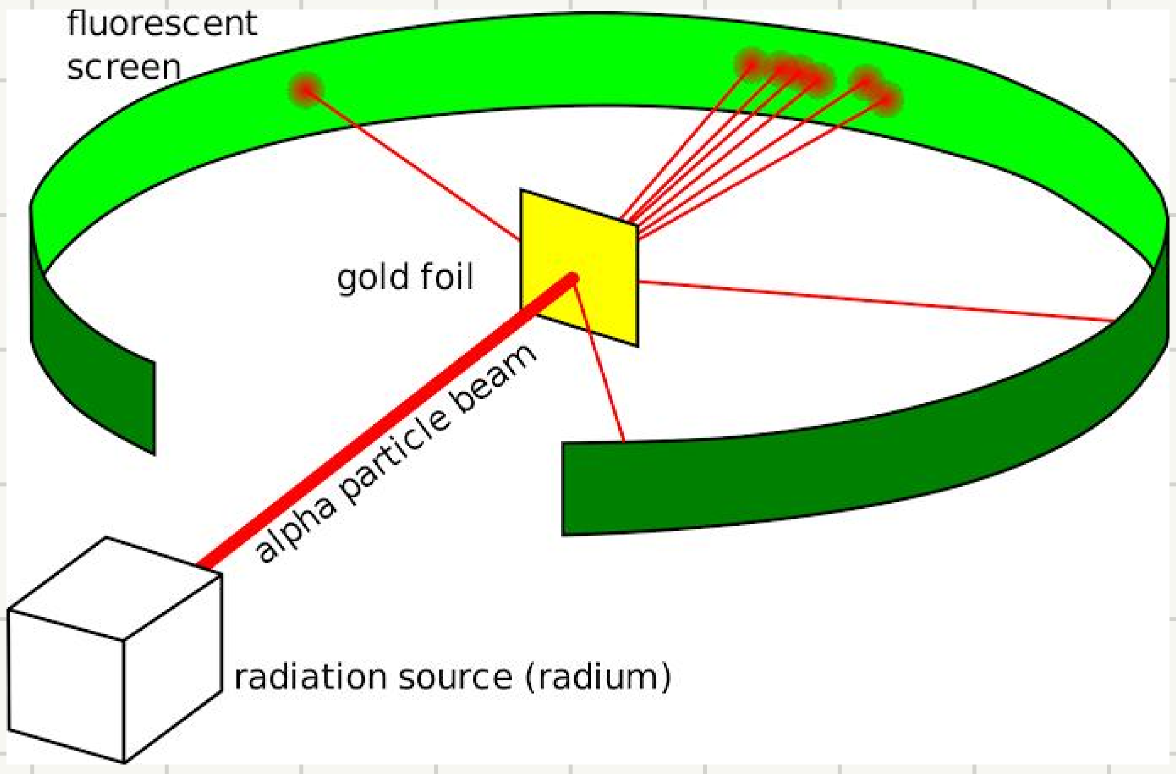
Radioactivity and Particle Physics

Geiger - Marsden Experiment



What happens :- It is an experiment in which a beam of alpha particles are fired at a thin gold foil.

Observation 1 :- About 99% of the alpha particles pass straight through the foil

Explanation :- Most of the atom is empty space

Observation 2 :- Some of the alpha particles are deflected through small angles

Explanation :- The nucleus of the atom is positively charged

Observation 3 :- A very small number of alpha particles rebound off / are reflected from the gold foil

Explanation :- Most of the mass of the atom is concentrated in the nucleus

---

Proton Number (Z) :- No of protons in an atom

Nucleon Number (A) :- Sum of protons and neutrons in an atom

$$^{A}_{Z}X$$ → Any element or particle

Isotopes :- Atoms that have the same proton number, but a different number of neutrons

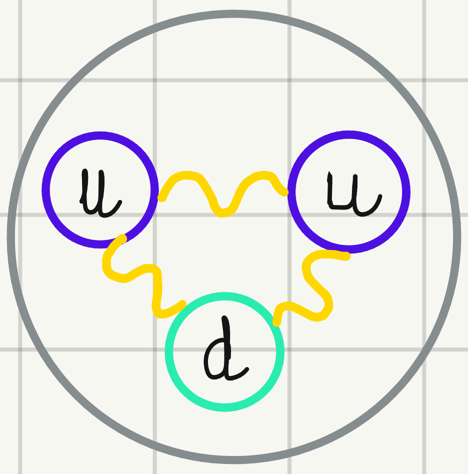
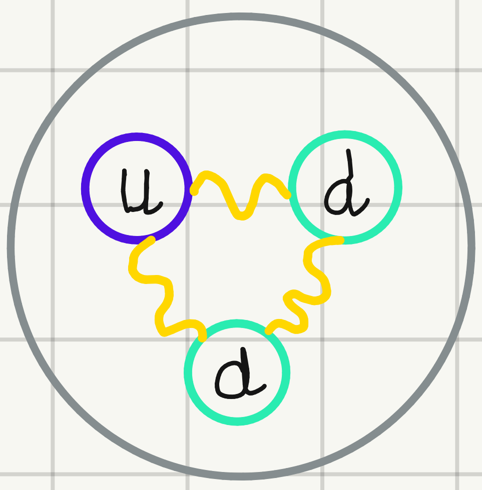
---

Fundamental Particles :- A particle that cannot be further broken down

Quarks :- Fundamental particles that make up neutrons, protons and other particles

Quark	Symbol	Charge	Anti-Quark	Symbol	Charge
Up	u	$+\frac{2}{3}e$	Anti-Up	$\bar{u}$	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$	Anti-Down	$\bar{d}$	$+\frac{1}{3}e$
Strange	s	$-\frac{1}{3}e$	Anti-Strange	$\bar{s}$	$+\frac{1}{3}e$

Quark model :-

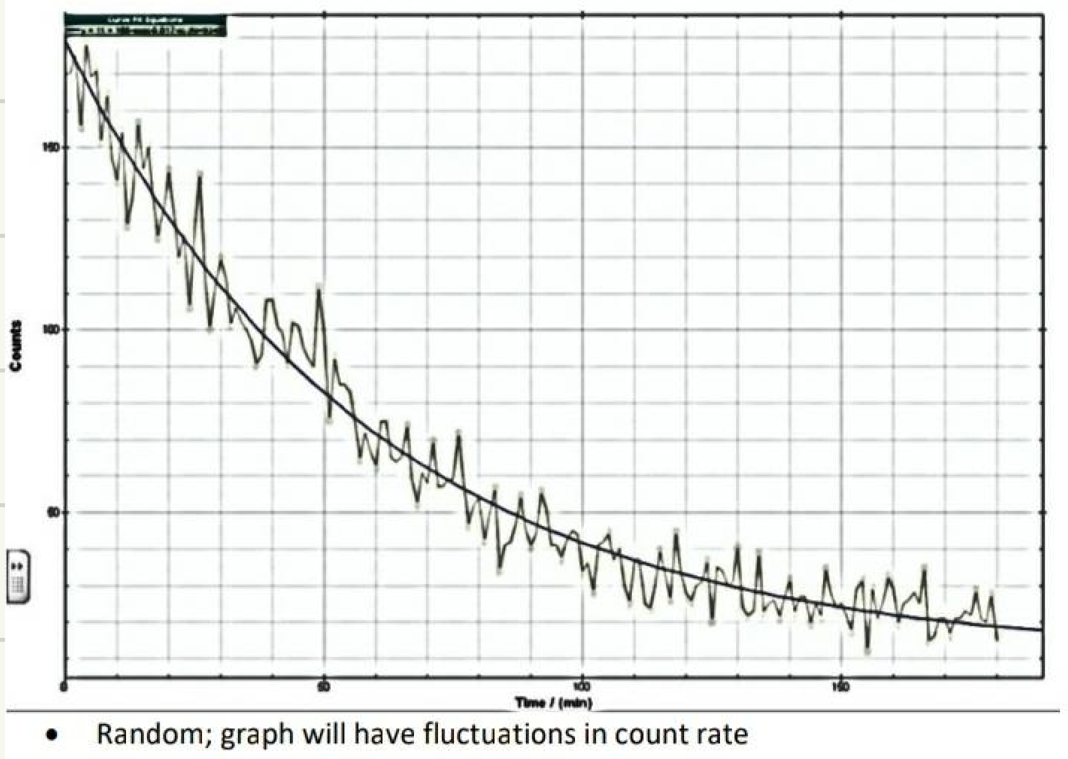
PROTON	NEUTRON
	
2 Up and 1 Down	1 Up and 2 Down
$+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=+1$	$+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$

∴ Quarks are held together by a strong nuclear force

Radioactive processes :- During a nuclear process, nucleon number, proton number and mass energy are conserved. The process is random and spontaneous

Random :- Impossible to predict and each nucleus has the same probability of decaying per unit time

Spontaneous :- The process is not affected by external factors such as presence of other nuclei, temperature and pressure



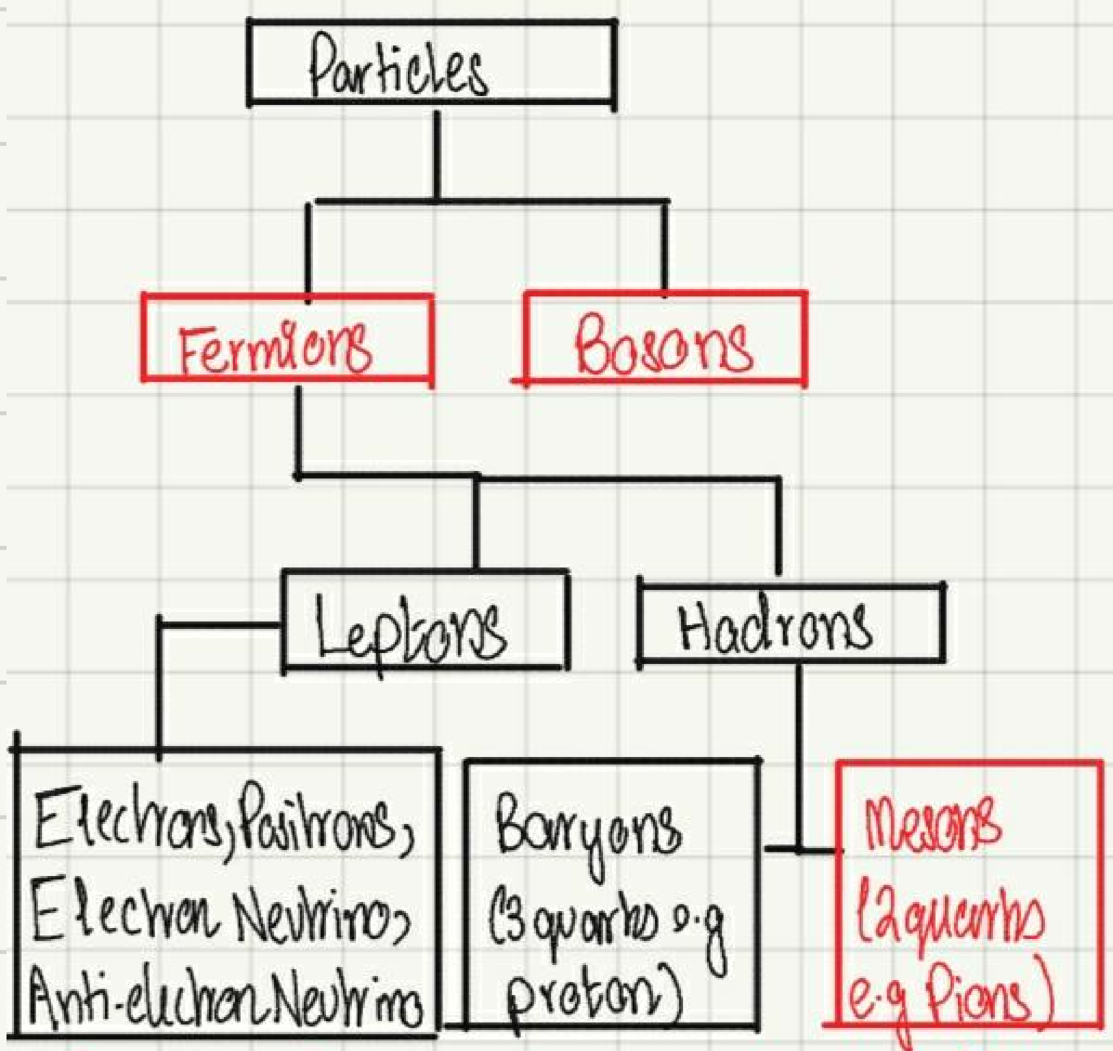
- Random; graph will have fluctuations in count rate
- Spontaneous; graph has same shape even at different temperatures, pressure etc.

Radioactive decay:- It is a random process in which a nucleus loses energy by emitting radiation. This is usually in the form of alpha particles, beta particles or gamma rays. The nucleus' energy reduces, making it more stable

α, β and γ properties

property	α-particle	β-particle	γ-radiation
mass	4 u	about u/2000	0
charge	+2e	−e or +e	0
nature	helium nucleus (2 protons + 2 neutrons)	negative or positive electron	short-wavelength electromagnetic waves
speed	up to 0.05c	more than 0.99c	c
penetrating power	few cm of air	few mm of aluminium	few cm of lead
relative ionising power	10^4	10^2	1
affects photographic film?	yes	yes	yes
deflected by electric, magnetic fields?	yes,	yes,	no

Particle Classification



∴ Ones in red are not part of the AS level syllabus

Gamma Radiation:- In gamma radiation no particles are emitted, so no change in either proton or neutron occur

Example: $^{234}_{90}Th \rightarrow ^{234}_{90}Th + \gamma$

eV:- A unit of energy equal to 'the work done on an electron in accelerating it through a potential difference of one volt'.

$$eV = \frac{\text{energy in Joules}}{1.6 \times 10^{-19}}$$

Alpha particles and decay:-

∴ Alpha particles are helium nuclei

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

Example:- $^{234}_{92}U \rightarrow ^{230}_{90}Th + ^{4}_{2}\alpha + \text{energy}$

Beta decays

Beta plus (β^+):- These are fast moving antielectrons, also known as positrons. A neutrino ν is also emitted. It is nearly a massless particle with no charge

Equation:- $^{A}_{Z}X \rightarrow ^{A}_{Z-1}X + ^{0}_{1}\beta^+ + ^{0}_{0}\nu + \text{energy}$

Example:- $^{30}_{15}P \rightarrow ^{30}_{14}Si + ^{0}_{1}\beta^+ + ^{0}_{0}\nu + \text{energy}$

∴ In terms of nucleons a proton changes into a neutron and a neutrino and β^+ particle is emitted

→ $p \rightarrow n + \beta^+ + \nu$

∴ In terms of quarks an up quark is changed into a down quark and a neutrino and β^+ particle is emitted

→ $u \rightarrow d + \beta^+ + \nu$

Beta Minus (β^-):- Beta minus particles are fast moving electrons. An anti-neutrino $\bar{\nu}$ is also emitted in the decay. It is a massless particle with no charge

Equation:- $^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta^- + ^{0}_{0}\bar{\nu} + \text{energy}$

Example:- $^{214}_{82}Pb \rightarrow ^{214}_{83}Bi + ^{0}_{-1}\beta^- + ^{0}_{0}\bar{\nu} + \text{energy}$

∴ In terms of nucleons, a neutron changes into a proton and an antineutrino and $^{0}_{-1}\beta^-$ is emitted

→ $n \rightarrow p + \beta^- + \bar{\nu}$

∴ In terms of quarks, a down quark changes into an up quark and an antineutrino and a β^- particle is emitted

→ $d \rightarrow u + \beta^- + \bar{\nu}$