Topic 4 Atomic structure and Radioactivity

4.1.1 Atoms

The smallest part of an element, diameter approximately 10^{-10} m

Mostly empty space

Positively charged nucleus, diameter approximately 1/10 000 that of the atom contains protons (positive charge) and neutrons (no charge)

↘ ↙

collectively called nucleons

Electrons (negative) sit in different energy levels around the outside of the nucleus. If an electron absorbs some energy it can move up to a higher energy level. If it falls back down to a lower energy level then the atom emits an electromagnetic wave

4.1.2 Symbolic Notation

An element is represented by a symbol eg C for Carbon

In front of the symbol we put the nucleon number (chemists call it the mass number) and the atomic number

atomic number ↓ the number of protons ↓ has to equal the number of electrons

nucleon number ↓ the number of nucleons

Nucleon number
- Atomic number
= Number of neutrons

Atoms of an element can have different numbers of neutrons – the different atoms are called isotopes

If any electrons are added to or removed from an atom then the atom becomes charged – it is called an ion and the process causing it is called ionisation

Practise what you have learned :-

1. How many of the following are there in an atom of oxygen $^{16}_{8}O$?

   Protons ____ Neutrons _______

   Nucleons ____ Electrons _______

2. An atom of carbon has 6 protons and 12 nucleons.

   How many electrons does it have ? ______

   How many neutrons does it have ? ______

3. An atom of sodium has 11 electrons and 23 nucleons.

   How many protons does it have ? ______

   How many neutrons does it have ? ______

4. An electron is removed from a hydrogen atom.

   Give two names for what remains __________________

   ____

5. An electron adds onto a chlorine atom.

   What would we call the resulting particle ? ______________________________

6. The commonest isotope of Uranium is $^{238}_{92}U$

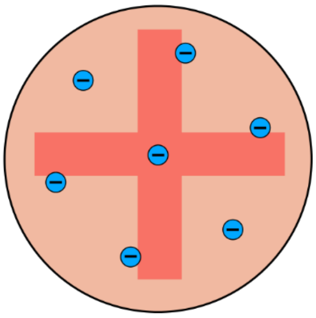
   How many electrons, protons and neutrons does it have ?

   e ______ p ______ n _______ .

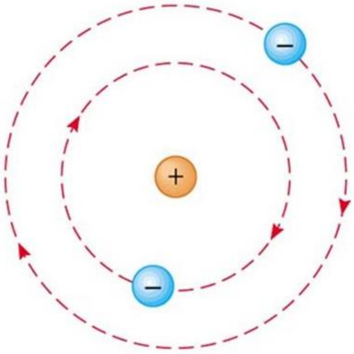
7. Repeat for an isotope of Uranium $^{235}_{92}U$ e ______ p _____ n ______.

4.1.3 Development of the model of the atom

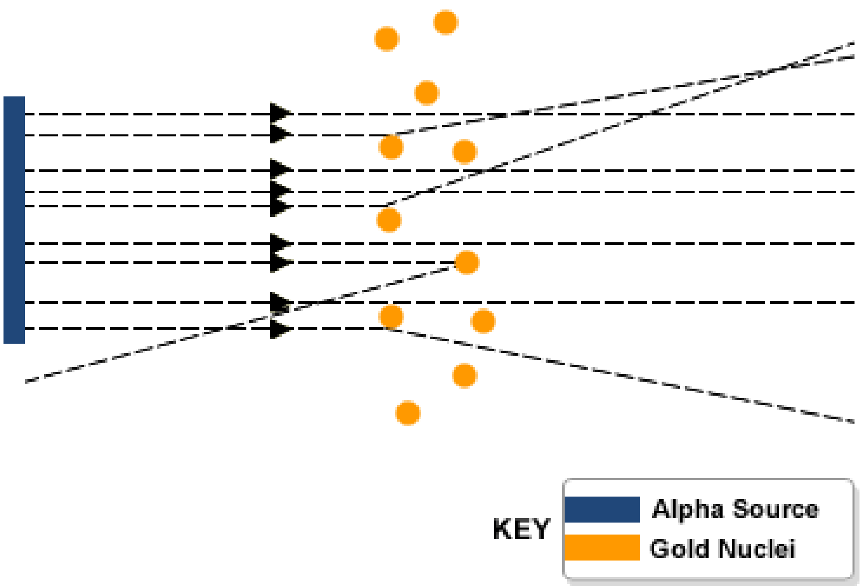
Prior to 1911, atoms were thought to be positively charged spheres having electrons stuck on the outside, what was known as the plum pudding model of the atom



In 1911, Ernest Rutherford's alpha particle scattering experiment led to the present day nuclear model of the atom described in 4.1.1



In the experiment, positively charged alpha particles were fired at a very thin piece of gold. The majority of the alpha particles went through to the other side but a very small fraction (1 in 10 000) were repelled back to the source



4.2 Radiaoctive decay

Some atomic nuclei are unstable.

They can spontaneously and randomly emit radiation in a process called radioactivity

no input necessary to make it happen — different amounts at any time

Radioactivity, which can be measured with a Geiger Counter, is the rate at which a nucleus decays, ie counts per second or Becquerel, Bq

In any place at any time there will be some radiation, called background radiation which comes naturally from rocks in the Earth

When measuring radioactivity of a substance we should always measure background radiation first and subtract it from the radiation measured with the source

Radiation can be one of three forms :-

Alpha radiation = 2 protons and 2 neutrons
Beta radiation = 1 electron (neutron decays into a proton and an electron)
Gamma radiation = electromagnetic wave

Alpha radiation, with its +2 charge is able to pull electrons out of atoms so is the most ionising, but it is the least penetrating radiation being easily stopped by a few cm of air or paper

Beta radiation, with its -1 charge is able to push electrons out of atoms so it is the next most ionising, but it is more penetrative requiring a few cm of aluminium to stop it

Gamma radiation has no charge so can only knock electrons out of atoms so is the least ionising but it is very penetrating, requiring thick lead to stop it

Practise what you have learned :-

1. The radiation in a room was measured three times. The number of counts recorded each minute was

46   54   53

(a) Why were three measurements made ?

(b) What was the average background radiation in Becquerel ?

2. A radioactive source was then brought out into the room and the radiation measured 1cm away from it. The number of counts recorded each minute was

824   850   830

(a) What was the average radiation in Becquerel ?

(b) Work out the average radioactivity of the source, accounting for background radiation

3. The radioactivity was then measured :-

A   5cm away from the source
B   1cm away but with 3mm of aluminium in between source and detector
C   1cm away but with 5mm of lead in between source and the detector

The readings obtained were

A   826
B   160
C   51

Explain how the results show that the source was emitting beta and gamma Radiations

4. A similar experiment was performed with a different radioactive source
The readings obtained were

A   195
B   196
C   52

What radiation was this source emitting ?

4.2.2 Nuclear equations

Alpha radiation can be represented as $^{4}_{2}\alpha$ (or $^{4}_{2}He$, helium nucleus)

If alpha radiation is emitted from a source, then the original substance will become an isotope of a different element

eg $^{219}_{86}Rn \rightarrow\ ^{4}_{2}\alpha + \ ^{215}_{84}Po$

Beta radiation can be represented as $^{0}_{-1}\beta$ (or $^{0}_{-1}e$)

If beta radiation is emitted from a source, then the original source will lose a neutron and gain a proton

eg $^{14}_{6}C \rightarrow\ ^{0}_{-1}e + \ ^{14}_{7}N$

Gamma radiation is represented by γ (no numbers since it isn't a particle)

The emission of a gamma wave only changes the energy of the source so there is no equation to write for that type of decay

Practise what you have learned :-

1. Which nuclear equation is correct ?

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

B $^{238}_{92}U \rightarrow ^{4}_{2}\alpha + ^{242}_{90}Th$

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

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

2. Which nuclear equation is correct ?

A $^{1}_{1}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e$

B $^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e$

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

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

3. Yttrium, Y , has atomic number 39
Barium, Ba , has atomic number 56
Neptunium, Np , has atomic number 93

Write nuclear equations for the following radioactive decays

(a) Alpha decay from Americium-241, Am, element number 95

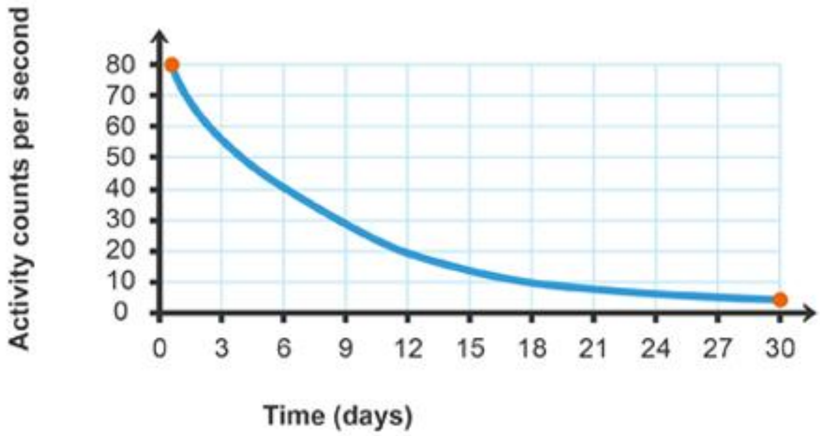
(b) Beta decay from Strontium-90, Sr, element number 38

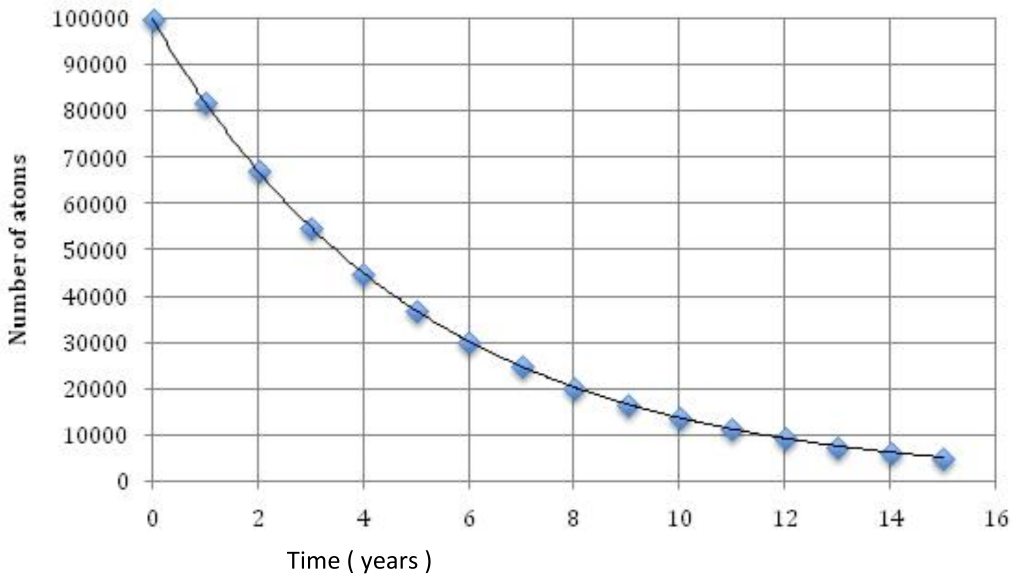
(c) Beta and gamma decay from Caesium-137, Cs, element number 55

4.2.3 Half Life

is the time it takes for radioactivity to half
equal to the time it takes for half the atoms of the substance to decay

Determine the half life of the following substances :-





Note that the activity or the number of atoms halves successively so that after two half lives the activity is one quarter of the original, after three half lives it is one eighth

4.2.4 Irradiation and Contamination

If radiation is coming from a source towards you, then are said to be irradiated.
The radiation does not necessarily get inside you
(it depends on its penetrative ability)

Gamma is the most penetrative radiation so, if a source is outside your body emitting gamma radiation, it is more dangerous

If radiation gets inside you then you are contaminated.

Alpha radiation is the most ionising radiation, so if a source has got inside your body emitting alpha radiation, it is the most dangerous

4.3.1 Hazards of radioactive emissions — Physics only

Background radiation comes naturally from rocks in the Earth and via cosmic rays in space.
Background radiation would be greater if you were near to a hospital or nuclear power station as these places use radioactive sources

Radiation is dangerous because it can ionise atoms in cells of the body and/or damage DNA in nuclei causing incorrect reproduction or growth of cells, leading to tumours and cancers

4.3.3 Uses for radioactive emissions — Physics only

Americium – 241, a source of alpha radiation of long half life, is used in smoke detectors

Strontium – 90, a source of beta radiation of long half life, is used in paper thickness monitors

Technetium – 99, a source of gamma radiation of half life 6 hours, is used as a medical tracer in medical diagnosis (put inside the body and detected outside)

Cobalt – 60, a source of gamma waves of long half life, is used to kill cancers
(circulates round the outside of the body, the radiation directed at the cancer)

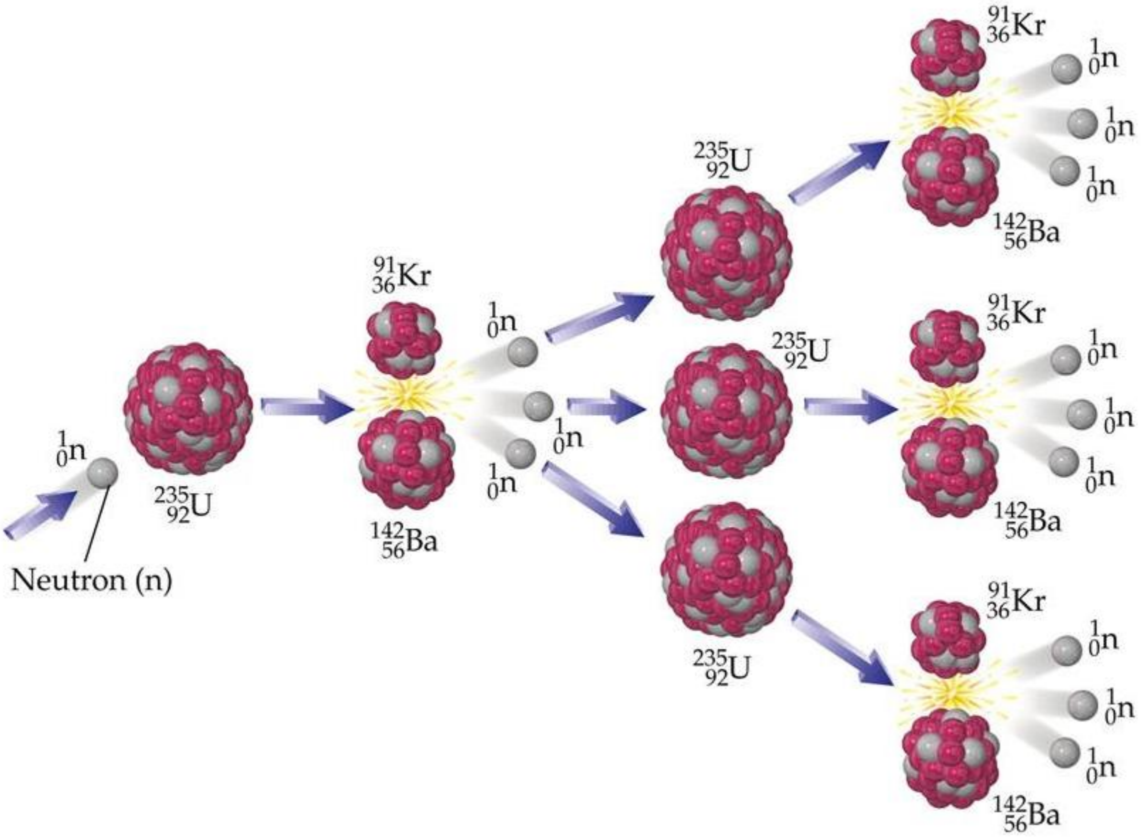
4.4 Nuclear fission and fusion — Physics only

Nuclear fission is the splitting of a large nucleus by firing a neutron into it

The large nucleus splits into two smaller (daughter) nuclei and some extra neutrons and a large amount of energy is released

The extra neutrons can go on to cause further fissions, leading to a chain reaction

eg $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n$



Uncontrolled, the chain reaction is a nuclear bomb

Controlled nuclear fission is used in nuclear power stations to produce electricity

A graphite moderator can be used to slow neutrons down making them more likely to split further Uranium atoms

Boron control rods can be used to absorb neutrons should the reaction become too large

Nuclear fusion is the joining of two small nuclei to form a larger one

eg $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$

Still experimental : because nuclei, being positively charged require high temperatures and pressures to overcome the electrical repulsive force preventing them going together

Fusion occurs in stars because they are at high temperatures

Practise what you have learned :-

Explain the following :-

1. An alpha emitting radioactive source is required in a smoke detector. Beta or Gamma would be no good

2. Beta radiation is required for a paper thickness monitor. Alpha or Gamma would be no good

3. Gamma radiation is required for medical diagnosis or treatment. Alpha or Beta would be no good

4. For radioactive ‘tracing’ a source with a relatively short half life is desirable.

5. Compare the waste products of coal-fired power stations with nuclear power stations. What advantages and disadvantages do each type of power station provide ?

6. Compare the waste products of fission and fusion reactions. Why would it be desirable to replace fission reactors with fusion ones ?