DEMONSTRATE UNDERSTANDING OF ATOMS AND RADIOACTIVITY

REVISION

Phenomena, Concepts and Principles:

- *Models of the atom (Dalton, Thomson and Rutherford)*
- *Gold foil experiment*
- *Radioactive decay*
- *Half life*
- *Conservation of atomic and mass number in alpha, beta and gamma emission reactions*
- *Ionising ability*
- *Penetration ability*
- *Behaviour in a magnetic field.*

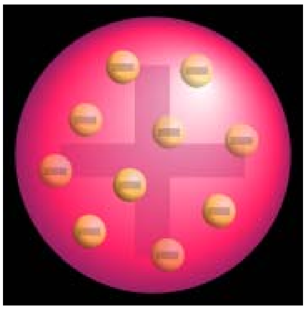
Dalton's Atomic Theory:

Elements are made of tiny particles called atoms:

- All atoms of a given element are identical
- The atoms of a given element are different from those of any other element
- Atoms of one element can combine with atoms of other elements to form compounds. A given compound always has the same relative numbers of types of atoms.
- Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process – they were **indivisible**. A chemical reaction simply changes the way atoms are grouped together.

J. J. Thomson’s plum pudding model:

The plum pudding model of the atom was proposed by J. J. Thomson, the discoverer of the electron in 1897. In this model, the atom is composed of electrons, surrounded by a soup of positive charge to balance the electron's negative charge, like plums surrounded by pudding. The electrons were thought to be positioned throughout the atom. Instead of a soup, the atom was also sometimes said to have had a cloud of positive charge. Thomson believed there were spaces between these atoms.



The Rutherford model:

The Rutherford model of the atom was devised by Ernest Rutherford. He performed his famous gold foil experiment, which showed that the Plum pudding model of the atom was incorrect. In the experiment, Rutherford allowed alpha particles to pass through a thin piece of gold foil. He expected that most of the particles would pass through the foil or only be deflected slightly. This happened most of the time, but a few particles, 1 in 8000, bounced back towards the source. This proved that atoms have a dense, positive inner core instead of spread-out positive field. Rutherford proposed that the atom is made up of a positive nucleus consisting of protons surrounded by a cloud of orbiting electrons. However, the Rutherford model did not attribute any structure to the orbiting electrons and it did not include neutrons (that were added later by Chadwick). The Rutherford model of the atom was later superseded by the Bohr atom.

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

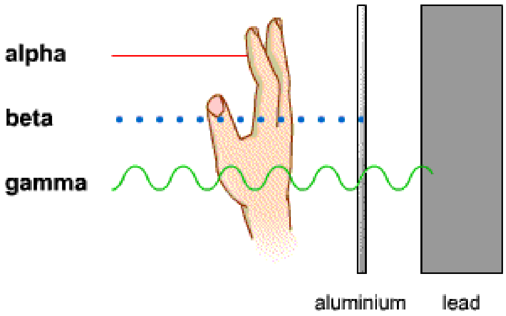
particle	*relative mass*	*electric charge*	*location*
proton (p)	1	+	nucleus
neutron (n)	1	zero	nucleus
electron (e)	1/2000	-	in energy levels

$^{A}_{Z}X$ e.g. $^{7}_{3}\mathrm{Li}$

means an atomic number of 3 (3 protons) & a mass number of 7 (3 protons plus 4 neutrons).

The nucleus is composed of protons and neutrons BUT only certain combinations of n:p seem to be stable. 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	Ionising power	Deflected by magnetic field
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 - low penetration.	Very high ionising power	yes
Beta particle β	$^{0}_{-1}e$	High kinetic energy electron	Stopped by a few mm of most metals e.g. aluminium.	Moderate ionising power	yes
Gamma radiation γ	$^{0}_{0}\gamma$	Very high frequency electromagnetic radiation	“Stopped” by several cm of steel or metres of concrete.	Lowest ionising power	no



Nuclear equations

Balancing: The changes can be represented as nuclear equations and they must balance in atomic number and mass number. In both α and β a new element is formed which is called the **transmutation** of one element into another.

- When alpha decay occurs, mass no. decreases by 4 and atomic no. decreases by 2.
- For beta decay, mass number does not change, atomic number increases by 1.
- Gamma decay, a gamma ray is released (energy), no change to mass & atomic number.

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

	α	β	γ
mass	4	1/2000	0
charge	2+	1-	0

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

Law of conservation of atomic number:

Here 92 (LHS) = 90 + 2 (RHS).

Law of conservation of mass number: Here 235 (LHS) = 231 + 4 (RHS).

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

A neutron in the nucleus changes spontaneously into a proton and the high kinetic energy electron formed is the emitted 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.

Gamma: The emission of gamma radiation from a nucleus does not involve any change in the atomic (proton) number or mass number. Gamma radiation accompanies α and/or β decay.

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.*

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

Detection and measurement of Radioactivity.

A Geiger counter set up anywhere will register 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 e.g. granite, and radiation due to human activity - atomic weapons testing & emissions from nuclear power stations.

- Geiger-Muller (GM) tube and counter electronically amplifies the ionising effect of the radiation.
- Photographic film badges (for workers in nuclear industry and hospitals) monitor how much radiation they are exposed to.

Dangers of radioactivity 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).

High doses of radiation cause burn effects and can kill cells. Doses too low to kill cells can still genetically damage them & if they replicate, the mutations can lead to the formation of cancerous cells / tumours. The 3 radiations have different capacities to cause cell damage. Inside the body the 'danger' order is alpha > beta > gamma. The bigger the mass or charge of the particle, the bigger its ionising impact on atoms or molecules. Outside the body, the order danger is gamma > beta > alpha because it depends on the pattern of penetrating power. The smaller the mass and charge the more penetrating the radiation. Gamma and beta are the most penetrating and will reach vital organs in the body and be absorbed. Most gamma passes through soft tissue but some is absorbed by cells. Since alpha radiation would not penetrate clothing its unlikely to reach living cells.

The Uses of Radioactive Isotopes.

Uses depend on their penetrating power & their half-life.

Alpha: easily stopped and used in some smoke detectors. Americium-241 (half-life 458 years) emits alpha particles which collide with the oxygen and nitrogen in air in the detector's ionisation chamber to produce ions. A low-level electric voltage applied across the chamber is used to collect these ions, causing a steady small electric current to flow between two electrodes. When smoke enters the space between the electrodes, the alpha radiation is absorbed by smoke particles. This causes the rate of ionisation of the air to decrease and therefore the electric current to fall, which sets off an alarm. The alpha particles from the smoke detector do not themselves pose a health hazard, as they are absorbed in a few centimetres of air or by the structure of the detector.

Beta: stopped by a few mm or cm of solid materials. The thicker the layer the more beta radiation is absorbed. A beta source is placed on one side of a sheet of material. A detector (eg a Geiger counter) is put on the other side and can monitor how much radiation gets through. The signal size depends on thickness of the sheet and it gets smaller as the sheet gets thicker. Therefore the signal can be used to monitor the sheet thickness.

Gamma: Gamma radiation is highly penetrating and so gamma sources are used where the radiation must be detected after passing through an appreciable thickness of material. This is used in various tracer situations eg monitoring pipes for leaks, medical tracers, radiotherapy (A beam of gamma radiation is directed onto the tumour site to kill the cancer cells), testing structure of materials (eg welds), and to sterilise surgical equipment or packaged food.

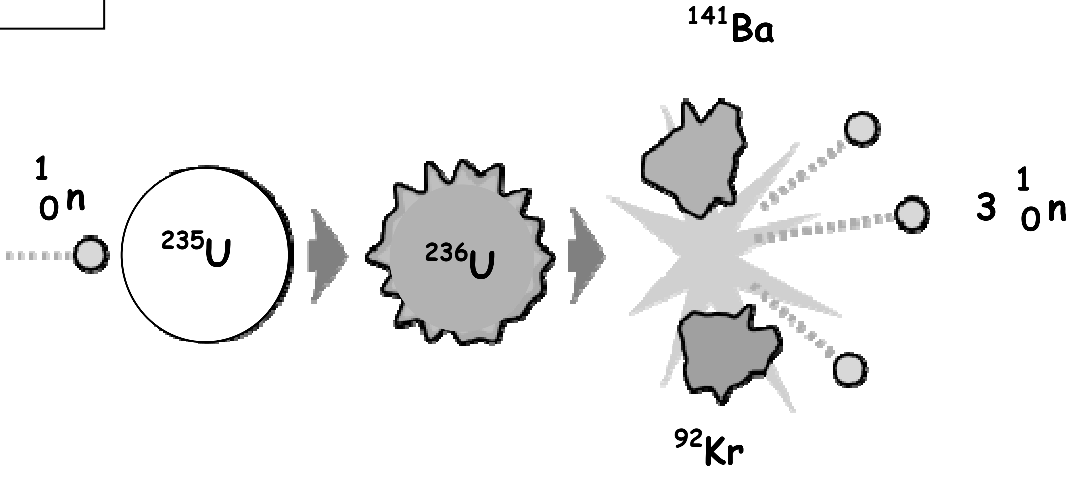
How long does material remain radioactive? Some atomic nuclei are very unstable, existing for a few minutes or seconds. Others are very stable and take millions of years to decay to form another atom. The **half-life** of a radioisotope is the average time it takes for half of the remaining radioactive atoms to decay to a different atom. The radioactivity of any sample will decrease with time as the unstable atoms decay to more stable atoms, though sometimes by complex decay series routes eg $_{92}U$ isotopes to $_{82}Pb$ isotopes. 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 due to radioisotopes with short half-lives so it is stored in containers under water until it has 'cooled off' and is safer to handle.

Nuclear Fission Reactions When large atomic nuclei are hit with neutrons they can become unstable and breaks into two smaller 'daughter' nuclei and releases more neutrons, (as well as α and β particles and γ). This is **nuclear fission** and 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 and electrical generator in the nuclear power station. During fission of each U atom more neutrons are formed which 'split' other U atoms making even more neutrons - a **chain reaction**, leading to an even greater energy release. If it goes uncontrolled a nuclear explosion results (a fission bomb based on uranium-235 was dropped on the city of Hiroshima, Japan, in 1945). In nuclear reactors, control rods of boron can lowered into the reactor core to absorb neutrons and slow down fission to keep the chain reaction under control. Moderator rods slow down the neutrons produced by the chain reaction as slow moving neutrons are needed to bring about further fission.

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

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

Nuclear Fission



Nuclear Fusion Reactions 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. The process by which a heavier atomic nucleus is made from two smaller atomic nuclei is called fusion and these changes also release enormous amounts of energy. Examples:

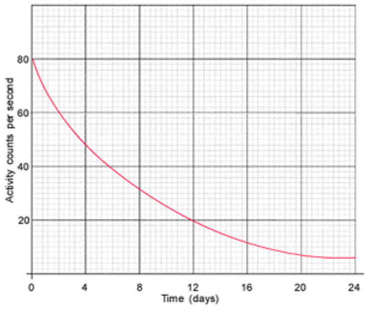
$$2\,{}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} \qquad {}^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

Half-Life

Half-life is the time it takes for half of the radioactive atoms in radioactive material to decay.

For example if the half-life of a substance was 1 hours - this means that after a time of 1 hour the number of radioactive atoms would reduce by half. After another hour the number of radioactive atoms would be halved again (ie the number of radioactive atoms remaining would be ¼ of the original number). After another hour the number of radioactive atoms would be 1/8 of the original and so on.

Since the activity of radioactive material is proportional to the number of radioactive atoms present, the activity reduces by half for each half-life. For example if the activity of a sample is 80 Bq, then after 1 half life has elapsed the activity would be halved (i.e. 40 Bq). After two half-lifes the activity would be 20 Bq and so on.



Shorthand notations – learn these!

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