Particle and Nuclear Physics

Radioactivity : The process of spontaneous and random disintegration (decay) of unstable nuclei to become stable.

Spontaneous : The process is not affected by any physical factors like temperature, pressure.

Random :- Unpredictable:

(i) Which nuclei will decay next.

(ii) Radiation will come out from which direction

α, β, γ

α - 5-8 cm

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

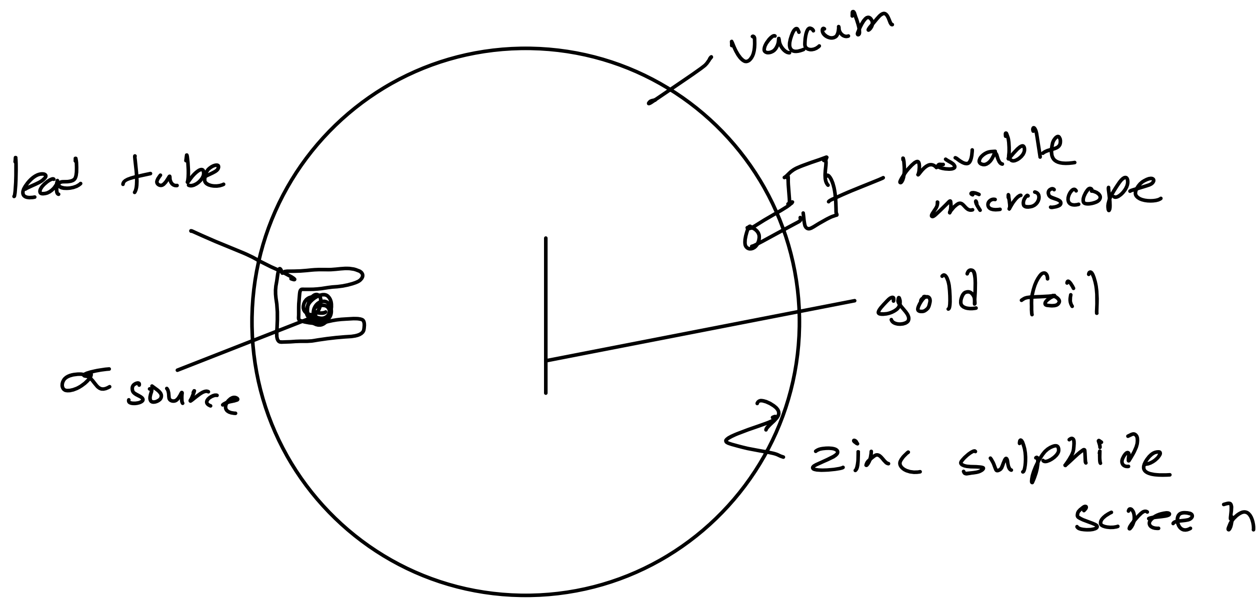
β^-

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

β^+

γ

α scattering experiment



In this experiment α particles are fired through an extremely thin gold foil in vacuum. Gold foil is thin enough to let α particles to pass through it. Lead tube is used to ensure that all α particles hit the foil surface perpendicularly. If α particles are emitted at other angles, they are absorbed in lead. Vacuum is made so that α particles are not slowed down or scattered

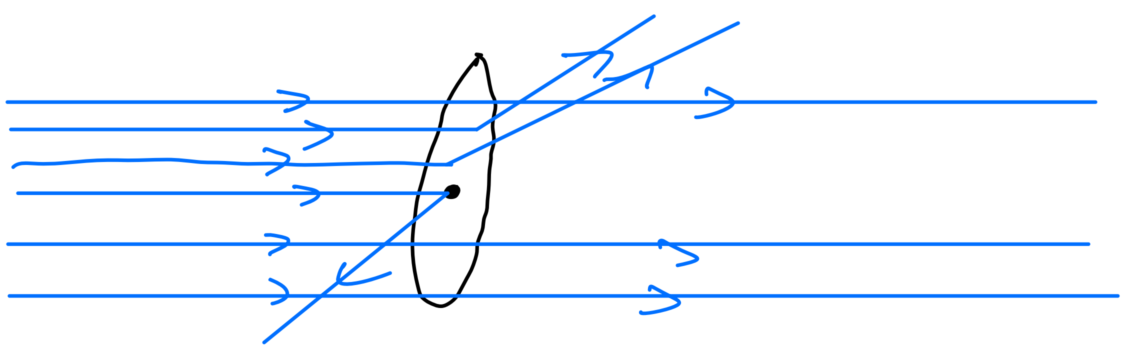
colliding with air molecules.
Flourescent screen glours when a charge particle hits it.

Results

1) Most of the α particles pass through the foil straight or with no deflection.

ii) Some of them are deflected 10° to 90° from their initial pathway.

iii) Very few of them ($\frac{1}{8000}$) are deflected through angles greater than 90° (rebounded)



Conclusion ① Most of the atom is empty space

② Most of the mass of the atom is concentrated in a tiny positively charged nucleus.

③ Alpha particles that are deflected through large angles had come very close to positively charged nucleus.

The standard model / Quark Model

Protons and neutron are not indivisible, rather discovery has been made of much smaller, consistant particles. Based on this, quark model was introduced.

They are 12 fundamental particles which we divided into two classes.

- Quarks — 6
- leptons — 6

Name	symbol	Charge	Mass
G_1 { up	u	$+\frac{2}{3}e$	a few MeV/c^2
down	d	$-\frac{1}{3}e$	
G_2 { charm	c	$+2/3\ e$	about 1 GeV/c^2
strange	s	$-\frac{1}{3}e$	about 0.1 GeV/c^2
G_3 { top	t	$+\frac{2}{3}e$	over 100 GeV/c^2
bottom	b	$-\frac{1}{3}e$	a few GeV/c^2

ev → electron volt

eV → unit of energy $\quad V = \frac{E}{Q}$

$$E = VQ$$

If 1 electron is moved across a potential difference of 1 V. 1 eV work is done.

$$1\ ev = 1\ e \times 1\ V$$

$$\Rightarrow 1.6 \times 10^{-19} C \times 1V$$

$$1\ ev = 1.6 \times 10^{-19}\ J$$

because $E = mc^2$

$$m = \frac{E}{c^2} \Big\} \text{ popular way to show mass in nuclear physics}$$

Mass $= 5 M \, eV/c^2$

$$\frac{5 \times 10^6 \times 1.6 \times 10^{-19}}{(3 \times 10^8)^2}$$

$\Rightarrow 8.89 \times 10^{-30}$ kg

Proton uud $\underbrace{\left(+\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e\right)}_{= +1e}$

Neutron udd $\underbrace{\left(+\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e\right)}_{= 0}$

→ All composite particles made of Quarks are called Hadrons.

→ Composite particles comprised of 3 quarks or 3 anti quarks are called Baryons. Hence protons and neutrons are called Baryons.

→ Composite particles comprised of 1 quark and 1 antiquark are called Mesons.

eg. pion (π^+ meson)

$u \bar{d}$

phi meson (ϕ meson)

($s \bar{s}$)

Hadron
- Baryons (3 quark)
- Meson (one quark and one anti quark)

<u>Anti particles</u> : Each of the 12 fundamental particles can have their anti particles. An anti particle has all the properties exactly opposite to the particles except mass is equal.

<u>example</u>:

① Anti up quark $\bar{u}$ has a charge of $-\frac{2}{3}e$.

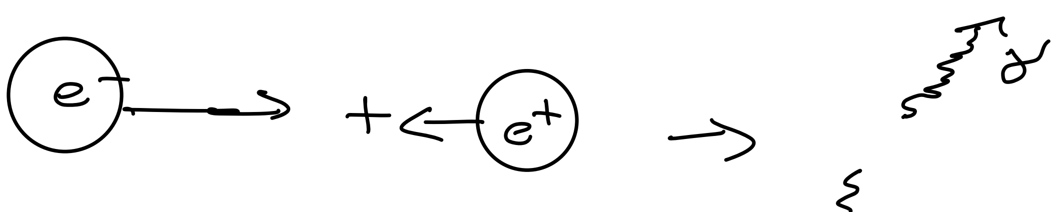
(ii) Anti proton $\bar{p}$ has a charge of $-1e$.

$\bar{u}\bar{u}\bar{d}$

If a particle and its anti particle combine up together. They immediately gets converted into energy producing $E = 2mc^2$. This process is called annihilation. This is the key process for energy production is fission and fusion.

eg. electron and positron

if they annihilate each other, their mass is converted into electromagnetic energy in the form of two gamma photons.



$e^- + e^+ \rightarrow \gamma + \gamma$

Photon → packet of energy.

Leptons

Name	symbol	Charge
electron	e^-	-1
electron neutrino	ν_e	0
Muon	μ^-	-1
Muon neutrino	ν_μ	0
Tau	τ^-	-1
Tau neutrino	ν_τ	0

β^- and β^+

It was noticed that β particles were emitted with a range of speed - some travelled more slowly than others. It was deduced that some other particles must be carrying off some of the energy and momentum released in the decay. These particles are neutrino (ν) or antineutrino ($\bar{\nu}$)

for

β^- decay

$${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e^{\beta^-} + \bar{\nu} \text{ (anti neutrino)}$$

β^+ decay

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e^{\beta^+} + \nu \text{ neutrino}$$

Neutrinos are bizarre particles. They have very little mass (less than electron) and no electric charge which makes them very difficult to detect.

Change of quark composition in

β decay

β^- decay $\quad \underset{(udd)}{n} \rightarrow \underset{(uud)}{p} + e^- + \bar{\nu}$

a down quark change to an up quark.

β^+ decay

$$p \rightarrow n + e^+ + \nu$$
$$(u\,u\,d) \quad (u\,d\,d)$$

an up quark becomes a down quark.

Note

Quarks must always be bound into particles by strong nuclear force.

The nucleus is held together by a strong nuclear force acting against the repulsive electrostatic force between protons.

Strong nuclear force → inside nucleus.
weak interaction → outside the nucleus.

Weak interaction (weak nuclear force)

This force that acts on both quarks and leptons. the weak interaction is responsible for β- decay.