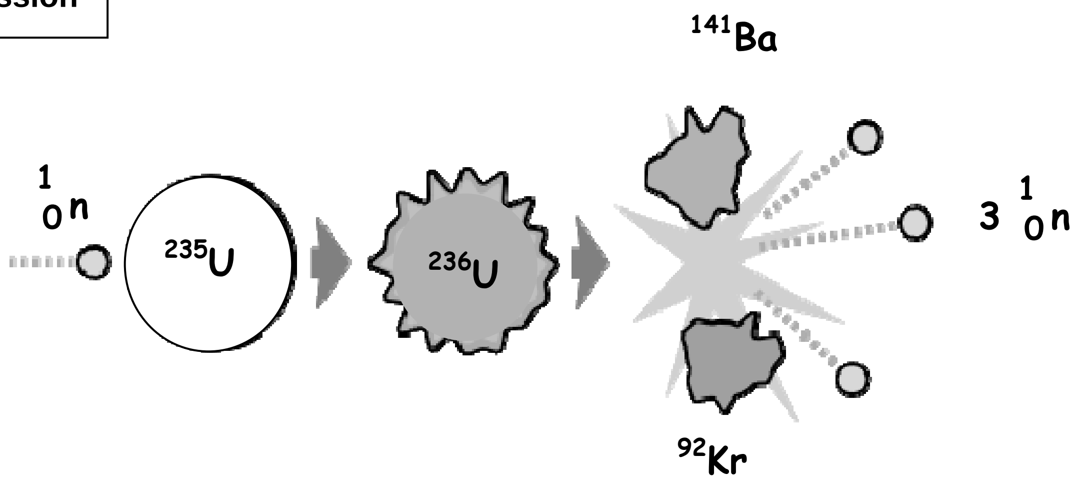
When large atomic nuclei are hit with neutrons they can become unstable & break into two smaller 'daughter' nuclei & release more neutrons, (as well as α and β particles and γ). This is **nuclear fission** & is accompanied by an enormous release of energy. It forms the basis of the nuclear power industry. Uranium-235 is particularly useful. The heat energy released is used to boil water to make steam drive a turbine & electrical generator in the nuclear power station.

During fission of each U atom more neutrons are produced than used in the fission reaction (see diagram). In a nuclear reactor these extra neutrons will collide with other nuclei to produce further reaction called a **chain reaction** leading to an even greater energy release. If it was to carry on, uncontrolled, it would lead to an explosive energy release. (A fission bomb based on uranium-235 was dropped on Hiroshima, in Japan, in 1945). In nuclear reactors, control rods of boron can lowered into the reactor core to absorb excess neutrons and slow down fission to keep the chain reaction under control. Other rods called moderator rods slow down the neutrons produced by the chain reaction as slow moving neutrons are needed to bring about further fission.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{141}_{56}\mathrm{Ba} + ^{92}_{36}\mathrm{Kr} + 3\,^{1}_{0}\mathrm{n}$$

The considerable amounts of highly radioactive waste from the nuclear power industry must be disposed of safely, and stored safely.

Nuclear Fission



Summary of the parts of a nuclear reactor

Part	Function	Material used
Coolant	heat exchange fluid to transfer energy from the reactor core to the turbines	Water / CO_2 / sodium
Moderator	to slow down neutrons so that they collide with nuclei	Graphite / carbon
Fuel	to provide a source of neutrons / fissionable material so that nuclear reaction may occur	Uranium (plutonium in some other designs of nuclear reactor)
Control rods	Control/slow down the rate of nuclear reaction by control rods absorbing excess neutrons produced by the fission of the U. If this did not happen, the reaction would become out of control	boron
Shielding	To contain the radiotivity	concrete

Nuclear Fusion

Fusion: Joining/combining nuclei with the release of a tremendous amount of energy.

At the extremely high temperatures in the 'heart' of stars the atomic nuclei have such enormous speeds and kinetic energies that they can fuse together if they collide. The extremely high energy is needed to overcome the natural and massive repulsion of the two positive nuclei. A heavier atomic nucleus is made from two smaller atomic nuclei and these changes also release enormous amounts of energy.

Eg $$2\,{}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{energy}$$

Examples: A nuclear reaction takes place between a tritium ${}^{3}_{1}\mathrm{H}$ nucleus and deuterium ${}^{2}_{1}\mathrm{H}$ nucleus in the sun. The products are a helium nucleus and a neutron. (You might be asked to write this as a nuclear equation). Eg

$$ {}^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} $$

The fusion process is difficult to reproduce on Earth as it is difficult to generate these temperatures and to contain the reaction in a suitable vessel.

Shorthand notations – learn these!

proton	neutron	electron / beta β	helium nucleus/ alpha α
${}^{1}_{1}\mathrm{p}$	${}^{1}_{0}\mathrm{n}$	${}^{0}_{-1}\mathrm{e}$	${}^{4}_{2}\mathrm{He}$