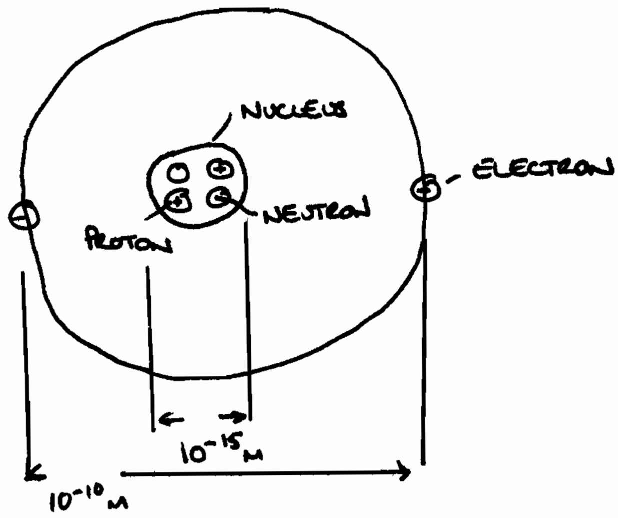
VTH BOOK REVISION GUIDE - RADIOACTIVITY

NEUTRONS, PROTONS AND ELECTRONS.

- NUCLEUS OF ATOM → 2 TYPES OF PARTICLE – PROTON (+ve charge) } approx
  NEUTRON (no charge) } SAME MASS.
- OUTSIDE NUCLEUS → ELECTRONS – FORM A 'CLOUD' AROUND NUCLEUS.
  - VERY LITTLE MASS
  - NEGATIVE CHARGE

The HELIUM ATOM



- A NEUTRAL ATOM WILL HAVE SAME NO OF PROTONS + ELECTRONS (CHARGES CANCEL OUT).

EXAMPLES:

	HYDROGEN, H	Helium, He	LITHIUM, Li
No. of e^-	1	2	3
No. of protons	1	2	3
No. of neutrons	0	2	4
No. of particles in nucleus	1	4	7
Mass relative to hydrogen	1	4	7

<u>IONS</u> – Possible to add or take away electrons (e^-) from an atoms.

Atom + extra electrons = NEGATIVE ION
Atom – electrons = POSITIVE ION

[All about balance of positive proton charge + surrounding negative electrons]

PROTON AND NUCLEON NUMBERS

$^{A}_{Z}El$

A ← Nucleon number or mass number = total no. of protons + neutrons.

Z ← Proton or Atomic number = no. of protons. No. of protons <u>defines what element it is</u>.

$\therefore \; {}^{14}_{6}C \Rightarrow$ 6 protons ∴ CARBON

$14 - 6 = 8$ neutrons.

Normally, unless it is an ION, the NUMBER OF PROTONS = NO OF ELECTRONS.

ISOTOPE - This is an Isotope of an element. It has the same no. of PROTONS (thus defining it as that element), but a different number of neutrons. eg.

92 PROTONS defines it as URANIUM.

${}^{235}_{92}U$ – URANIUM

${}^{238}_{92}U$ - Isotope of URANIUM.

NB these are examples of 2 types of Isotopes of Uranium (there are others!).

α, β and γ DECAY

α DECAY ALPHA PARTICLE = HELIUM NUCLEUS ${}^{4}_{2}He$ [no electrons ∴ has 2+ charge].

$$\therefore \; {}^{A}_{Z}El_1 \rightarrow {}^{A-4}_{Z-2}El_2 + {}^{4}_{2}He \quad \text{eg.} \quad {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

NOTES:

- El_1 loses 2 PROTONS ∴ El_2 must be a different Element.
- Numbers on LHS must equal those of RHS.

$$A = (A-4) + 4, \quad Z = (Z-2) + 2$$ always check they add up correctly.

β DECAY BETA PARTICLE ${}^{0}_{-1}\beta$ = ELECTRON ${}^{0}_{-1}e$

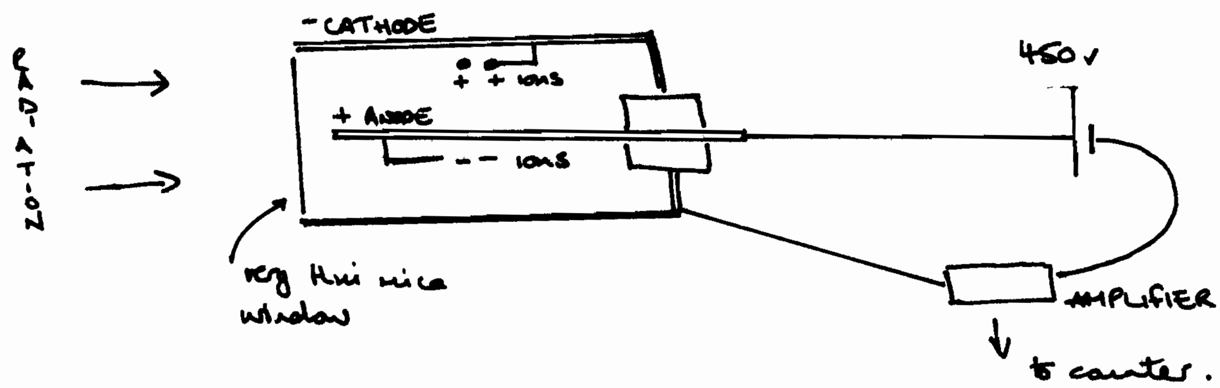
- created when neutron turns into proton and an electron is thrown out.
- MASS of electron very small, so overall MASS does not change.

$${}^{A}_{Z}El_1 \rightarrow {}^{A}_{Z+1}El_2 + {}^{0}_{-1}\beta \quad \text{eg.} \quad {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e.$$

γ DECAY When some ~~particular~~ nuclei decay by α and β decay, they also send out γ-rays.

- γ rays are ELECTROMAGNETIC WAVES. (V high frequency, short λ).
- They carry away a lot of ENERGY → leaving a more STABLE NUCLEUS.
- γ rays have **NO** MASS or CHARGE ∴ no change in NUCLEON or PROTON NUMBER.

DETECTING PARTICLES.



ABOVE: SIMPLE GEIGER-MÜLLER TUBE

- Make use of ionising properties of α, β + γ to detect them.
- Use a G-M tube (above).
  - How it works:
    + Metal tube filled with ARGON at low pressure
    + Inside tube – thin wire ANODE (+ve).
    + P.d of 450v applied between inside + outside of tube.
    + When α, β or γ radiation enters, they ionise the argon atoms.
    + Ions attracted to the electrodes in the tube INDUCING A SMALL CURRENT.
    + Current is amplified and a counter is used to count the number of particles entering a tube.

- Ionising radiation can also be detected using photographic film. The ionising radiation causes the film to become exposed. RADIATION WORKERS wear badges with photographic film to detect exposure.

PROPERTIES OF RADIATION

- ALPHA (α) PARTICLES
  - travel approx 5cm through air
  - Stopped by a thin sheet of paper
  - Ionise air very strongly
  - travel at speed of 10^7 m/s - slower than β and γ.
  - can be deflected by strong magnetic field, but deflection is small ∵ α particle is so massive.

- BETA (β) PARTICLES
  - travel several metres through air
  - Stopped by sheet of aluminium (metal) a few mm thick.
  - Do not ionise as strongly as α particles.
  - Travel at speeds just below speed of light (3×10^8 m/s)
  - β particles can be deflected quite easily by a magnetic field as the particle is so light.

- GAMMA RAYS
  - γ rays can only effectively be stopped by thick piece of lead.
  - They are electromagnetic waves, so they travel at speed of light.
  - Gamma rays only ionise air very weakly.
  - cannot be deflected in magnetic field as they carry no charge.

IONISATION

- All 3 types of radiation (α, β and γ) cause IONISATION.
- IONISATION occurs when the particles collide with other molecules, effectively 'knocking off' electrons and therefore creating IONS.
- This is why we must be careful when handling radioactive materials → the radiation can cause ions in our body leading to damaged tissue.
  → increased risk of cancer due to DNA damage

BACKGROUND RADIATION

- Lots of rocks on earth contain radioactive elements - Uranium, thorium, potassium - ∴ always exposed to IONISING ~~RADIATIONS~~. RADIATION
- SUN emits PROTONS which can create IONS in the atmosphere. ("COSMIC RAYS").
- Rocks + Sun ⇒ BACKGROUND RADIATION - always present.
  + levels in most places very low ∴ minimal risk to health.
- Some work places are more dangerous:
  + X-rays in hospital cause ionisation.
  + Nuclear power stations
  + Airline pilot exposed in cockpit to Sun's radiation.

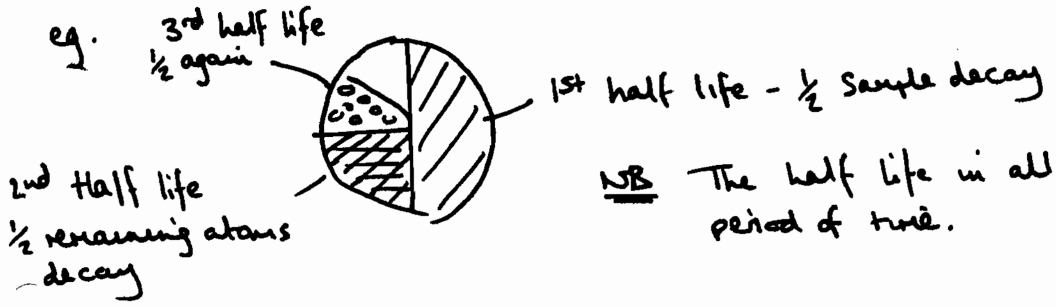
RADIOACTIVE DECAY

- Radioactive materials decay by emitting α or β particles from their nucleus.
- It is **not** possible to predict when the NUCLEUS OF ONE PARTICULAR ATOM WILL DECAY.

HOWEVER,

- Radioactive materials decay in the same way - take a sample of 1 million atoms, for a given period of TIME (the half life), half of the atoms decay. In the next half life time period, half the remaining atoms will decay.

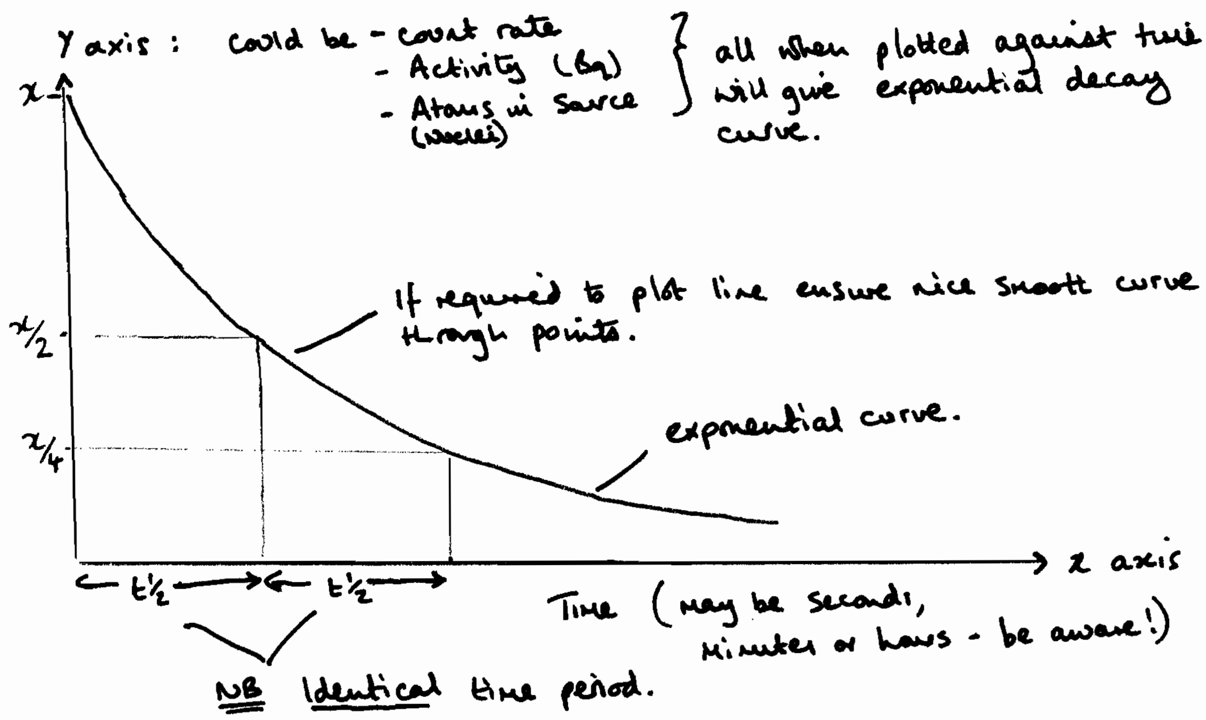
eg.



NB The half life in all cases is the same period of time.

DEFINITION OF HALF LIFE : The period of time taken for half the number of atoms to decay in a radioactive sample/source.

- Half life can be written as $T_{1/2}$.
- When the half life is plotted the graph will look as follows:



DATING ARCHEOLOGICAL REMAINS

- Carbon-14, $^{14}_{6}C$ is a radioactive isotope - it decays to Nitrogen with $t_{1/2}$ = 5500yrs.
  - All living things contain Carbon - small fraction of which is Carbon-14 - including human.
  - By measuring the level of carbon-14 scientists can determine the age of things.
  - eg. tree dies - after 5500yrs the fraction of Carbon-14 will be half that of a living tree.

USES OF RADIOACTIVITY

MEDICAL

- Radioactive tracers used to examine inside of human bodies
  - IODINE-131 used to check whether THYROID GLAND functions properly.
    - ↳ governs rate at which body functions.
    - ↳ located in throat.
  - Thyroid gland absorbs IODINE-131.
  - Dectector detects the tracer allowing functioning to be investigated.
  - Short half life is essential ∴ minimise exposure.

- Cobalt-60 emits high energy γ rays
  - Used to ~~Steri~~ steralise surgical equipment
  - γ rays kill all bacteria.

- Cobalt-60 also used to treat cancer.
  - Doctors direct strong beam of γ radiation on to the cancerous tissue (Gamma knife). This kills the cancer cells.
  - very unpleasant, making the patient ill.
  - Successful in slowing growth or completely killing cancerous growth.

INDUSTRY

- Tracers: used to detect leaking under ground pipes.
  - place radioactive source into water pipe and then G-M tube above ground can be used to detect increased radiation levels due to leak.
- Controlling thickness of paper rolling.
- Radio isotope of iron used to detect wear on moving parts of machinery.
- ALPHA emitters used in some types of SMOKE ALARMS

AGRICULTURE

- Phosporus-32 - used as tracer to determine how well plants are absorbing phosphates.

- γ-radiation - used to extend shelf life of food.
  - γ rays very penetrating so can be used on pre-packed or frozen foods.
  - γ rays kill the bacteria ∴ eliminate chance of food poisoning.
  - However, γ rays can also kill food cell, thus altering taste.

- γ-radiation - also used to produce new types of crops
  - cause cells to mutate - grow and observe.
  - if stronger, more resilient, better yield, ⇒ KEEP!!

THE DISCOVERY OF THE NUCLEAR MODEL OF THE ATOM

- BROWNIAN MOTION led to the discovery of atoms.
- How was the model of the atom discovered?

- 1909 : Geiger and Marsden designed a way of exploring atoms.
  - directed a beam of α particles at a thin sheet of gold foil.
  - α particles were known to be positively charged helium ions (He^{2+}) which were travelling very quickly.
  - They expected all of the energetic particles to pass straight through the foil
  - SURPRISE! A very small number of them bounced back, although most travelled through with no noticeable change of direction.
- RUTHERFORD produced a theory to explain these results:
  - suggested that atom is made up of a very small positively charged NUCLEUS.
  - NUCLEUS surrounded by electrons which are negatively charged.
  - He thought electrons orbited around the NUCLEUS ⇒ modern physics suggest it is more of a CLOUD OF ELECTRONS.
  - The gap between the nucleus and electrons is large.
    $\varnothing$ atom ≥ 100,000 × $\varnothing$ nucleus.
  - ∴ much of the atom is empty space, most He^{2+} particles could pass straight through.
  - Those passing close to NUCLEUS, due to 2+ charge where repulsed causing change in direction.
  - Those that collided head on where repulsed back in the direction from which they came. NB - faster moving ALPHA particles are deflected least.
- RUTHERFORD proposed that
  - all the mass and positive charge of an atom are contained in the NUCLEUS.
  - e^-'s outside the nucleus balance the charge of the PROTONS.
  - (He did appreciate that there were NEUTRONS in the nucleus).

    ↑ Neutrons not discovered until 1933.

MEASURING RADIATION

- When scientists try to determine the effect on our bodies of a dose of radiation, need to know how much energy each part of the body has absorbed.
- Damage done depends on amount of energy each kg of the body absorbs.
- Unit to measure radiation dose is GRAY (Gy).
- A dose of 1 Gy means that each kg has absorbed 1J ∴ 1 Gy = 1 J/kg
- Some radiations are more damaging ∴ talk about DOSE EQUIVALENTS, measured in SIEVERTS (Sv).

$$\text{DOSE EQUIVALENT} = Q \times \text{DOSE (Gy)}$$

Q = is a number that depends on the type of radiation.

- Usually doses we are exposed to are very small eg. $\frac{1}{1000}$ Sievert/year
  ← mSv = milli sievert.

Vth Book – Nuclear Power Revision Notes

Nuclear Power – the future?

- UK – approx 28% electricity from Nuclear Power (Fission).
- Political hotbed. Build more nuclear power stations – yes or no?
- Coal, oil and gas running out.
- Britain has saved 20,000 tonnes of Uranium
  - how long will it last?
  - Not very efficient at present – only 0.7% is the fissionable U-235. (7 in 1000 atoms).
  - 1976 Dounraey, Scotland – FAST BREEDER REACTOR powered on PLUTONIUM – by product of U-235 fission.

Plutonium

- Element 94 in the periodic table – does not occur naturally in any significant quantities.
- Created in Nuclear reactor when U-238 absorbs neutrons. U-239 decays to Np-239, which decays to Pu-239, taking approx 2.35 days.
- Plutonium can the be seperated from the Uranium as it has different chemical properties.
- Can be used:
  - in fast breeder reactor to create energy [CONTROLLED FISSION].
  - to manufacture nuclear weapons [UNCONTROLLED FISSION].
    - ↳ 1x tennis ball size lump of Pu-239 could flatten a town.

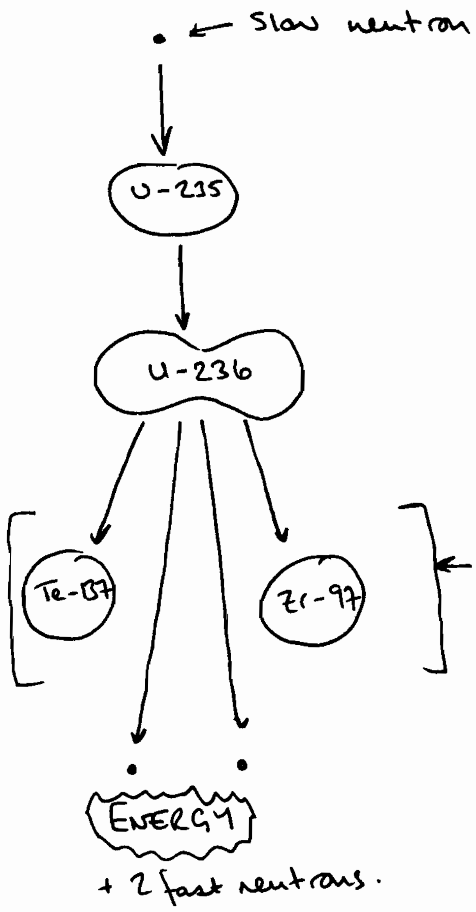
Nuclear Fusion

- Sun's energy is produced from the fusing together of hydrogen nuclei.
- Fusing means 'melting together'.
- At the centre of the Sun the temperature is about 15,000,000 K – at these temperatures the nuclei of atoms are stripped of all their electrons and are moving very quickly.
- Fusion involves two small nuclei colliding and sticking together to form a large nucleus – the fusion of two small nuclei releases a lot of energy.
- At present – scientists are trying to develop an efficient way to reproduce fusion and harness the energy for use commercially.

The Nuclear Debate – See topic notes.

NUCLEAR FISSION

- nuclei of some large atoms are unstable ⇒ lose alpha and beta particles to become more stable.
- Some heavy nuclei - eg. U235 - may increase their stability by FISSION
- Unlike α or β decay, which happens randomly, the fission of a nucleus is caused by a neutron hitting it.



$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\,{}^{1}_{0}n $$

NB there are a variety of different fission products that are possible.

WHAT HAPPENS?

- Slow moving neutrons collides with U-235 nucleus and is absorbed, creating a very unstable U-236 nucleus.
- U-236 is very unstable and splits into 2 daughter nuclei releasing several fast moving neutrons and a large amount of energy.
- The daughter nuclei and no. of neutrons released will vary → there are several different combinations that are possible.
- The daughter nuclei are usually radioactive and will decay by the emission of β particles to form more stable nuclei.

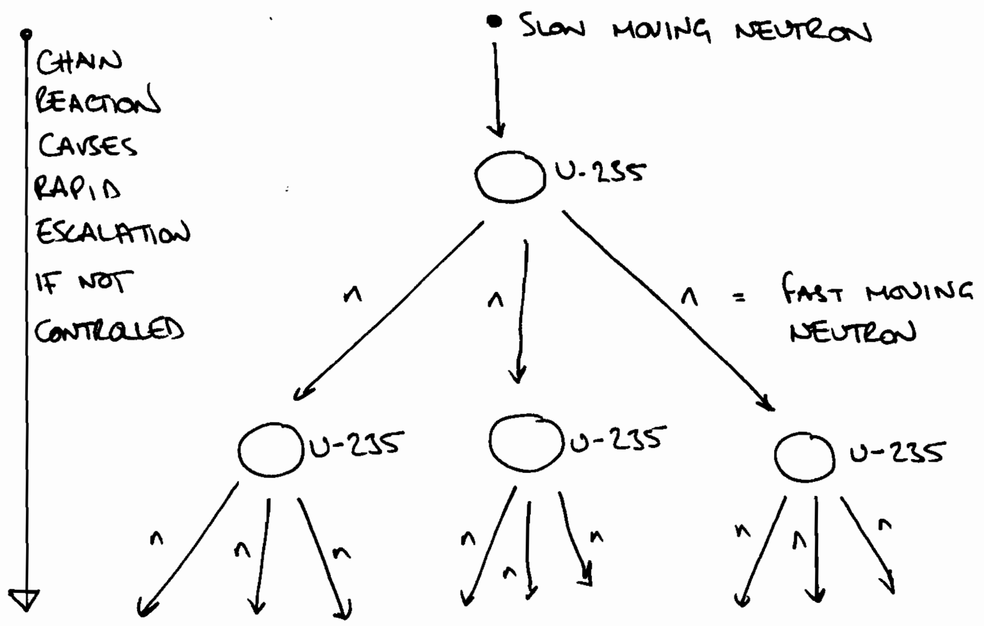
FISSION ITSELF....

- Releases a large amount of energy.
- The fission of a nucleus provides 40x more energy than the release of an alpha particle from a nucleus.

- Fission is important because we can control the rate at which it happens, such that we can use the energy released to create electrical energy.

CHAIN REACTION

- Once a nucleus has divided by fission, the emitted neutrons can strike other neighbouring nuclei causing a chain reaction.



- What is the difference between the initiating neutron and the ones created by fission? The initiating neutron is slow moving. Slow moving neutrons are more likely to trigger fission of U-235. Accordingly, a MODERATOR is used to slow down the fast moving neutrons released by fission in order to allow the chain reaction to develop.
- To control the rate of reaction, CONTROL RODS are used. Control rods absorb the neutrons, preventing them from being absorbed by the U-235.

WHERE DOES THE ENERGY IN NUCLEAR FISSION COME FROM?

- "As mass disappears, energy is created." A simplified statement of Einstein's Theory of Special Relativity [$E = mc^2$]
- The example we shall look at is:

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{137}_{52}Te + ^{97}_{40}Zr + 2\,^{1}_{0}n \qquad (1)$$

- We will analyse the mass on both the left hand side [LHS] and the right hand side [RHS] of the above eqn.

ISOTOPE	MASS IN u
$^{235}_{92}U$	235.048
$^{92}_{137}Te$	136.918
$^{97}_{40}Zr$	96.966
$^{1}_{0}n$	1.008

Note
- $1u = 1.66 \times 10^{-27}$ kg
- In the equation the proton and mass numbers balance. However, on close inspection of the mass in u, we see that they are very slightly different.
- $1u = \frac{1}{12}$th the mass of a carbon atom.

- So, inserting into the eqn 1

$$LHS = {}^{1}_{0}n + {}^{235}_{92}U$$

$$= 1.008 + 235.048 = \underline{236.056u}$$

$$RHS = {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\,{}^{1}_{0}n$$

$$= 136.918 + 96.966 + 2(1.008) = \underline{235.84u}$$

Mass is lost in the reaction.

$$\Delta m = 0.216u.$$

The lost mass is turned into the K.E of the fission fragments

$$E = mc^2$$

$$E = 0.216 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = \underline{3.2 \times 10^{-11} J}$$

NUCLEAR POWER STATIONS

- Several different types have been developed:
  - GAS COOLED NUCLEAR REACTOR – moderator is graphite, control rods BORON. Design of the first British Magnox Reactor.
  - BRITISH ADVANCED GAS COOLED REACTOR – CO_2 used as the moderator.
  - PRESSURISED WATER REACTOR – use water as both the coolant and moderator.

BASIC SYSTEM FUNCTION [Gas Cooled Nuclear Reactor]

- Energy released by the fission processes in the uranium fuel rods produces a lot of heat energy
- Heat is carried away by CO_2 gas which is pumped around the reactor.

- hot CO_2 gas used to produce superheated steam in the gas heat exchanger which then goes on to drive the turbines.
- From turbines onwards, it is the same process of electricity generation as a coal powered power station.

KEY TERMINOLOGY

- Fuel rods – made of U-238, enriched to about 2-4% U-235.
  - U-238 is the most common isotope, but only U-235 will produce fission.
  - U-238 will absorb neutrons and decay to Pu-239 (by-product of U-235 fission).
- MODERATOR – fuel rods are embedded in graphite – the moderator.
  - Purpose of moderator is to slow down neutrons which are produced in fission.
  - A U-235 nucleus is split more easily by a slow moving neutron.
  - The fuel rods are long and thin so the high speed neutrons can escape to collide with the moderator.
  - In turn, the neutrons will then trigger a reaction in a neighbouring fuel rod.
- BORON CONTROL RODS – The rate of production of energy in the reactor is carefully regulated by the BORON CONTROL RODS.
  - Boron absorbs neutrons well, so by being lowered into the reactor, the reaction can be slowed.
  - In an emergency, they are pushed right into the reactor core, and the chain reaction stops completely.