Particle physics

11 Particle physics

11.1 Atoms, nuclei and radiation

Candidates should be able to:

1 infer from the results of the α-particle scattering experiment the existence and small size of the nucleus

2 describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons

3 distinguish between nucleon number and proton number

4 understand that isotopes are forms of the same element with different numbers of neutrons in their nuclei

5 understand and use the notation $^{A}_{Z}X$ for the representation of nuclides

6 understand that nucleon number and charge are conserved in nuclear processes

7 describe the composition, mass and charge of α-, β- and γ-radiations (both β^- (electrons) and β^+ (positrons) are included)

8 understand that an antiparticle has the same mass but opposite charge to the corresponding particle, and that a positron is the antiparticle of an electron

9 state that (electron) antineutrinos are produced during β^- decay and (electron) neutrinos are produced during β^+ decay

10 understand that α-particles have discrete energies but that β-particles have a continuous range of energies because (anti)neutrinos are emitted in β-decay

11 represent α- and β-decay by a radioactive decay equation of the form $^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\alpha$

12 use the unified atomic mass unit (u) as a unit of mass

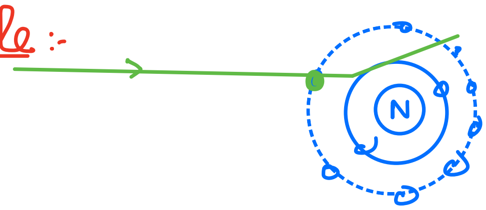
Rutherford / Geiger-Marsden Alpha particle scattering experiment.

Significance:- (i) Small size of nucleus] V↓] $\rho = \frac{m\uparrow}{V\downarrow}$ ↑
(ii) Greater mass of nucleus] m↑]

There is a dense nucleus is present inside an atom.

Significance of apparatus:-

(a) Why Alpha particle:-



Why α-particles:

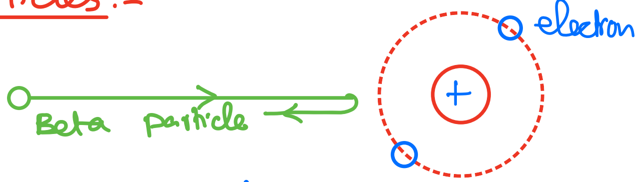
1- Alpha is a
massive particle and
not deflect due to orbiting electron and is
very able to come closer to nucleus of an atom.

2- Alpha particles emitted from a source have
constant energy.

i) Massive particle and does not show any deflection due to orbiting electrons and is able to come closer to Gold nucleus to identify its mass and volume.

(ii) Alpha particles emitted from a source have constant energy.

(b) Why not Beta particles:-



(i) Light particle and is bounced back due to repulsive force of orbiting electrons and can not come closer to nucleus.

(ii) Beta particles emitted from a source have a range of kinetic energy.

(c) Why not Gamma:

Gamma particle does not have charge and pass straight through the nucleus without any change of energy.

(d) Lead block - as a collimator:- Lead absorbs all other randomly emitted α-particles and allow single path which is directed towards Gold foil.

(e) <u>Evacuated chamber</u> is used so that Alpha particles do not transfer their energy in collision with air/gas particles inside chamber and reach Gold foil with constant energy

(f) <u>Gold foil</u> :- Thin foil and Alpha particle is very able to pass through it and hit the fluorescent screen.

(g) <u>Fluorescent screen/boundary of chamber</u> provides position where Alpha particles hit the screen as light spot is formed when particle hit a fluorescent material

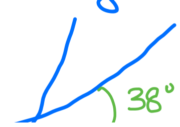
(h) <u>Travelling microscope</u> : It moves along the boundary of chamber to locate position where particles hit the screen.

<u>Observation</u>:

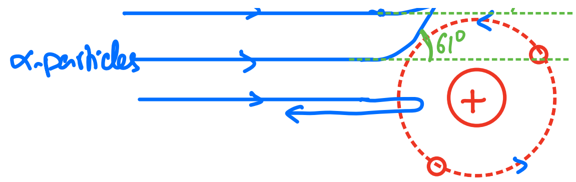
Most of Alpha particles pass through the foil with out any deflection and very few of them are deflected at large angles. 1 out of 8000 are bounced back at an angle greater than 150°.

<u>Reason</u> :-

Alpha particles are deflected due to repulsive forces exist between the +vely charged Alpha particles and Gold nucleus.



$F \propto \frac{1}{r^2}$



(gap)↓

(Repulsive force)↑

Rutherford Alpha particle scattering experiment:-

Significance:

(1) Smaller size of nucleus, V↓
(2) Greater mass of nucleus, m↑

$\uparrow \rho = \frac{m\uparrow}{V\downarrow}$

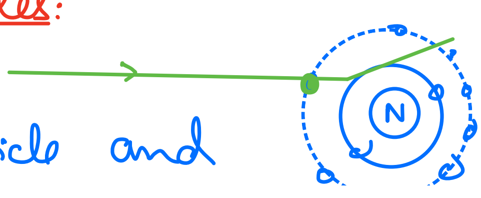
OR

There is a dense nucleus is present inside an atom.

Significance of apparatus:

Why α-particles:

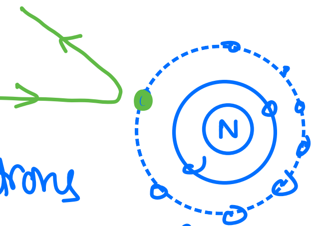
1- Alpha is a massive particle and



not deflect due to orbiting electron and is very able to come closer to nucleus of an atom.

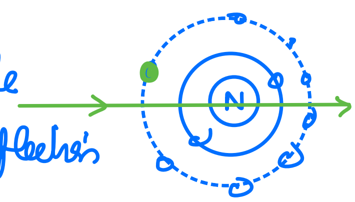
2- Alpha particles emitted from a source have constant energy.

Why not Beta particle:

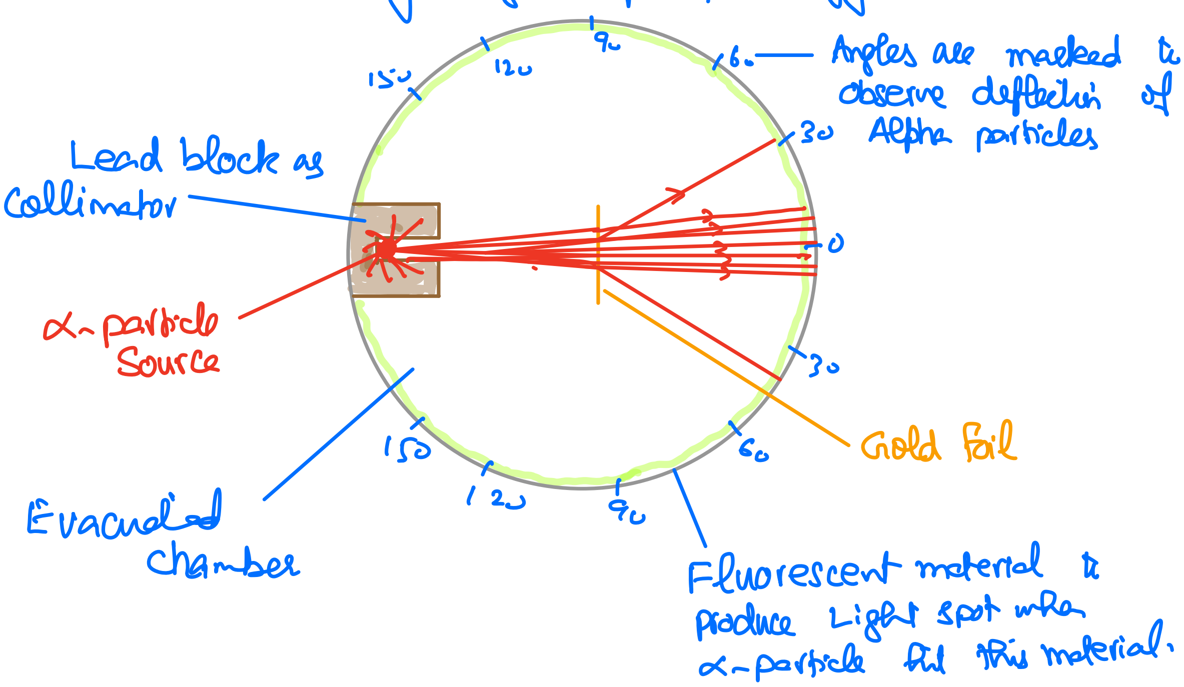


1. Light particle and shows deflection due to orbiting electrons and can not come closer to nucleus.
2. Beta particles emitted from a source have a range of energy.

Why not Gamma particle:-

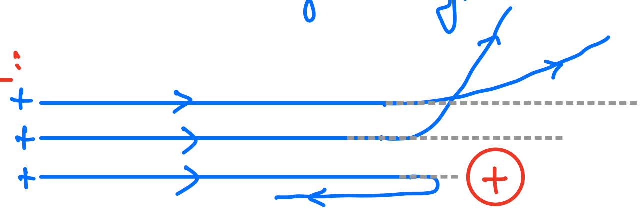


Gamma is a neutral particle and does not show any deflection due to very high speed/Energy.



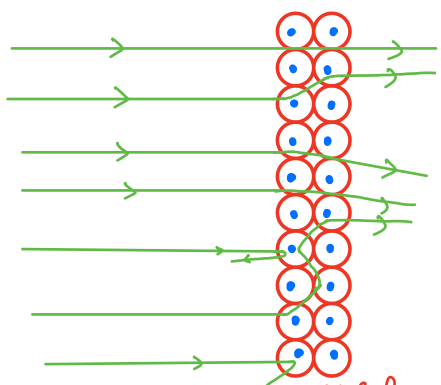
Observation: Most of Alpha particles pass through the foil with very little deflection and very few of them are deflected at large angle. 1 out of 8000 are bounced back at an angle greater than 150°.

Reason:

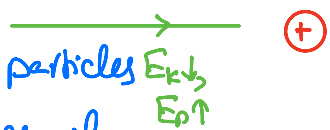


$\uparrow F \propto \frac{1}{r^2} \downarrow$

α- particles are deflected due to repulsive electric force b/w α-particles and +ve nucleus.



Result:



(1) The bouncing back of Alpha particles provide evidence that mass of Gold nucleus is much greater than mass of Alpha particle.

(2) The deflection of Alpha particles through different atoms show smaller size of nucleus.

Q) Calculate density of Gold nucleus.

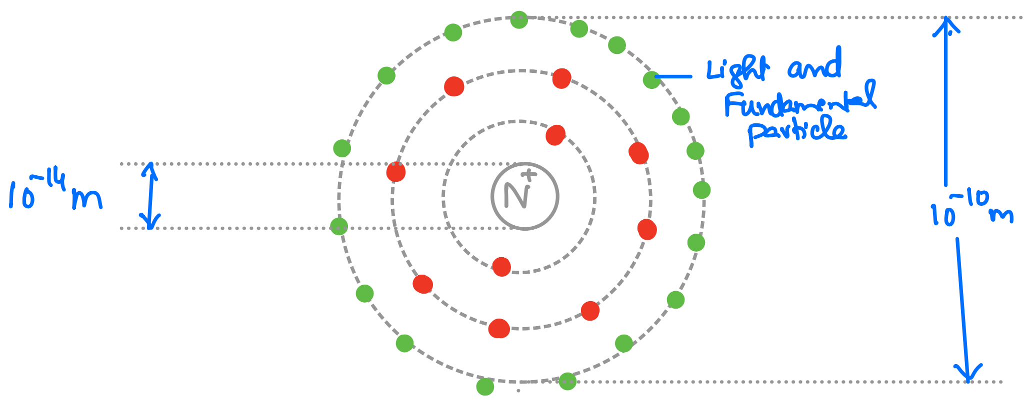
$^{197}_{79}Au$ diameter of nucleus $= 4.2 \times 10^{-14}$ m

$$\rho = \frac{m}{V} = \frac{197\,u}{\frac{4}{3}\pi r^3} = \frac{(197)(1.66\times10^{-27})}{\frac{4}{3}(3.14)(2.1\times10^{-14})^3}$$

$$= \underline{2.67\times10^{30}}\ kg\ m^{-3}$$

Atom:

- Nucleus ($+Q$, $m\uparrow$, $V\downarrow$, $\rho\uparrow$)
  - Proton ($+Q$)
  - Neutron ($Q=0$)
- electrons ($-Q$ and orbiting around nucleus in defined orbits)



Nucleus is around 10,000 times smaller than the entire atom

Mass Number/ Nucleon number:-

Def. Number of protons and no. of neutrons in the nucleus of an atom.

Symbol: A

Formula: $A = Z + N$, Z – no. of protons
N – No. of neutrons.

Charge number:

Def. Number of protons in the nucleus of an atom.

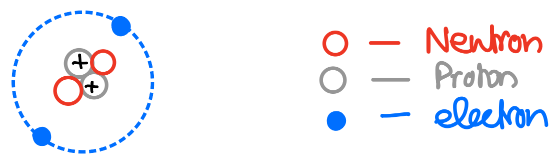
Symbol: Z

Nuclide:

Def. An element which is identified by its charge and mass number.

Notation. Symbol of an element ie ${}^{A}_{Z}X$ (A – nucleon no, Z – charge no)

Examples. ${}^{12}_{6}C$, ${}^{4}_{2}He$, ${}^{1}_{1}H$, ${}^{16}_{8}O$



Isotope:-

Def. Nuclei/atoms of same element which contain an identical no. of protons, but a different no. of neutrons.

Note: Despite having different no. of neutrons, isotopes of same element have very similar physical properties.

Notation: ${}^{A}_{Z}X$ (Variable A, Constant Z)

Examples: Hydrogen has three isotopes

Notation	No. of protons (Z)	no. of neutron (N)
$^{1}_{1}H$	1	0
$^{2}_{1}H$	1	1
$^{3}_{1}H$	1	2

Types of Decay:

Four types of radiations / particles are emitted in a Radioactive decay. They are identified as.

1- Alpha decay ($^{4}_{2}He$ or α)

2- −ve Beta decay / electron decay ($^{0}_{-1}e$ or $^{0}_{-1}\beta$)

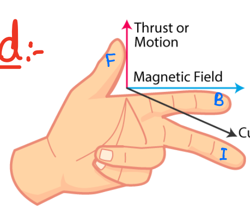
3- +ve Beta decay / positron decay ($^{0}_{+1}e$ or $^{0}_{+1}\beta$)

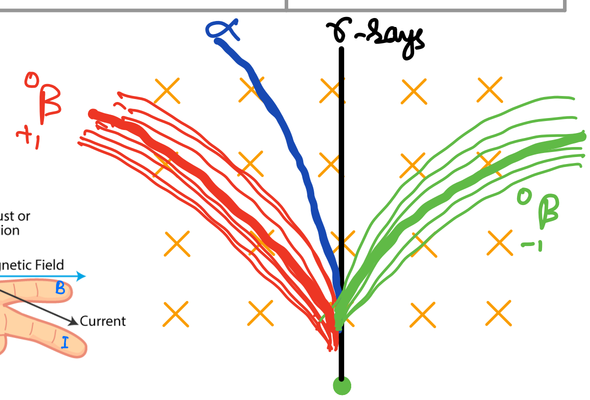
4- Gamma decay (γ)

S.No	Properties	Alpha particle	Beta particle	Gamma particle
1.	Charge	$+2e$ $e = 1.60 \times 10^{-19} C$	$+e$ (+ve Beta decay) $-e$ (−ve Beta decay)	Zero
2.	Relative mass	$4u$ $u = 1.66 \times 10^{-27} kg$	$\frac{u}{1840}$	Zero
3.	Nature charge & mass ratio	Helium nucleus	Fast moving electron or Positron	Electromagnetic wave / ray of highest frequency.
4.	Symbol	$^{4}_{2}He$	$^{0}_{-1}e$ or $^{0}_{+1}e$ $^{0}_{-1}\beta$ or $^{0}_{+1}\beta$	γ

S.No	Properties	Alpha particle	Beta particle	Gamma particle
5.	Energy	Discrete (Defined)	Varying due to range of radii in magnetic field	Discrete ($E = hf$)
6.	Speed in vacuum	Least up to 0·05 C	Intermediate more than 0·99C	Fastest $C = 3{\cdot}00 \times 10^8\ ms^{-1}$
7.	Ionising Ability (Relative order)	Highest 10^4	Low 10^2	Very Low $10^0 = 1$
8.	Penetration ability in air	very low 5 cm	High 40 cm	very high Infinite
9.	Blocking/Stopping material	Paper	1mm of Aluminium	Few cm of thick Lead
10.	Effect due to Electric field.	Attracted towards −ve plate (+ / −)	Attracted toward +ve plate for −ve Beta particle −ve plate for +ve Beta particle	undeflected
11	Effect due to magnetic field	slightly deflected	Greater deflection	undeflected
12.	Effects photographic film	Yes	Yes	Yes

Deflection of Alpha, Beta and Gamma particles in a uniform magnetic field:-





Result: Single path of α and γ- particles show that they have constant energy (/ discrete / defined value).

Multiple paths of Beta particles show the range of energies when emitted from a source.

The direction of deflection also provide us the charge on particle by Flemming's Left hand rule.

Reason: No other particle is emitted in Alpha decay shows constant energy of Alpha particles. In Beta decay, other particles ie neutrino / anti-neutrino are also emitted with different kinetic energy. So the energy of Beta particles also not constant.

Nuclear Decay Reactions:

[Radioactive Parent Nucleus] → [Daughter nucleus] + [Emitted Particle] + [Energy]

Note:

1- Nucleon no (A), proton no. (Z), mass, energy and momentum all are conserved in a Nuclear reaction / process.

2- Neutron no. (N) may not be conserved in a Nuclear process.

Example:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

(a) **Alpha decay:** $^{4}_{2}He$ or α

An α- particle is identical to a Helium nucleus

General reaction:

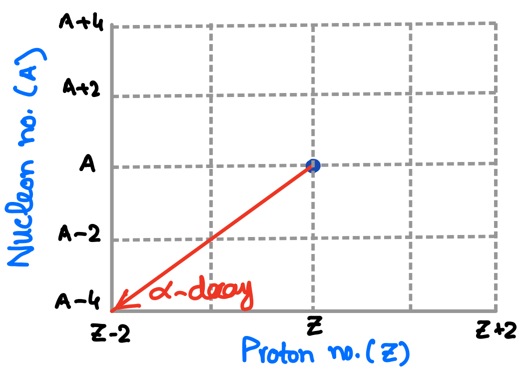
$$^{A}_{Z}X \longrightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$$

Example:

$$^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + \alpha$$

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

Note: In α-decay, the proton number of the nucleus decreases by two, and the nucleon number decreases by 4 and a new element is formed.



(b) **Beta decay:**

(i) **-ve Beta decay** - electron decay ($^{0}_{-1}\beta$ or $^{0}_{-1}e$)

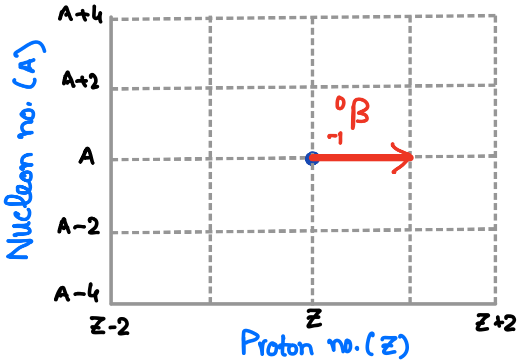
General reaction:

$$^{A}_{Z}X \longrightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e + ^{0}_{0}\bar{\nu} + \text{Energy}$$

Example:

$$^{214}_{82}Pb \longrightarrow ^{214}_{83}Bi + ^{0}_{-1}e + ^{0}_{0}\bar{\nu} + \text{Energy}$$

Note : (1) In −ve β − decay, the proton number of the nucleus increased by 1, and the nucleon number remain constant and a new element is formed.



(2) Another particle called anti-neutrino ($^{0}_{0}\bar{\nu}$) with no electrical charge and negligible mass is also emitted from nucleus at the same time

(3) Here a neutron in the nucleus changes to a proton, a −ve electron and an anti-neutrino are released.

$$^{1}_{0}n \longrightarrow {}^{1}_{1}P + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu} + \text{Energy}$$

(ii) +ve Beta decay − Positron decay ($^{0}_{+1}\beta$ or $^{0}_{+1}e$)

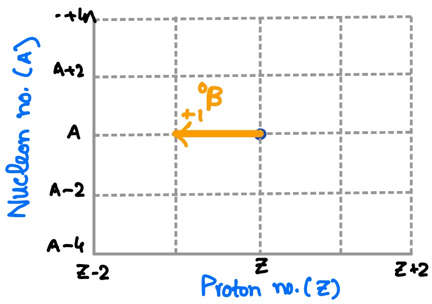
General reaction :

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + {}^{0}_{0}\nu + \text{Energy}$$

Example :

$$^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{1}e + {}^{0}_{0}\nu + \text{Energy}$$

Note : (1) In +ve β − decay, the proton number of the nucleus decreased by 1, and the nucleus number remain constant and a new element formed.



(2) Another particle called neutrino ($^{0}_{0}\nu$) with no electrical charge and negligible mass is also emitted from nucleus at the same time

(3) Here a proton in the nucleus changes to a neutron, a +ve electron and an neutrino are released.

$$^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + {}^{0}_{0}\nu + \text{Energy}$$

REASON FOR BETA DECAY :-

Beta decay (electron or positron) is due to weak interaction / nuclear forces. The range of nuclear forces is with in the nucleus i.e of the order of 10^{-14} m and is the fundamental strongest force that exist in nature.

Gamma decay: γ

General reaction:

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z}X + \gamma$$

Example:

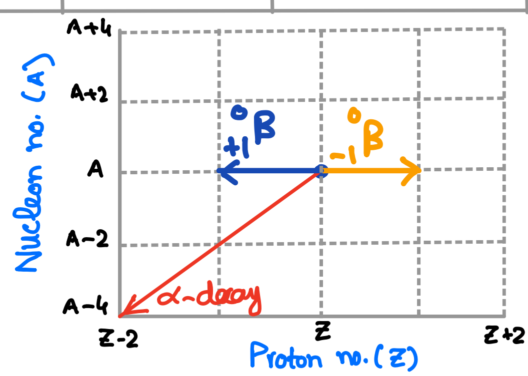
$$^{234}_{90}Th \longrightarrow {}^{234}_{90}Th + \gamma$$

Note: 1- Parent nuclide $^{234}_{90}Th$ is unstable unstable/ excited to form a stable $^{234}_{90}Th$ nuclide by emitting a Gamma particle/ray.

2- In γ- emission, no particles are emitted and there is, therefore, no change to the proton number or nucleon no. of the parent nuclide.

Summary:

S.No.	Decay reaction	Daughter Nuclide	Change in Mass no. (A)	Change in charge no. (Z)	Any new Particle emitted
1.	Alpha decay	New Nuclide is obtained	decreases by 4	decreases by 2	—
2.	Electron decay ($^{0}_{-1}\beta$)	New Nuclide is obtained	Unchanged	Increased by 1	Anti-neutrino ($\bar{\nu}$)
3.	Positron decay ($^{0}_{+1}\beta$)	New Nuclide is obtained	Unchanged	Decreased by 1	Neutrino (ν)
4.	Gamma decay	No change	No change	No change	—



Unified atomic mass unit:

Def: It is the mass of $(\frac{1}{12})^{th}$ part of mass of C−12 isotope.

Symbol: u

Value (given on page 2) $1u = 1.66 \times 10^{-27}$ kg

Example:

1. **Mass of Helium nucleus in u** $({}^{4}_{2}He)$

$$m = 4u = 4(1.66 \times 10^{-27}) = 6.64 \times 10^{-27} \text{ kg}$$

So, mass of Alpha particle is also 6.64×10^{-27} kg

2. **Mass of Uranium nucleus:** ${}^{235}_{92}U$

$$m = 235u = 235(1.66 \times 10^{-27}) = \_\_\_\_\_\_\_\_ \text{ kg}$$

Energy associated with 1u:

$$E = mc^2$$

$$= (1.66 \times 10^{-27})(3.00 \times 10^{8})^2$$

$$= 1.49 \times 10^{-10} \text{ J}$$

$V = \frac{W}{Q}$

$V = \frac{W}{e}$

$eV = W$

$(1e)(1V) = 1.60 \times 10^{-19}$ J

But $1 eV = 1.60 \times 10^{-19}$ J

$1 MeV = (10^{6})(1.60 \times 10^{-19}) = 1.60 \times 10^{-13}$ J

$$E = \frac{1.49 \times 10^{-10}}{1.60 \times 10^{-13}} = \underline{931} \text{ MeV}$$

11.2	Fundamental particles

Candidates should be able to:

1 understand that a quark is a fundamental particle and that there are six flavours (types) of quark: up, down, strange, charm, top and bottom

2 recall and use the charge of each flavour of quark and understand that its respective antiquark has the opposite charge (no knowledge of any other properties of quarks is required)

3 recall that protons and neutrons are not fundamental particles and describe protons and neutrons in terms of their quark composition

4 understand that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and one antiquark)

5 describe the changes to quark composition that take place during β^- and β^+ decay

6 recall that electrons and neutrinos are fundamental particles called leptons

Composition of matter:

Composition	Diameter or Size / m
Molecule	10^{-10} to 10^{-6} = 10^{-8}
Atom	10^{-10}
Nucleus	10^{-14}
Protons or Neutrons	10^{-15}
Quarks	Less than 10^{-18}

Particle:

→ Classical Physics : Any thing whose rest mass is defined.

→ Modern/ Quantum Physics : Any thing whose momentum is defined.

Types of particles:-

→ Leptons

→ Hadrons

Leptons:

Meaning: Light ones in Greek language

Def: Particles which are considered as fundamental and are not made of other particles.

Note: (1) Leptons are not affected by strong forces (electric or nuclear forces)

(2) All Leptons have very small masses.

Examples: (i) Positron and anti-neutrino

(ii) Electron and neutrino

Hadrons:-

Meaning: Heavy ones in Greek language.

Def: These are not fundamental particles and are made of other particles called Quarks.

Note: 1. Hadrons are affected by strong nuclear forces.

2. Each Hadron is made of three quarks.

Examples: 1- Proton

2- Neutron

Types of Hadrons:

(1) **Baryons:** Baryons are particles consisting of three quarks e.g. protons and neutrons.

(2) **Mesons:** Measons are particles consisting of one quark and one antiquark.

Quark model:-

Fundamental particles which are combined to form Hadrons are Quarks. There are six types of Quarks. A Quark can never exist as independent in nature.

Types:

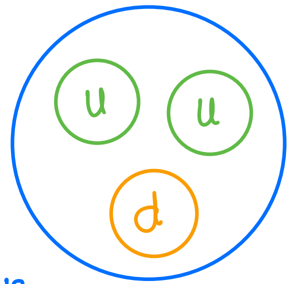
Quark	Symbol	Charge
up	u	$+\frac{2e}{3}$
down	d	$-\frac{e}{3}$
Charm	c	$+\frac{2e}{3}$
Strange	s	$-\frac{e}{3}$
top	t	$+\frac{2e}{3}$
bottom	b	$-\frac{e}{3}$

Note: Top quark is the heaviest with a mass of approximately 200 times the mass of a proton.

Composition of a proton: A proton is an example of Baryons and is made of two upquarks, one down quark and a strange quark.

Proton : u u d

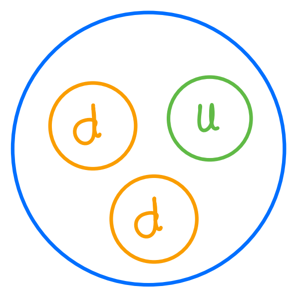
$$\text{proton} = u + u + d$$
$$= +\frac{2e}{3} + \left(\frac{2e}{3}\right) + \left(-\frac{e}{3}\right)$$
$$= \frac{2e + 2e - e}{3}$$
$$= +\frac{3e}{3} = +e = +1.60 \times 10^{-19}\,C$$



Composition of a neutron: A proton is also an example of Baryons and is made of two down quarks, one up quark and a strange quark.

Neutron : u d d

$$= u + d + d$$
$$= +\frac{2e}{3} + \left(-\frac{e}{3}\right) + \left(-\frac{e}{3}\right)$$
$$= \frac{2e - e - e}{3}$$
$$= \frac{0(e)}{3} = 0$$



Change in quark model in Beta decay:

(1) Positron decay (+ve Beta decay) :-

$${}^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + {}^{0}_{0}\nu + \text{Energy}$$

uud → udd

Here a proton changes to a neutron. So an up quark changes to a down quark.

(ii) Electron decay (−ve Beta decay)

$$ {}^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu} + E $$

u d d → u u d

Here a neutron changes to a proton. So a down quark changes to an up quark.

Composition of Helium nucleus interms of Quark model: ${}^{4}_{2}He$

$$ {}^{4}_{2}He \text{ nucleus} = 2\,{}^{1}_{1}p + 2\,{}^{1}_{0}n $$

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

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

$$ = 4u + 2d + 2u + 4d $$

$$ = 6u + 6d $$

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

$$ = 4e - 2e $$

$$ = +2e $$

$$ = +2(1.60\times10^{-19}) $$

$$ = 3.20\times10^{-19}\,C $$

Fundamental particles

Electrons, neutrons, and protons were once thought to be **fundamental particles** (i.e., they did not consist of combinations of other particles). It was later discovered that, although electrons are still believed to be fundamental particles, protons and neutrons consist of combinations of smaller particles. These particles were given the name **quarks**.

The **standard model of particle physics** asserts that there are 12 fundamental particles, which can be divided into two groups, according to their properties, as shown in Table 26.2.

Quarks: there are six types of quark. Protons and neutrons are made up of different combinations of quarks.

Leptons: there are six types of lepton. An electron is one example of a lepton. All leptons have very small masses (lepton means light in Greek).

▼ **Table 26.2** Quarks and leptons

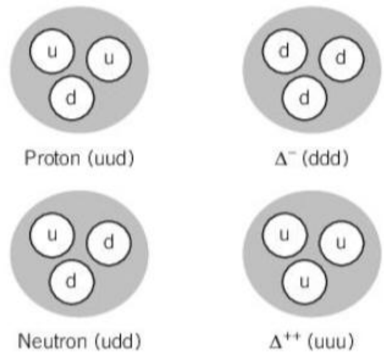
				Charge / *e*
Quarks	up, u	charm, c	top, t	$+\frac{2}{3}$
	down, d	strange, s	bottom, b	$-\frac{1}{3}$
Leptons	electron, e	muon, μ	tau, τ	− 1
	electron-neutrino, ν_e	muon-neutrino, ν_μ	tau-neutrino, ν_τ	0

Quarks occur in groups of two or three, never separately. The top quark is the heaviest with a mass approximately 200 times the mass of a proton. As well as the 12 fundamental particles, there are 12 equivalent antiparticles.

There are four fundamental forces that control the interactions between fundamental particles, as shown in Table 26.3.

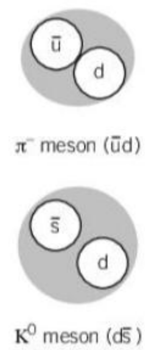
▼ **Table 26.3** Fundamental forces

Force	Range	Acts on
Gravity	no limit	all objects
Electromagnetic	no limit	charged objects
Strong nuclear force	10^{-15} m	quarks and antiquarks
Weak nuclear force	10^{-18} m	fundamental particles



▲ **Figure 26.7** Some baryons

A proton consists of two up quarks and one down quark (uud), held together by the **strong nuclear force**. A neutron consists of one up quark and two down quarks (udd). Particles that consist of combinations of quarks and antiquarks are called **hadrons** (hadrons are defined as particles held together by the strong nuclear force). Baryons are particles consisting of three quarks (Figure 26.7). They include protons and neutrons. Mesons (Figure 26.8) are particles consisting of one quark and one antiquark. Antibaryons consist of three antiquarks (Figure 26.9).



▲ **Figure 26.8** Some mesons

Worked example

One type of hadron consists of two down quarks and one strange quark. State the charge on this hadron.

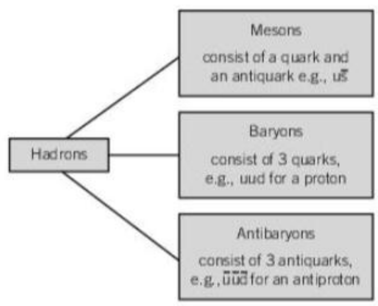
Answer

Both the down quark and the strange quark have a charge $-\frac{1}{3}e$, so the total charge must be $-e$.

Quarks and beta decay

In β^--decay, a down quark changes into an up quark in one of the neutrons in a nucleus, making it a proton, and in doing so emits an electron (the β^--particle) and an electron antineutrino. In β^+-decay, one of the protons in a nucleus changes into a neutron by one of the up quarks changing into a down quark, emitting a positron (the β^+-particle) and an electron neutrino in the process.

The force (or interaction) responsible for beta decay, causing a neutron to change into a proton (or a proton into a neutron), is the **weak nuclear force** (or **weak interaction**).



▲ **Figure 26.9** Hadrons

9702/13/M/J/20

39 Radiation from a radioactive source has a range of a few millimetres in air and can be deflected by an electric field.

Which type of radiation is being emitted?

A α-radiation

B β^- radiation

C β^+ radiation

D γ-rays

40 Which equation describes the process of β^+ decay?

key:

u = up quark

d = down quark

ν = (electron) neutrino

$\bar{\nu}$ = (electron) antineutrino

A ddu $\rightarrow$ uud + β^+ + ν

B ddu $\rightarrow$ uud + β^+ + $\bar{\nu}$

C uud $\rightarrow$ ddu + β^+ + ν

D uud $\rightarrow$ ddu + β^+ + $\bar{\nu}$

9702/12/M/J/20

39 An unstable nucleus goes through successive decays to become a final, stable nucleus.

The initial nucleus and the final nucleus are isotopes of each other.

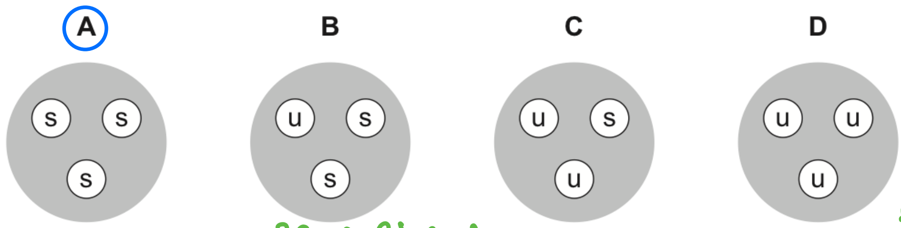
How many α and β^- particles could have been emitted during the decay sequence?

	particle	
	α	β^-
A	1	0
B	1	2
C	2	0
D	2	1

40 A hadron has a charge of $-e$ and is composed of three quarks. *(Baryons)*

s s s: $-\frac{e}{3} + (-\frac{e}{3}) + (-\frac{e}{3}) = -e$

What could be the quark composition of the hadron?



key

u = up quark
s = strange quark

B: $\frac{2e}{3} + (-\frac{e}{3}) + (-\frac{e}{3}) = 0$

C: $\frac{2e}{3} + \frac{2e}{3} - \frac{e}{3} = +e$

D: $+\frac{2e}{3} + \frac{2e}{3} + \frac{2e}{3} = \frac{6e}{3} = 2e$

9702/11/M/J/20

39 An element has two isotopic forms.

What are the nuclear arrangements of these two isotopes?

A They have different nucleon numbers and different proton numbers.

(B) They have different nucleon numbers but the same proton number.

C They have the same nucleon number and the same proton number.

D They have the same nucleon number but different proton numbers.

40 A hadron has a charge $+e$, where e is the elementary charge. *(Proton)*

Which combination of up (u) and down (d) quarks could form this hadron?

A ddd **B** udd **(C)** uud **D** uuu

9702/11/M/J/21

39 A nucleus of uranium, ${}^{235}_{92}U$, undergoes a series of decays. During the series of decays, two α-particles and one β^- particle are emitted.

As a result, a nucleus of actinium, Ac, is formed.

What is the correct notation for the nuclide of actinium that is formed?

A ${}^{227}_{87}Ac$ **(B)** ${}^{227}_{89}Ac$ **C** ${}^{231}_{87}Ac$ **D** ${}^{231}_{89}Ac$

$235 - 8 = 227$

$92 - 4 + 1 = 89$

${}^{235}_{92}U \rightarrow {}^{227}_{89}Ac + 2\,{}^{4}_{2}He + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

40 Which particle is a fundamental particle? (Lepton i.e electron, neutrino, β-particle

(A) electron

B hadron — Composed of other fundamental particles ie quarks)

C neutron — u+2d + 0s

D proton — 2u+1d + 0s

Strange quark

9702/12/M/J/21

39 A nucleus of magnesium decays into a nucleus X by emitting a β^+ particle. The decay is represented by the equation shown.

$$^{23}_{12}\text{Mg} \rightarrow \, ^{P}_{Q}\text{X} + \, ^{0}_{1}\beta^{+}$$

What are the values of P and Q?

	P	Q
A	22	11
B	22	13
C	23	11
D	23	13

40 In β^- decay, a neutron inside a nucleus changes to a proton.

Which statement describes the quark composition of the nucleus during the decay?

A The number of down quarks decreases by one.

B The number of down quarks increases by one.

C The number of down quarks stays the same.

D The number of up quarks stays the same.

9702/13/M/J/21

39 A beam of α-particles is incident on a thin gold foil. One α-particle collides head-on with a gold nucleus and is deflected back along its original path.

Which statement could explain why the recoil speed of the gold nucleus is small compared with the recoil speed of the α-particle?

A Most α-particles are only slightly deflected as they pass through the gold foil.

B The α-particle and the gold nucleus repel each other.

C The mass of the gold nucleus is much greater than the mass of the α-particle.

D The momentum of the α-particle decreases as it approaches the gold nucleus.

40 A hadron is composed of three quarks. The hadron has a charge.

What is a possible quark composition of the hadron?

A down, down, up

B down, up, strange

C up, strange, strange

D up, up, strange

9702/22/O/N/19

7 A nucleus of plutonium-238 ($^{238}_{94}Pu$) decays by emitting an α-particle to produce a new nucleus X and 5.6 MeV of energy. The decay is represented by

$$^{238}_{94}Pu \rightarrow X + \alpha + 5.6\,MeV.$$

(a) Determine the number of protons and the number of neutrons in nucleus X.

$^{238}_{94}Pu \longrightarrow ^{234}_{92}X + ^{4}_{2}He + 5.6\,MeV$

number of protons = 92

number of neutrons = 234 − 92 = 142

[2]

(b) Calculate the number of plutonium-238 nuclei that must decay in a time of 1.0 s to produce a power of 0.15 W.

Convert 5.6 MeV energy into joule

$E = (5.6)(10^6)(1.60 \times 10^{-19})$

$= 8.96 \times 10^{-13}$ J

$\frac{\text{Total energy}}{\text{Total time}} = \text{Average Power}$

$\frac{nE}{t} = P \Rightarrow \frac{(n)(8.96 \times 10^{-13})}{1.0} = 0.15$

number = ... [2]

$n = 1.67 \times 10^{11}$

[Total: 4]

9702/21/M/J/19

7 **(a)** One of the results of the α-particle scattering experiment is that a very small minority of the α-particles are scattered through angles greater than 90°.

State what may be inferred about the structure of the atom from this result.

There is small and massive charged nucleus is present inside an atom.

[2]

(b) A hadron has an overall charge of $+e$, where e is the elementary charge. The hadron contains three quarks. One of the quarks is a strange (s) quark.

(i) State the charge, in terms of e, of the strange (s) quark.

charge = $-\frac{e}{3}$ [1]

(ii) The other two quarks in the hadron have the same charge as each other.

By considering charge, determine a possible type (flavour) of the other two quarks. Explain your working.

2(quark) + 1(Strange quark) = +e

2(quark) − $\frac{e}{3}$ = e

quarks = $\frac{1}{2}\left(\frac{4e}{3}\right)$ ⇒ quark = $+\frac{2e}{3}$

....

Up quarks .... [2]

9702/22/M/J/20 [Total: 5]

7 **(a)** A nucleus of an element X decays by emitting a β^+ particle to produce a nucleus of potassium-39 ($^{39}_{19}K$) and a neutrino. The decay is represented by

$$^{Q}_{S}X \rightarrow {}^{39}_{19}K + {}^{P}_{R}\beta^+ + {}^{0}_{0}\nu.$$

(i) State the number represented by each of the following letters.

P ....0........

Q ....39........

R ....+1........

S ....20........

Q = 39, S = 19 + 1 = 20: $^{39}_{20}X \rightarrow {}^{39}_{19}K + {}^{0}_{+1}\beta + {}^{0}_{0}\nu$

[2]

(ii) State the name of the interaction (force) that gives rise to β^+ decay.

........Weak nuclear force........ [1]

(b) A hadron is composed of three identical quarks and has a charge of +2*e*, where *e* is the elementary charge.

Determine a possible type (flavour) of the quarks. Explain your working.

3x = +2e

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

........So flavour of quarks is up (u)........

.... [2]

[Total: 5]

6 (a) One of the results of the α-particle scattering experiment is that a very small minority of the α-particles are scattered through angles greater than 90°.

State what may be inferred about the structure of the atom from this result.

Scattering is caused due to electrostatic repulsive force that exist in between positively charged Alpha particle and the nucleus. Greater scattering signifies that majority of mass is concentrated in the nucleus. [2]

(b) An α-particle is made up of other particles. One of these particles is a proton.

Composition of Proton: 2 up quarks, 1 down quark and zero strange quark

State and explain whether a proton is a fundamental particle.

Proton is not a fundamental particle because it is made of other particles, called quarks. [1]

(c) A radioactive source produces a beam of α-particles in a vacuum. The average current produced by the beam is 6.9×10^{-9} A.

Calculate the average number of α-particles passing a fixed point in the beam in a time of 1.0 minute.

Total charge, $Q = It$

$= (6.9\times10^{-9})(60) = 4.14\times10^{-7}$ C

Total charge = (no. of charge carriers)(charge on an elementary particle)

$Q = ne$

$4.14\times10^{-7} = n[2(1.60\times10^{-19})]$

$n = 1.29\times10^{12}$

number = 1.29×10^{12} [3]

(d) and (e) parts are not in syllabus from June 2022.

Q7/23/M/J/19

33 A sample of a radioactive substance may decay by the emission of either α-radiation or β-radiation and/or γ-radiation.

State the type of radiation, one in each case, that:

(a) consists of leptons

β .... [1]

proton = 2u + d

(b) contains quarks

α = 2(2u + d) + 2(u + 2d) .... [1]

(c) cannot be deflected by an electric field

γ .... [1]

(d) has a continuous range of energies, rather than discrete values of energy.

β .... [1]

[Total: 4]

March 20/22

7 (a) State and explain whether a neutron is a fundamental particle.

Neutron is made of other fundamental particles i.e. Quarks. So it is not a fundamental particle [1]

(b) A proton in a stationary nucleus decays. $^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + \nu$

(i) State the **two** leptons that are produced by the decay.

Positron $({}_{+1}\beta)$

neutrino (ν) [2]

(ii) Part of the energy released by the decay is given to the two leptons.

State **two** possible forms of the remainder of the released energy.

Kinetic energy of emitted particles

Energy in the form of electromagnetic ray ie Gamma particle. [2]

[Total: 5]