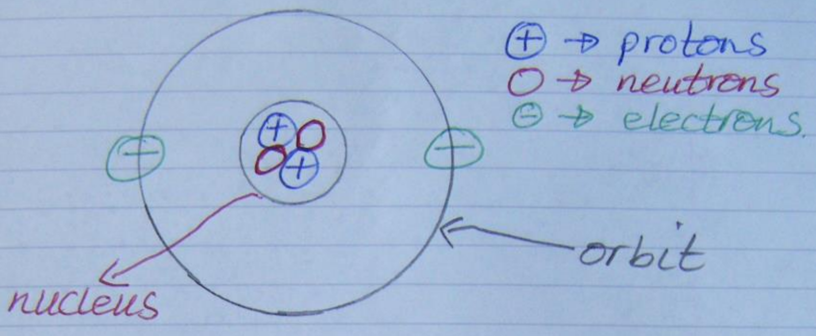
Nuclear Reactions – B. McMULLEN

The Atom



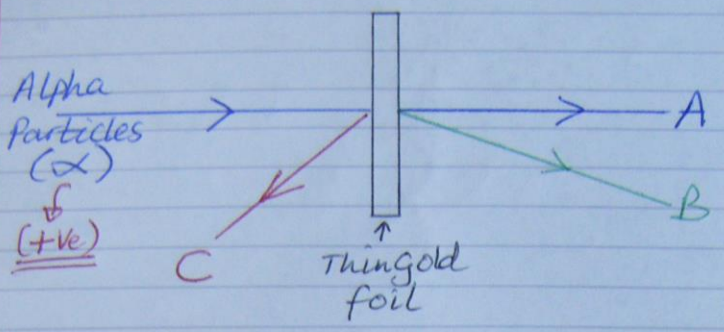
Relative sizes

Nucleus → Centre Spot
Atom Overall → Size of a large sports stadium
eg Celtic Park, Ibrox or Hampden.

Conclusion

- An atom is almost entirely empty space with the mass concentrated in the nucleus.
- An atom is neutrally charged as it has the same number of protons in the nucleus as it has electrons in the orbits.

The Rutherfords Scattering Experiment



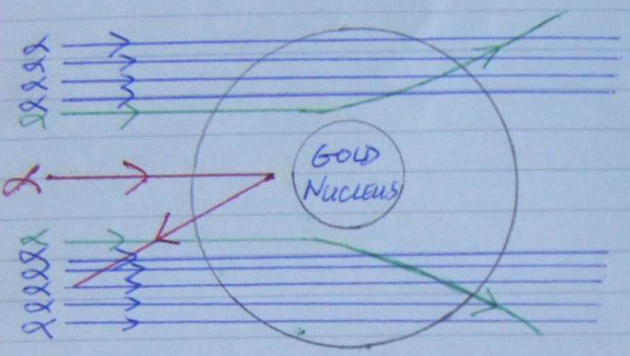
Alpha particles are highly positively charged particles which are extremely small in comparison to gold atoms.

A ⇒ The vast majority of the alpha particles pass straight through the gold foil undeflected.

B ⇒ A small quantity of alpha particles are deflected through an angle less than 90°. These alpha particles approach near the vicinity of the gold nucleus. This causes electrostatic repulsion with the alpha particles being slightly deflected.

C ⇒ Here the alpha particles deflect at an angle > 90°. This shows that the alpha particles are on an almost head-on collision with the gold nucleus. The alpha particles slow down and at a distance of closest approach they will come to rest and be heavily repelled back.

Visual Explanation



- Here the alpha particles are slightly deflected away from the nucleus at an angle <90°.
- Here the alpha particles meet the nucleus head-on and will deflect off and be repelled at an angle >90°.

Conclusions

- Atom is almost entirely empty space.
- most of the mass of an atom is concentrated in the nucleus.
- The nucleus of an atom is positively charged.

Ionisation

This occurs when an atom gains or loses an electron from its orbit.

If an atom gains an electron → Negative Ion

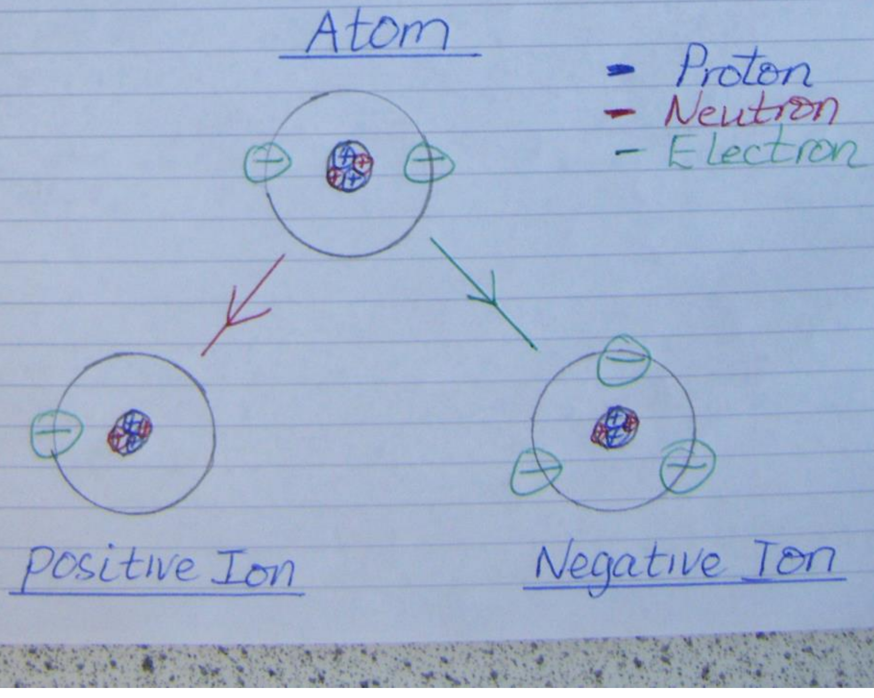
If an atom loses an electron → positive Ion

Negative Ion

No. of electrons in the orbit > No. of protons in the nucleus

Positive Ion

No. of protons in the nucleus > No. of electrons in the orbit.



Element Identification

$^{A}_{Z}X$

A = Mass number
Z = Atomic number
X = Element

An element is identified by the atomic number. ie Z
ie the number of protons in the nucleus.

A = No. of protons + No. of neutrons in the nucleus

Z = No. of protons in the nucleus.

A-Z = No. of neutrons in the nucleus.

Ex 1

Q Find the following information from the elements below:

a) No. of protons in the nucleus.
b) No. of neutrons in the nucleus.
c) Identify the elements.

i) $^{212}_{82}Pb$ ii) $^{92}_{36}Kr$ iii) $^{235}_{92}U$

A i) a) 82 b) 130 c) Lead
ii) a) 36 b) 56 c) Krypton
iii) a) 92 b) 143 c) Uranium.

Isotopes

These are atoms of the same element which have the same atomic numbers but have different mass numbers.

Atoms can have possibly (usually) 2 or 3 isotopes.

Ex2

Q: How many protons and neutrons do each of the following isotopes have?

a) $^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$ (Hydrogen)

Hydrogen, Deuterium, Tritium

b) $^{127}_{53}I$ $^{131}_{53}I$ (Iodine)

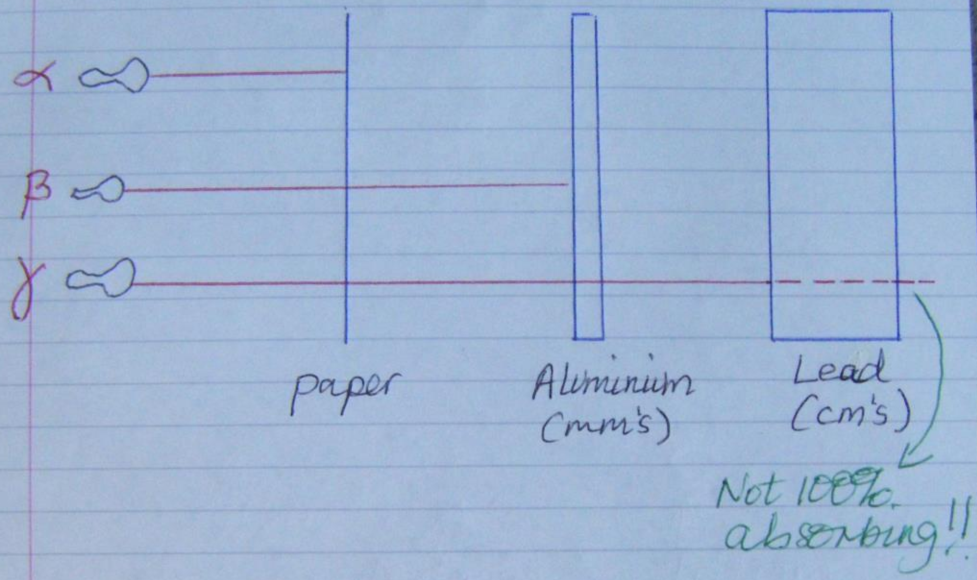
c) $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$ (Carbon)

A: a) Protons: 1, 1, 1
Neutrons: 0, 1, 2

b) Protons: 53, 53
Neutrons: 74, 78

c) Protons: 6, 6, 6
Neutrons: 6, 7, 8

Alpha, Beta and Gamma radiation

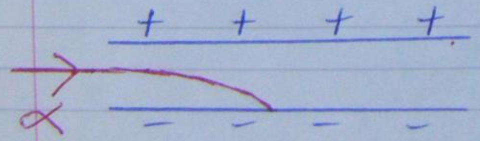


1) Alpha Particles (α)

$^{4}_{2}He^{(+2)}$ or $^{4}_{2}He$

charge = +2

$W_R = 20$
↓
Weighting Factor
↓
The highest W_R



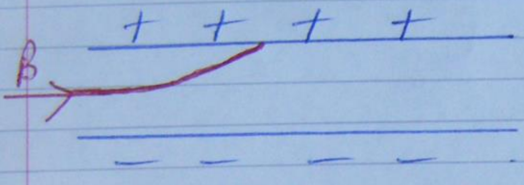
Conclusion

- α – particles are the most ionising and are the most dangerous to living tissue.
- α – particles are the least penetrating.

2) Beta Particles (β)

$^{0}_{-1}e$ or $^{0}_{-1}\beta$ charge = −1

A beta particle is a fast moving electron.



Weighting factor
$W_R = 1$

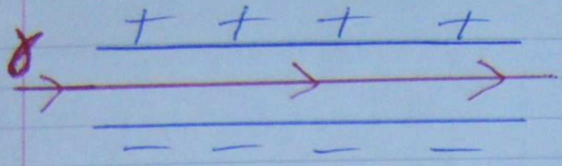
Conclusion

- Beta particles will be attracted to the positive plate as they have a negative charge.
- Beta particles can pass through air and paper but are absorbed by mm's of Aluminium.

3) Gamma Radiation (γ)

$^{0}_{0}\gamma$ Gamma radiation has zero mass and zero charge.

This is high frequency / high energy electromagnetic radiation. (ie top of the em spectrum)



This is the least dangerous to living tissue, though it is the most penetrating ie even thick Lead is not 100% absorbant.

Nuclear Decay Equations

This involves balancing the LHS and RHS of a nuclear equation.

If a nuclei decays to form a new element then radiation will be given off.

Ex3

$$^{212}_{82}Pb \longrightarrow {}^{212}_{83}X + Y$$

Q Identify X and Y in the equation above.

A X - Bismuth → Bi → 83 Atomic number

Y - $^{0}_{-1}e$ → Beta particle.

Ex4

$$^{230}_{90}X \rightarrow ^{226}_{88}Y + Z$$

Q Identify X, Y and Z.

A X → Thorium (Th)

Y → Radium (Ra)

Z → $^{4}_{2}He$ → Alpha particles.

Ex5

Part of a radioactive decay series is shown below.

State the names of the particles emitted at each stage.

$$^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$$

⇑ $^{0}_{-1}e$ (β)

⇑ $^{4}_{2}He$ (α)

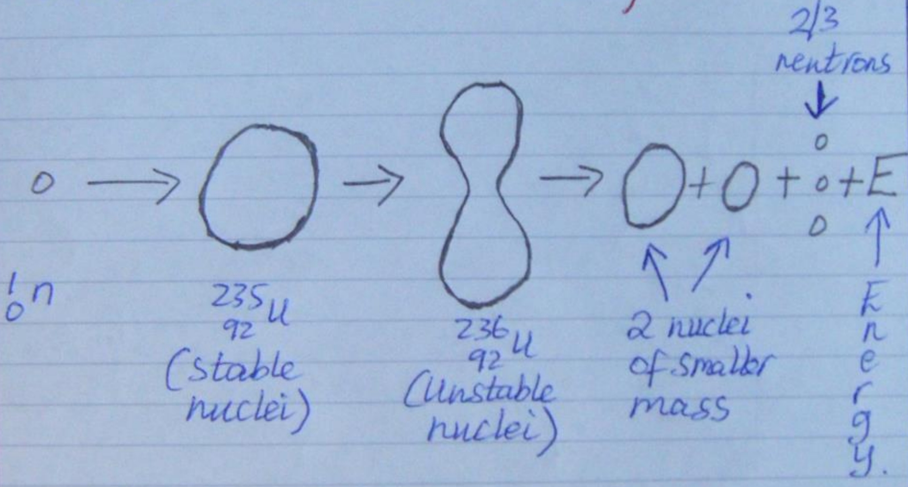
- $^{210}_{83}Bi \rightarrow ^{210}_{84}Po + ^{0}_{-1}e$
- $^{210}_{84}Po \rightarrow ^{206}_{82}Pb + ^{4}_{2}He$

We are unable to tell when gamma is given off as it involves no change in mass or charge!!

Nuclear Fission

This occurs when a nuclei of large mass is split up into two nuclei of smaller mass, with neutrons and energy released in the process.

(This usually occurs when a neutron is fired at an element with nuclei of large mass such as Uranium or Plutonium)



eg

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{138}_{56}Ba + ^{95}_{36}Kr + 3\,^{1}_{0}n + \text{Energy}$$

LHS $\Rightarrow$ $A = 235 + 1 = 236$, $Z = 92 + 0 = 92$

RHS $\Rightarrow$ $A = 138 + 95 + (3 \times 1) = 236$, $Z = 56 + 36 + 0 = 92$

* The mass number (A) and the atomic number (Z) match up on the LHS and RHS. *

Although the mass number (A) and the atomic number (Z) are the same on the RHS and LHS of the equation, there is a decrease in mass before and after the nuclear reaction.

The decrease in mass is converted into energy where:

$$E = mc^2$$

- E → Energy released in one nuclear reaction (J)
- m → Decrease in mass/ Lost mass/mass defect (Kg)
- c^2 → (Speed of light in air)^2

There are 2 types of Nuclear Fission reaction:

- Induced nuclear fission reaction (By far the most common)
- Spontaneous nuclear fission. (Very uncommon, but are possible with very heavy elements)

Ex6

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2\,^{1}_{0}n + \text{Energy}.$$

Nuclei	mass (Kg)
$^{235}_{92}U$	3.901×10^{-25}
$^{1}_{0}n$	0.017×10^{-25}
$^{144}_{56}Ba$	2.388×10^{-25}
$^{90}_{36}Kr$	1.492×10^{-25}

Q Calculate or find:

a) i) The change in mass in the nuclear reaction.

ii) What type of reaction is this?

b) The energy released in this nuclear reaction.

(* DO NOT round up figures until the last line of $E = mc^2$ *)

A a) i) change in mass $= m_{LHS} - m_{RHS}$.

$m_{LHS} = 3.901 \times 10^{-25} + 0.017 \times 10^{-25} = 3.918 \times 10^{-25}$ Kg

$m_{RHS} = 2.388 \times 10^{-25} + 1.492 \times 10^{-25} + 2 \times 0.017 \times 10^{-25}$
$= 3.914 \times 10^{-25}$ Kg

Change in mass $= 3.918 \times 10^{-25} - 3.914 \times 10^{-25} = 4 \times 10^{-28}$ Kg

a) ii) Induced nuclear fission reaction.

b) $E = mc^2 = 4 \times 10^{-28} \times (3 \times 10^8)^2 = 3.6 \times 10^{-11} J$

Nuclear Fusion

This occurs when two nuclei of smaller mass combine to form a nuclei of larger mass with energy released in the process.

* Similar to Nuclear Fission, the total mass of the nuclei before the reaction is greater than the total mass of the nuclei after the reaction.

This change in mass is converted into energy using $E = mc^2$, where m is the change in mass.

Ex7

$${}^3_1H + {}^2_1H \rightarrow {}^4_2He + {}^1_0n + \text{Energy}$$

${}^3_1H$ and ${}^2_1H$: 2 nuclei of smaller mass

${}^4_2He$: Nuclei of larger mass

Q a) What type of nuclear reaction is shown above?

b) Calculate the energy released using the information from the table below:

Nuclei	mass(Kg)
$^{2}_{1}H$	3.342×10^{-27}
$^{3}_{1}H$	5.005×10^{-27}
$^{4}_{2}He$	6.642×10^{-27}
$^{1}_{0}n$	1.675×10^{-27}

A a) Nuclear Fusion

b) $m_{LHS} = 5.005\times10^{-27} + 3.342\times10^{-27}$
$= 8.347\times10^{-27}$ Kg

$m_{RHS} = 6.642\times10^{-27} + 1.675\times10^{-27}$
$= 8.317\times10^{-27}$ Kg

(* Do NOT round up these figures for mass *)

change in mass $= m_{LHS} - m_{RHS}$

$= 8.347\times10^{-27} - 8.317\times10^{-27}$
$= 0.030\times10^{-27}$
$= 3\times10^{-29}$ Kg

$E = mc^2 = 3\times10^{-29}\times(3\times10^{8})^2$

$E = 2.7\times10^{-12}$ J

EXTRA!!! I have added a part c) to this question to highlight ratios that might come up.

Q c) A nuclear reactor releases energy at a rate of 1200MW.
Calculate the minimum number of nuclear fusion reactions occuring per second.

A $E = Pt = 1200 \times 10^6 \times 1 = 1200MJ = 1200 \times 10^6 J$

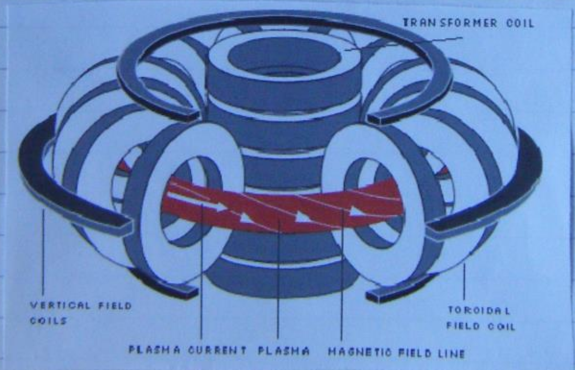
From part b)

$2.7 \times 10^{-12} J \rightarrow 1$ nuclear fusion reaction

$\Rightarrow 1200 \times 10^6 J \rightarrow \frac{1200 \times 10^6}{2.7 \times 10^{-12}} = 4.44 \times 10^{20}$

ie 4.44×10^{20} Nuclear Fusion reactions.

Plasma inside a nuclear fusion reactor



Magnetic fields are used to contain the plasma in a nuclear fusion reactor.

Plasma would cool down if it came too close to the sides of the reactor and this would also destroy the container.

Ex8 (2006 Q29b) PAST PAPER)

Q

A nuclear fission reaction is represented by the following statement.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{137}_{r}Cs + ^{s}_{37}T + 4^{1}_{0}n$$

(i) Is this a spontaneous or an induced reaction? You must justify your answer. 1

(ii) Determine the numbers represented by the letters *r* and *s* in the above reaction. 1

(iii) Use the data booklet to identify the element represented by *T*. 1

(iv) The masses of the nuclei and particles in the reaction are given below.

	Mass/kg
$^{235}_{92}U$	$390\cdot219 \times 10^{-27}$
$^{137}_{r}Cs$	$227\cdot292 \times 10^{-27}$
$^{s}_{37}T$	$157\cdot562 \times 10^{-27}$
$^{1}_{0}n$	$1\cdot675 \times 10^{-27}$

Calculate the energy released in the reaction. 3

A

i) Induced nuclear fission.
This is due to a neutron being added or fired in the LHS of the equation.

ii) r – 55 s – 95

iii) Element Rubidium ⇒ Rb (Element T).

iv) $m_{LHS} = (390\cdot219 + 1\cdot675) \times 10^{-27} = 391\cdot894 \times 10^{-27}$ Kg

$m_{RHS} = (227\cdot292 + 157\cdot562 + 4(1\cdot675)) \times 10^{-27}$
$= 391\cdot554 \times 10^{-27}$ Kg

Lost mass $= 391\cdot894 \times 10^{-27} - 391\cdot554 \times 10^{-27}$
$= 0\cdot34 \times 10^{-27}$ Kg

Loss in Energy, $E = mc^2 = 0\cdot34 \times 10^{-27} \times (3 \times 10^8)^2 = 3\cdot06 \times 10^{-11}$ J