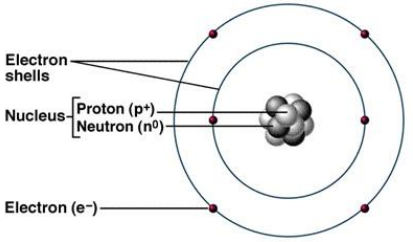
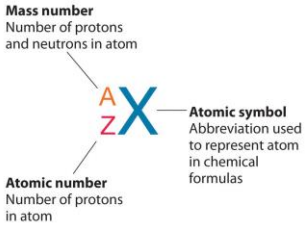
Physics 4: Atomic Structure

Section 1: Key words and definitions

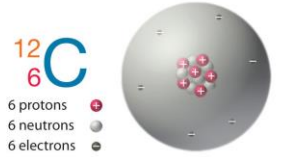
absorb	To take in
activity	How many nuclei decay per second. Units: Bq (becquerel) or counts per second.
alpha particle	A particle made of two protons and two neutrons that has come from nuclear decay (looks like a helium nucleus)
atom	A neutral particle made of a nucleus and electrons. The smallest amount of an element you can have.
atomic number	The number of protons in the nucleus of an atom
background radiation	Radiation that is around us all the time. Comes from: cosmic rays, rocks, radon gas in the atmosphere, food, medical scans, nuclear power stations, weapons testing
beta particle	A fast moving electron that has come from nuclear decay
contamination	When a radioactive material gets into the environment.
electron	A particle with negative charge (-1) and tiny mass (0.005). Orbits the nucleus of an atom.
emit	To give out
fission	A large, unstable nucleus splits into two smaller nuclei and releases a few neutrons. Also releases energy that is used in nuclear power stations.
fusion	Two small nuclei join together to make a larger one and releases energy in the process. This is the source of energy within stars.
gamma radiation	Electromagnetic wave released by an unstable nucleus during nuclear decay.
half life	The length of time it takes for the activity of a sample of radioactive material to drop to half of its original value.
ionising	Capable of pulling some electrons off an atom and turning it into an ion.
irradiation	When something is exposed to nuclear radiation but does not itself become radioactive.
isotopes	Atoms of the same element that have the same number of protons but a different number of neutrons (hence they have different mass)
mass number	The total number of protons plus neutrons in the nucleus of an atom.
neutron	A neutral particle in the nucleus, with charge 0 and relative mass of 1
nucleus	The dense, central part of an atom where most of the mass is concentrated. Contains protons and neutrons.
penetrating	Capable of going deep inside a material.
proton	A positively charged particle in the nucleus. Relative mass 1, charge +1

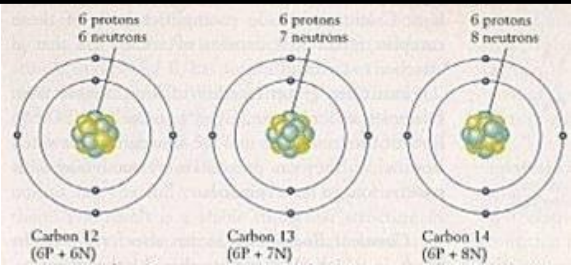
Section 2: Structure of the Atom & Isotopes





Atoms have a NUCLEUS in the centre containing protons and neutrons, and electrons orbit the nucleus. A neutral atom has the same number of electrons as protons.

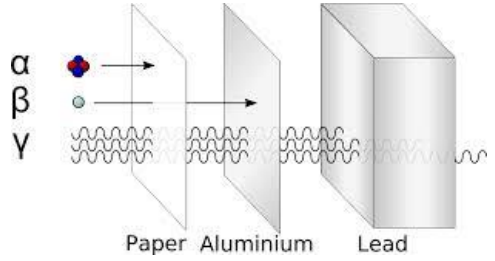




Isotopes are atoms of the same element that have different mass. Isotopes of an element have the same number of protons in the nucleus but different numbers of neutrons.

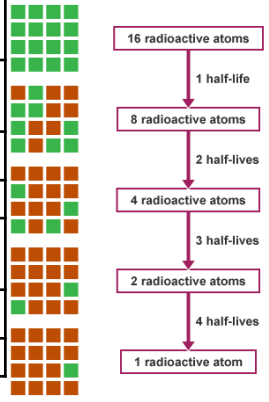
Section 3: Nuclear Radiation

The nucleus of a radioactive isotope is unstable and may emit radiation. This makes the nucleus more stable. Alpha, beta and gamma radiation come from an unstable nucleus.

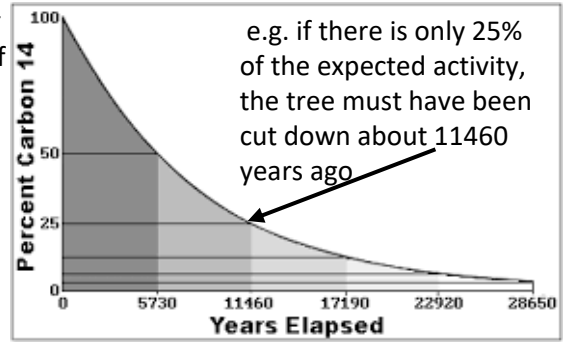


	Alpha (α)	Beta (β)	Gamma (γ)
Nature	It's a nucleus of helium $^{4}_{2}He$. Two protons and two neutrons	It's an electron e^-	It's an electromagnetic wave
Charge	+2	-1	0
Mass	Relatively large	Very small	No mass
Speed	Slow	Fast	Speed of light
Ionizing effect	Strong	Weak	Very weak
Most dangerous	When source is inside the body	When source is outside the body	When source is outside the body

Section 4: Half Life & Radioactive Dating



Half life is the amount of time it takes for the number of radioactive nuclei or the measured activity to drop to half of its original value.
In radioactive dating, the activity of a sample of ancient wood used to make something is compared with an identical sample of modern wood to find out how much the activity has fallen. This tells us how long ago the tree was cut down.



Section 5: Nuclear Decay Equations

Alpha decay changes the nucleus – an alpha particle is made of 2 protons and 2 neutrons so when it leaves, the remaining nucleus has 2 fewer protons and 2 fewer neutrons than before. It is now a different element with an atomic number that has dropped by 2 and a mass number that has dropped by 4.

Beta decay changes the nucleus – a beta particle is made when a neutron in the nucleus turns into a proton and spits out an electron. The remaining nucleus has 1 more proton and 1 less neutron than before. It is now a different element with an atomic number that has gone up by 1 but the mass number has not changed.

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

$${}^{A}_{Z}X \longrightarrow {}^{A}_{(Z+1)}Y + {}^{0}_{-1}e$$

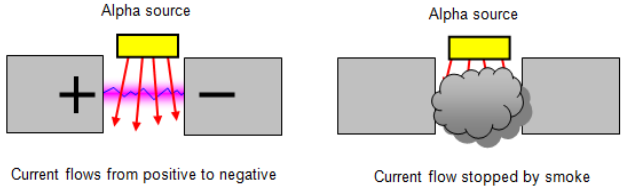
$${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$$

Uranium 238 decays to Thorium 234 plus an alpha particle.

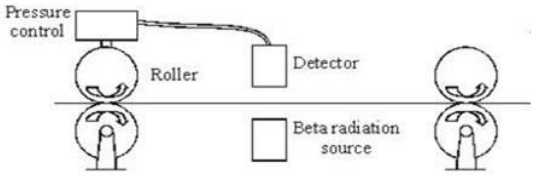
$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

Gamma decay is easy – the gamma ray carries away excess energy but the number of protons and neutrons in the nucleus does not change.

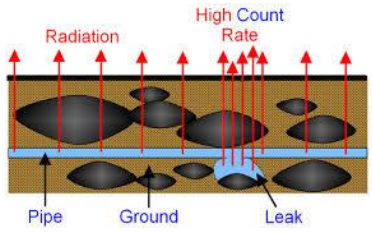
Section 6: Uses of radioactive isotopes



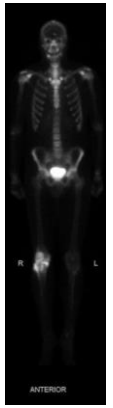
Alpha radiation is used in smoke detectors. The alpha particles ionise the air and allow a small current to pass across the gap between two electrodes. Smoke particles absorb alpha particles and prevent the current. An electronic system detects a drop in current and sets off an alarm.



Beta radiation is used to monitor the thickness of paper in a paper-mill. If too few beta particles are detected, the paper must be absorbing too many because it is too thick and the rollers are pressed together more to make the paper thinner.

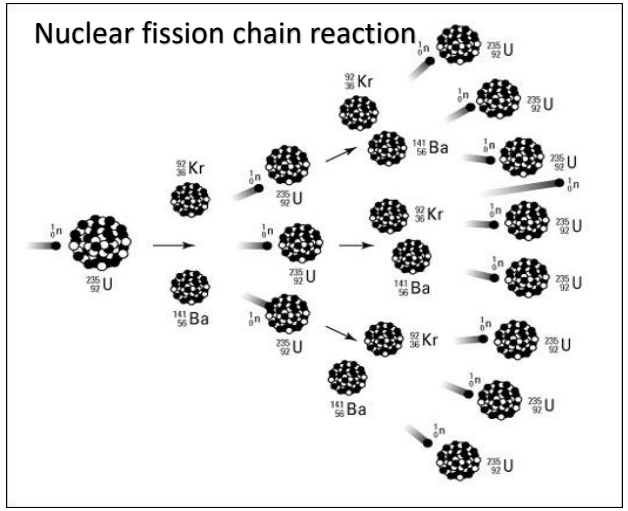


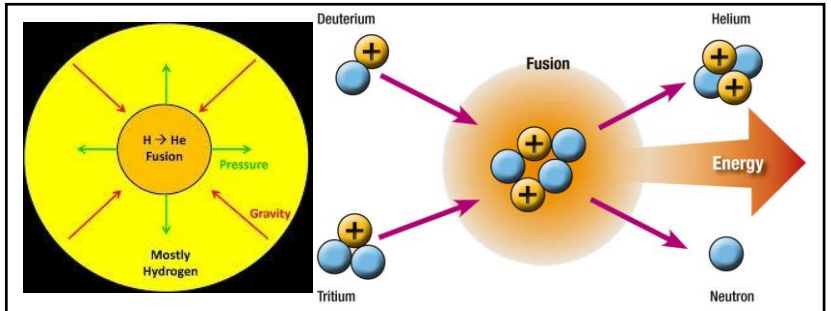
Gamma radiation is used as a tracer in industry and in medicine.
In industry, if there is a leak in a pipe underground, a radioactive isotope is put through the pipe and a detector called a "GM Tube" is used to measure the amount of radioactivity on the surface. Where the measurement goes up, there must be radioactive material leaking out of the pipe. In medicine, Tc-99m (technetium-99) is used because it has a half life of 6 hours: long enough to do medical tests but short enough that the patient is not radioactive for too long. A "gamma camera" takes pictures of where the tracer is.



Section 7: Nuclear Fusion & Nuclear Fission

In nuclear fission, a large unstable nucleus splits up into two or more smaller nuclei and 2 or 3 free neutrons. Energy is released because the free neutrons have kinetic energy. In a chain reaction, these neutrons go on to cause more fission to happen. For a stable chain reaction, you want only one of the neutrons to cause another nucleus to undergo fission.





In nuclear fusion, two small nuclei join together (fuse) to make a larger nucleus e.g. in a star, hydrogen nuclei fuse to produce helium. This releases energy. It is very difficult to make nuclear fusion happen in a laboratory because it requires extremely high pressures and temperatures (like you get in the core of a star).

Section 8: Nuclear Power Stations

A nuclear power station uses nuclear fission of uranium or plutonium to generate heat. The heat is used to make steam to turn a turbine connected to a generator just like in a coal-fired power station.

Advantages:

- Does not release carbon dioxide
- Needs very little fuel to produce a lot of energy
- Easy to control by raising or lowering the control rods (made of boron which is good at absorbing neutrons) to increase or decrease the rate of nuclear fission

Disadvantages:

- Expensive to build and to decommission (shut down at the end of its useful life)
- Produces long lasting radioactive waste that has to be stored safely
- Risk of catastrophic accident