FUNDAMENTAL PARTICLES : RADIOACTIVITY

The term "fundamental particles" refers to all particles that make up an atom

Fundamental particles are divided into three families:

i) Hadron family
ii) Lepton family
iii) Boson family

HADRONS

The following particles belong to the hadron family:

1. Protons (p)
2. Neutrons (n)
3. π^+ mesons (pi+)
4. π^- mesons (pi-)
5. ϕ mesons (phi)

etc.

Note: Hadrons are not fundamental particles, that is, they are believed to be composed of quarks, anti-quarks, and gluons.

- The quarks are further classified into 6 types. Their names, symbols, and charges are listed below:

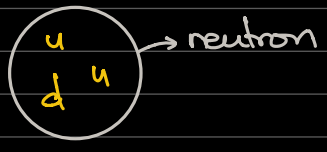
Name	Symbol	Charge
up quark	u	$+\frac{2}{3}e$
down quark	d	$-\frac{1}{3}e$
strange quark	s	$-\frac{1}{3}e$
charm quark	c	$+\frac{2}{3}e$
top quark	t	$+\frac{2}{3}e$
bottom quark	b	$-\frac{1}{3}e$

... where e represents the charge of an electron, ie. 1.6×10^{-19} C

- Similarly, the anti-quarks are also classified into 6 types. Their names, symbols, and charges are listed below

Name	Symbol	Charge
up anti quark	$\bar{u}$	$-\frac{2}{3}e$
down anti quark	$\bar{d}$	$+\frac{1}{3}e$
Strange anti quark	$\bar{s}$	$+\frac{1}{3}e$
charm anti quark	$\bar{c}$	$-\frac{2}{3}e$
top anti quark	$\bar{t}$	$-\frac{2}{3}e$
bottom anti quark	$\bar{b}$	$+\frac{1}{3}e$

Composition of a proton:
A proton is made up of 2 up quarks and 1 down quark

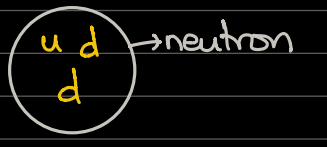


Charge of a proton = $u + u + d$

$= +\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e$

$= +1e \rightarrow$ Charge of proton

Composition of a neutron:
A neutron is made up of 1 up quark and two down quarks



Charge of a neutron = $u + u + d$

$= +\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e$

$= 0 \rightarrow$ hence, neutral

Composition of an α particle:
Since α particle consists of 2 protons and 2 neutrons, it belongs to the Hadron family

Charge of an α particle = $2n + 2p$

$= 2(u+d+d) + 2(u+u+d)$

$= 6u + 6d$

$= 6(+\frac{2}{3}e) + 6(-\frac{1}{3}e)$

$= 4e - 2e$

$= +2e \rightarrow$ charge of α particle

LEPTONS

- Leptons are fundamental particles
- Examples of particles belonging to the lepton family are given below:

1. electron (${}^{0}_{-1}e$, ${}^{0}_{-1}\beta$, β^-)
2. positron (${}^{0}_{+1}e$, ${}^{0}_{+1}\beta$, β^+)

Note: electrons and positrons have equal masses but they carry opposite charges

3. neutrino (ν)
4. anti neutrino ($\bar{\nu}$)

Note: neutrinos and antineutrinos have zero charge and negligible mass

5. muons (μ)
6. tau (τ)

etc...

Q. How is an electron and an antineutrino produced during radioactive decay (β^- decay)?

A. It is believed that when a neutron inside the nucleus decays, it results in the formation of a proton, an electron, and an anti-neutrino.

This decay can be shown as follows:

neutron ⟶ proton + electron + antineutrino

${}^{1}_{0}n$ ⟶ ${}^{1}_{1}p$ + ${}^{0}_{-1}e$ + $\bar{\nu}$

${}^{1}_{1}p$: stays in nucleus

${}^{0}_{-1}e$ + $\bar{\nu}$: emitted from nucleus

If you are asked to represent this equation in the form of a quark model:

udd ⟶ uud + ${}^{0}_{-1}e$ + $\bar{\nu}$

From the quark model, it can be noticed that when a neutron decays, it results in the conversion of a down quark into an up quark

↳ The force that is responsible for converting a neutron into a proton or a down quark into an up quark is known as the weak interaction / nuclear force

Note: Since antineutrinos have a range of speeds / KEs, electrons / β^- particles also have a range of speeds / KEs.

Q. How is a positron and a neutrino produced during radioactive decay (β^+ decay)?

A. It is believed that when a proton inside the nucleus decays, it results in the formation of a neutron, a positron and a neutrino

This is shown in the following equation

proton ⟶ neutron + positron + neutrino

$^{1}_{1}p \longrightarrow \underbrace{^{1}_{0}n}_{\text{stays in the nucleus}} + \underbrace{^{0}_{+1}e + \nu}_{\text{emitted from the nucleus}}$

$uud \longrightarrow \underline{u}d\underline{d} + {}^{0}_{+1}e + \text{neutrino}$

Note: The β^+ and neutrino are emitted from the nucleus with a range of speeds / KEs.

- The same force responsible for the conversion of d to u is responsible for the reverse process as well (ie. weak nuclear / interacting force)

BOSONS

Examples:

1. γ rays, aka. γ-photons
2. W-Boson
3. Z-Boson
4. Higgs Boson

etc....

Q. How are γ-rays / γ-photons produced?

A. It is believed that an electron ($^{0}_{-1}e$, $^{0}_{-1}\beta$, β^-) combines with a positron ($^{0}_{+1}e$, $^{0}_{+1}\beta$, β^+) and this results in the formation of γ-photons/rays.

This interaction can be represented using the following equation:

electron	+	positron	⟶	Gamma Rays	
β^-	+	β^+	⟶	"	"
$^{0}_{-1}e$	+	$^{0}_{+1}e$	⟶	"	"
$^{0}_{-1}\beta$	+	$^{0}_{+1}\beta$	⟶	"	"