PARTICLE PHYSICS

- Electron was discovered in 1987 by JJ Thompson
- Atom is electrically neutral so there must be a positive particle as well.

α-particle experiment

- The α particle source was encased in metal with a small apreture, following a fine beam of α particles to emerge.
- Air in the apparatus was pumped out to leave a vacuum ; α radiation is absorbed by few cms of air.
- The α particles were detected when they struck a fluorescent powder.

Result of α particle scattering experiment.

- Most α particles have little or no deviation so most of an atom is empty space.
- A few α particles are deviated more than 90°, so most of the mass of an atom is concentrated in a small space and most atom is empty space.
- An α particle is deviated due to repulsion between α-particle and +ve charge in the atom
- Diameter ~~w~~ of gold nucleus was about 10^{-14} m.

Model of atom after discovery of nucleus, proton and neutron.

- Protons and neutrons make up nucleus
- Electrons move around nucleus.

radius of nucleus $\approx 10^{-15}$ to 10^{-14} m.
radius of atom $\approx 10^{-10}$ m
size of atom is about 10^4 times that of nucleus.
Thus, if size of nucleus was 1m, size of atom ~~will~~ would be about 10 km. (diameter)

1 femtometer (fm) = 10^{-15} m.

Nuclear density

for gold, proton no. = 79, neutron no. = 118
mass of nucleus = 3.27×10^{-25} kg
Volume of nucleus = $\frac{4}{3}\pi r^3 = 4.19 \times 10^{-45}\ m^{-3}$
Density of nucleus = $\frac{mass}{volume} = 7.8 \times 10^{19}\ kg\,m^{-3}$.

- About 99.9% of atom is concentrated inside the nucleus.
- Except hydrogen, all atoms have nucleus.
- Protons and neutrons are collectively called nucleons.
- Total no. of nucleons is also called mass number.
- mass no. (A) = proton no. (Z) + neutron no. (N)
- $^{235}_{92}U$, is a symbol for an atom where 92 is proton number and 235 is mass/nucleon number

- A specific combination of protons and neutrons in a nucleus is called a neuclide.
- Electron $_{-1}^{0}e$, proton $_{+1}^{1}p$, neutron $_{0}^{1}n$

38. The table lists nucleon and proton number for various nuclei represented by letters L to T. Which row correctly shows three nuclei of same element, and three nuclei with same neutron number.

Answer: A (LMN, RPN)
Same element because proton no. is same (89)
Same neutrons because no. is 136

Isotopes

- Atoms of elements with same proton number but different nucleon number.
- Their chemical properties are very similar but have different nuclear properties.
- Artificially isotopes can be made by firing high velocity neutrons and bombard them to nuclei to create isotopes.
- Example protium, deuterium and tritium.
- when synthesizing, in β decay for example mass number and nucleons must always be conserved.

Forces in the nucleus

- Protons are positively charged, and like charge repels. So how is it possible to hold them in a small volume.
- There is attractive force between nucleons, known as strong nuclear force, which is stronger than electrostatic force.
- It only acts over short distance (10^{-24} m) also known as short range force.
- When at. no > 83, nucleus are unstable ~~f~~ and they undergo radioactive decay, emitting α, β^- and γ radiation.

Radiation	Symbol	Relative mass	Charge	Speed
α-particle	${}_2^4He$	4	+2e	$10^6\ ms^{-1}$
β^- particle	${}_{-1}^{0}e$	1/1840	-e	$10^8\ ms^{-1}$
β^+ particle	${}_{+1}^{0}e$	1/1840	+e	$10^8\ ms^{-1}$
γ-ray	γ	0	0	$3\times10^8\ ms^{-1}$

- α-particle and β-particle are particles of matter, γ ray is a photon of elektromagnetic radiation.
- α-particle is Helium nucleus, β^- particle is electron and β^+ is positron.
- mass of an α-particle is nearly 10000 times that of electron
- γ-ray has dual ~~particle~~ nature, wave and particle like nature.

//.

→ when heavy α-particle passes through matter, it ionizes atoms losing energy, so it can only penetrate through small thickness.

→ β^{+-} particles ionize less particles, so loses less energy, thus penetrating higher depth.

→ γ ray ionizes least so penetrates most.

→ β^- and β^+ particles are emitted during radioactive decay, but how can nucleus release electrons?

β^- decay

→ Inside nucleus, neutrons decay to proton and electron antineutrino.

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

→ Neutrino has very less mass even in comparison to electron and no electric charge.

→ Neutrino was detected when it was realised that energy dosen't balance when neutron only decays into proton & electron.

β^+ decay

→ Inside nucleus protons decays to become neutron and anti electron neutrino.

→ ${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$

α decay

→ ${}^{222}_{86}Ra \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$

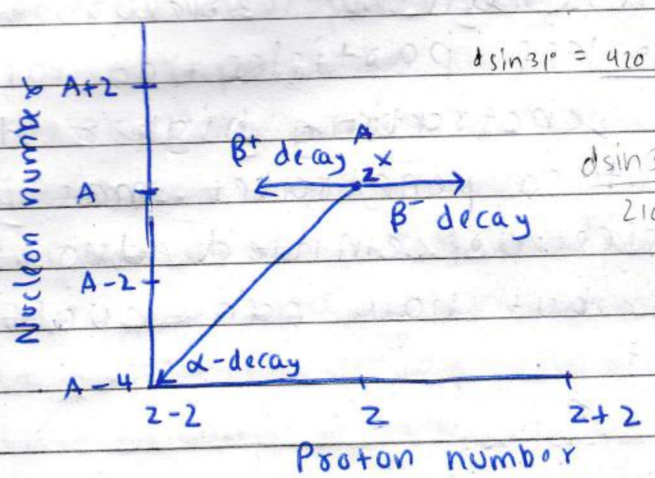
→ Where Radon is mother nucleus, and Polonium is daughter nucleus

ρA $\quad P = \frac{F}{A_2}$ $\quad \frac{A_1}{A_2} = \frac{1}{8}$ $\quad 8A_1 = A_2$

$\rho A_1 \times \frac{4}{100} = \rho A_2 \times \frac{0.5}{100}$

- In these decays, charge and mass number is always conserved.

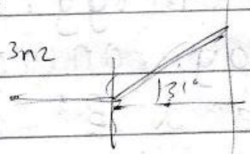
$d \sin\theta_n = n\lambda$



$d\sin 31° = \frac{420 \times (2n_1+3n_2)}{2}$ $\quad 2d\sin 31° = 420n_1 + 630n_2$

$= 420\left(n_1 + \frac{3}{2}n_2\right)$

$\frac{d\sin 31°}{210\times10^{-9}} = 2n_1+3n_2$ $\quad = 420(2n_1+3n_2)$



$d\sin 31° = n_1 \times 420$

$d\sin 31° = n_2 \times 630$

$\frac{420n_1}{630n_2} = 1$

$2n_1 = 3n_2$.

Particles and anti-particles

Antiparticle are particles having same mass as one of the particles of ordinary matter but opposite electric charge.
Eg: electron's antiparticle is positron.

Anihilation

- When particles and antiparticles interact, then energy is released following mass-energy equivalence ($E = mc^2$)
- The reverse of this is called creation.

$m_e\, e^- \longrightarrow \longleftarrow e^+\, m_e$

Total mass destroyed $= 2m_e$

$\therefore E = 2m_ec^2$

$A_1 \times \frac{4}{100}$

When α-particle is emmited energy is always discrete, but when β decays occur energies are shared between electron and neutrinos.

Atomic mass unit (u/amu)

$\sin 31° = \frac{n \times 420}{d}$

$\sin 31° = \frac{n \times 630}{d}$

- $e = 10^{-31}$ kg and $p = 10^{-27}$ kg
- 1 amu is defined as $(1/12)^{th}$ of a neutral C-12 atom.
- 6.023×10^{23} atoms of C-12 = 12g.

$n = 3/2$

- 1 atom of C-12 = $\frac{12}{6.023 \times 10^{23}}$ g.
- $1/12^{th}$ of 1 atom of C-12 = 1.66×10^{-27} kg.
- This is mass of $1p^+$ or $1n^0$.

The electronvolt (eV)

- Energy possesed by such particles is very small.
- So, electronvolt is a unit of energy.
- It is energy gained by an e^-, when it travels through a p.d. of 1 Volt.
- p.d = ~~word~~ $\frac{\text{work done}}{\text{charge}}$, $eV = \frac{W}{Q}$

$\sin(\theta$

$\theta_2 - \theta_1 = 31°$

$\sin\theta_2 \cos\theta_1 - \cos\theta_2 \sin\theta_1 = \sin 31°$

- $W = p.d \times Q = 1 \times (1.6 \times 10^{-19}) = 1.6 \times 10^{-19}$ J.
- 1 electron volt = 1.6×10^{-19} J.

F 0.5

$d\sin\theta = 1$

4cm

0.5 01

12N

$\sin\theta = \frac{1}{d}$

F — A

4r

$\sin\theta_2 - \sin\theta_1 = \frac{d_1 - d}{d_1}$ $\frac{d_1 - d_2}{d}$

4F

$\frac{4}{100} F = (F - 12) \times \frac{0.5}{100}$

Fundamental particles

- Matters are made up of atoms, atoms are made up of electrons, protons and neutrons
- These are detected in CERN.
- Fundamental particles can be divided into quarks and Leptons.

Quarks	Leptons	
up (u) $+2/3$	electron (e^-)	first gen
down (d) $-1/3$	electron neutrino (ν_e)	
strange (s) $-1/3$	muon (μ^-)	second gen
charm (c) $+2/3$	muon neutrino (ν_μ)	
bottom (b) $-1/3$	tau (τ^-)	third gen
top (t) $+2/3$	tau-neutrino (ν_τ)	

- Electrons are abondantly found in atoms, but muons are produced generally by nuclear reaction and in opper atmosphere by cosmic ray, while tau particles have so far only been discovored in lab.
- Neutrinos have little to no reaction with other (Higgs) and other fields, so they are very hard to detect.
- Tau and muons are heavier.

Quarks	Leptons
Fundamental particles with fractional charges.	Fundamental particles with $-e$ or 0 charge.
Affected by strong force so combine to form mesons and baryons (hadrons)	Not affected by strong force, so arent in combined form.

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→ Weak force can turn one quark into another, if two leptons come within range of weak force, then it is ~~respon~~ possible for them to change to other leptons.

Baryons

→ Made up of three quarks.
→ Protons (uud) and neutrons (udd)

Mesons

→ Made up of one quark and another antiquark.
→ π^+ meson, one up quark and anti down quark.
→ K^+ meson, one up quark and anti strange quark

A neutron decays by emitting a β^- particle.

a) Complete the eq^n below for the decay

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + \cancel{{}^{-1}_{0}\beta^-} \cancel{+} \cancel{\bar{V}} \; {}^{0}_{-1}\beta^- + {}^{0}_{0}\bar{V}$$

b) State the name of particle represented by $\bar{V}$
→ Here, $\bar{V}$ represents electron anti-neutrino.

c) State the ~~mame~~ name of class of particles that includes β^- and $\bar{V}$
→ Leptons

d) i) Quark structure of neutron ÷ udd
ii) Change to quark structure when neutron decays ÷ uud

Quark conversion in beta decay

+ β^- decay

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

udd → uud [weak force is responsible]

$$d \rightarrow u + {}^{0}_{-1}e + \bar{\nu}_e$$

$$-\tfrac{1}{3}e \rightarrow +\tfrac{2}{3}e - e$$

$$\therefore -\tfrac{1}{3}e = -\tfrac{1}{3}e$$

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PARTICLE PHYSICS ASSIGNMENT.

1. $^{238}_{92}U$ undergoes nuclear decays to form $^{234}_{92}U$. Which series of decays could give this result.

Mass number decreases by 4, so possible option narrows down to option C (1α and 2β)

$^{238}_{92}U \longrightarrow ^{234}_{90}U + ^{4}_{2}He$
$^{234}_{90}U \longrightarrow ^{234}_{92}U + 2\,^{0}_{-1}e$
$\therefore$ Answer = C

2. The eq^n for a fission reaction is shown.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{93}_{x}Rb + ^{141}_{55}Cs + y\,^{1}_{0}n$$

Balancing charge numbers,
$92 + 0 = x + 55 + y \times 0$
or, $92 - 55 = x$
$\therefore x = 37$
Balancing mass numbers,
$235 + 1 = 93 + 141 + y \times 1$
or, $236 - 93 - 141 = y$
$\therefore y = 2$
$\therefore$ Answer = C

3. A neutral atom has nucleus $^{133}_{55}Cs$. Find no. of p^+, e^- and n^0
No.(p^+) = 55
No(e^-) = 55
No(n^0) = 133 - 55 = 78
$\therefore$ Answer = A

4. A nucleus of neptunium -236 contains 93 protons and 143 neutrons. Nucleus decays with emmission of α-particle, then the nucleus formed emits β^- particle. Which diagram is correct. ($P = p^+$ number, N = neutron number).

Let's consider a representation $^{b}_{a}X$, where a is proton number and b is neutron number.

$$^{143}_{93}X \longrightarrow {}^{141}_{91}Y \longrightarrow {}^{140}_{92}Z$$

$\therefore$ Answer = D //.

5. The diagram shows sequence of decays.

$$^{237}_{93}Np \xrightarrow{\alpha} Q \xrightarrow{\beta^-} R \xrightarrow{\alpha} S \xrightarrow{\alpha} T$$

What is nuclide T?

$$^{237}_{93}Np \longrightarrow {}^{233}_{91}Q + {}^{4}_{2}He$$
$$^{233}_{91}Q \longrightarrow {}^{233}_{92}R + {}^{0}_{-1}e + {}^{0}_{0}\overline{Ve}$$
$$^{233}_{92}R \longrightarrow {}^{229}_{90}S + {}^{4}_{2}He$$
$$^{229}_{90}S \longrightarrow {}^{225}_{88}T + {}^{4}_{2}He$$

$\therefore$ Answer = A ($^{225}_{88}Ra$) //.

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6. A sample of radioisotope emits a beam of β^- radiation

a) State the change, if any, to the no. of neutrons in a nucleus of the sample that emits a β^- particle.
→ The number of neutrons decreases by 1, as in a β^- decay, a neutron changes to a proton.

b) The no. of β^- particles passing a fixed point in a beam in a time of 2 mins is 9.8×10^{10}. Calculate current in pA, produced by the beam of β^- particles.

$I = Q/t = ne/t = (9.8 \times 10^{10}) \times (1.6 \times 10^{-19}) / 120$
$= 1.3 \times 10^{-10}$ A

[We know $1A = 10^{12}$ pA]

$\therefore I = (1.3 \times 10^{-10}) \times 10^{12} = 130$ pA

c) Suggest why the β^- particles are emitted with a range of kinetic energies.
→ It is so because during β^- decay, an electron antineutrino is also released and the energy released is shared between the electron and the antineutrino in varying proportions. This causes the β^- particles to be emitted with a range of kinetic energies.

7a) The names of four particles are listed below:
alpha, beta-plus, neutron, proton

State the names of particles in this list that

i) aren't fundamental
→ alpha, neutron, proton

ii) don't experience force in electric field
→ neutron

iii) has largest charge to mass ratio
→ beta-plus.

b) A hadron has +e charge, where e is elementary charge. It is a meson where one quark is an antidown ($\bar{d}$) quark. State and explain the name (flavour) of the other quark.

Charge of anti-down quark $= +\frac{1}{3}e$

$+e = +\frac{1}{3}e + x$

$\therefore x = +\frac{2}{3}e$

$\therefore$ Charge of other quark $= +\frac{2}{3}e$

$\therefore$ The other quark is either an up quark, top quark or a charm quark.

8a) Use ~~a~~ quark model to show:

i) charge of proton is +e

Quark model of proton = uud

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

$= +\frac{4}{3}e - \frac{1}{3}e$

$= +\frac{3}{3}e$

$= +e$ //

ii) charge of neutron is zero.
Quark model of neutron = udd
Charge of neutron = $+\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e$
$= +\frac{2}{3}e - \frac{2}{3}e$
$= 0$,,

b) A nucleus of $^{90}_{38}Sr$ decays by emission of β^- particle
A nucleus of $^{64}_{29}Cu$ decays by emission of β^+ particle.

i) Fill the table.

	nucleus formed, β^-	nucleus formed β^+
nucleon number	90	64
proton number	39	28

ii) State the name of force responsible for β decay.
→ The force is weak nuclear force.

iii) State name of leptons produced in the following decay processes.

β^- decay : electron and electron antineutrino.
β^+ decay : positron and electron neutrino.

9. One of the particles is a Σ^+ hadron with +e charge which hadron is the Σ^+ particle?

Charge of A = $-\frac{1}{3}e - \frac{1}{3}e - \frac{1}{3}e = -e$,,
Charge. B = $-\frac{1}{3}e - \frac{1}{3}e - \frac{1}{3}e = -e$,,
Charge. C = $+\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e = 0$,,
Charge. D = $+\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e = +e$,,
∴ Answer = D ,,