Week 7-8

The Nuclear Atom

Radioactivity:

Radiation that comes from the nuclei of an atom

Radiation:

Energy transferred through an empty space

Ionising Radiation:

- Is high-energy radiation
- That can affect the electrons surrounding an atom so that a charged ion is formed
- Includes alpha and beta particle, gamma and X-rays.

Non-Ionising Energy:

- Low energy
- Does not change the electron configuration

Background Radiation:

-there are two types:

- Terrestrial Radiation
  Comes from the decay of radioactive elements on the Earth's crust
- Cosmic Radiation:
  Comes from space

Nuclide:

Is a species of atom classifies according to the number of protons and neutrons as well as its energy state.

-e.g. $^{123}Ga_{34}$

Isotope:

Any nuclide of the same atomic number , but differs due to the number of neutrons

Radioactive Decay

Particles or rays that come from energy re-arrangements in a nucleus

-is random, spontaneous and uncontrollable

When a radioactive nucleus emits an alpha or beta particle, it breaks into 2 parts

i. The lighter, emitted particle
ii. New nucleus of a different element

In a gamma emitter, the same nucleus emerges, but at a lower energy level

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Types:

Alpha particle	α, ${}^{4}_{2}He^{2+}$	Helium-4 nuclide
Beta particle	β^{-}, ${}^{0}_{-1}e$ β^{+}, ${}^{0}_{+1}e$	Electron Positron
Gamma ray	γ, ${}^{0}_{0}\gamma$	Electromagnetic radiation
Neutrino **Antineutrino**	ν_e, ${}^{0}_{0}\nu_e$ $\overline{\nu}_e$, ${}^{0}_{0}\overline{\nu}_e$	Energy carrier Energy carrier

Alpha Decay:

Is when an alpha particle is released

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

e.g.

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

.

Beta Decay:

There are two types electron emission and positron emission

Electron Emission

Is when an electron is ejected form the nucleus

- A neutron is capable of changing a proton to an electron

* * an anti-neutrino is also released

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{\nu} $$

e.g.

$$ {}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + \overline{\nu} $$

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Positron Emission or B^{+} Emission

The ejection of a positron from the nucleus

-by regarding a proton is capable of changing into a neutron and a positron

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

e.g.

$$^{195}_{81}Tl \rightarrow {}^{195}_{80}Hg + {}^{0}_{+1}e + \nu$$

Ionising Power:

Ability to ionise materials: inversely proportional to penetrating power

Alpha>Beta>Gamma

Alpha

Attract the electrons from the atoms

$Beta^{-}$

Is repelled by the electrons, which then causes it to bounce between the atoms. This continuous bouncing causes some electrons to be ejected.

$Beta^{+}$

Interact with the atoms.

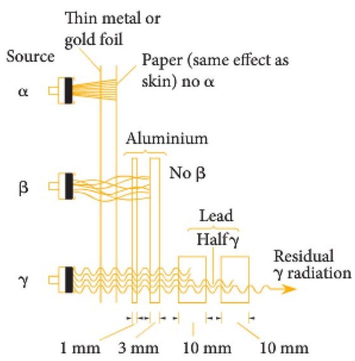
Gamma:

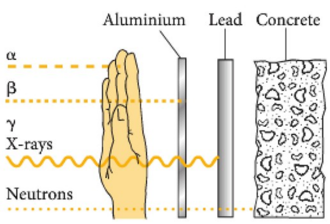
Gives the electron energy so it can break free

Penetrating Power:

Ability of ionising radiation to move into or through materials

Gamma> Beta> Alpha





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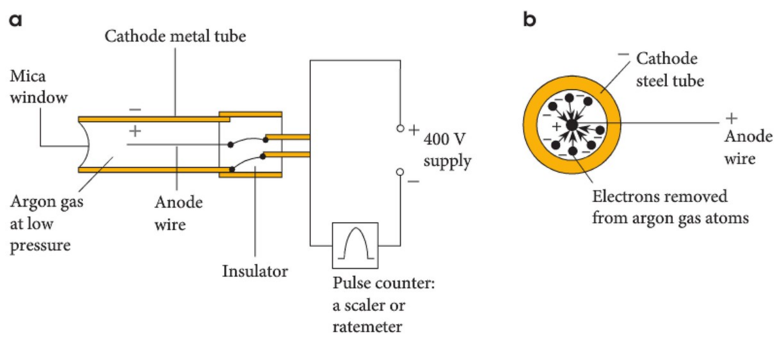
In summary

	α particles	β particles	γ ray
Nature	A helium nucleus (i.e. 2 protons and 2 neutrons)	A fast-moving electron or positron	High-frequency (short wavelength) electromagnetic radiation (i.e. a high-energy photon)
Charge	+2 elementary charges	−1 (electron) +1 (positron) elementary charge	Uncharged
Mass	4 atomic mass units (i.e. 4 u); $4 \times 1.66 \times 10^{-27}$ kg	0.0005 u; 9.11×10^{-27} kg	No mass
Ionising effect	Strong	Weak	Very weak
Penetration	Few centimetres in air	Few metres in air	Very weakly absorbed in air (most radiation absorbed by a few centimetres of lead)
Effect of electric and magnetic fields	Very small deflection	Large deflection	No deflection
Effect on photographic plate	Blackens	Blackens	Blackens
Typical emission velocity	5–7% of speed of light	30–90% of speed of light	Speed of light (3×10^8 m s^{-1})

Geiger-Muller Tube

Detects radioactivity

count rate $= \frac{\text{number of counts}}{\text{time interval}}$. The uncertainty associated with radiation-counting experiments relates to the randomness of decay events. For N counts, the uncertainty is $\pm\sqrt{N}$.



Half lives and decay series:

Half life is:

i. The time it takes for half of the radiation to decay
ii. The radioactivity to half

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Radioactive decay is a random event. Half-life is the time taken for half the nuclei to decay.

$$N = N_0 \left(\tfrac{1}{2}\right)^n$$

where n = whole number of half-lives.

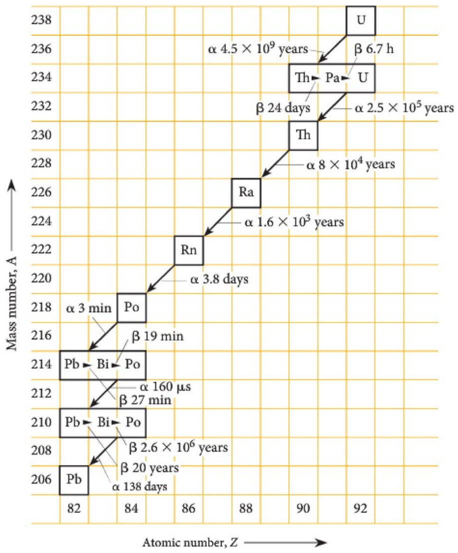
<u>Decay series:</u>

Cascade of decays from a radioactive nuclide until a stable nuclide is reached

e.g.

Radium series

The radium series can be represented graphically.



The nuclides in the radium series are:

parent: $^{238}_{92}U \rightarrow$

daughters: $^{234}_{90}Th \rightarrow {}^{234}_{91}Pa \rightarrow {}^{234}_{92}U \rightarrow {}^{230}_{90}Th \rightarrow {}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po$
$\rightarrow {}^{214}_{82}Pb \rightarrow {}^{214}_{83}Bi \rightarrow {}^{214}_{84}Po \rightarrow {}^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb$

<u>Transuranic Elements:</u>

Elements beyond uranium; artificially produced with more than 92 protons

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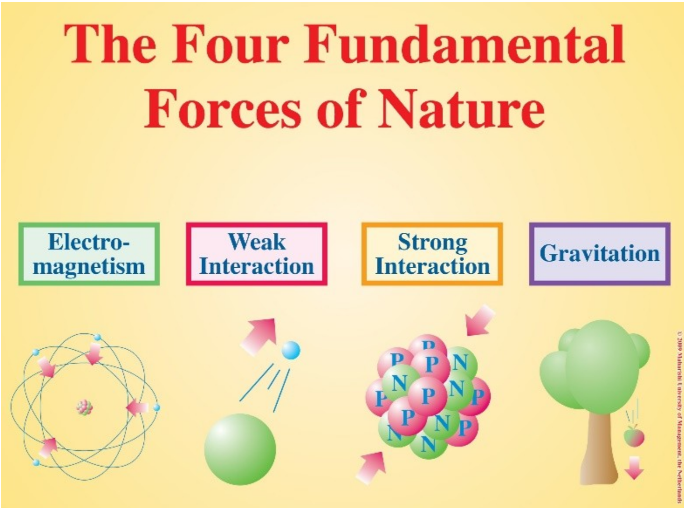
Energy from the Nucleus:

Four Fundamental Forces:

1. Strong nuclear force
2. Weak nuclear force
3. Electromagnetic force
4. Gravity



Stability:

A nucleus is stable when the strong nuclear force and the electrostatic force are equal

Energy Stored in, and Released from, Nuclei

Nuclear Binding Energy:

The total energy needed to hold a nucleus together.

Mass defect:

The difference between the sum of the individual masses and the mass of the nucleus into which they are combined is

Mass and energy are equivalent. Mass is a manifestation of energy.

$$\Delta E = (\Delta m)c^2$$

The more binging energy => the nuclide is more stable

Iron-56 is the most stable of the nuclides

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<u>Fusion:</u>

Is the coming together of two nuclides to form a new nucleus with a greater atomic number

<u>Fission:</u>

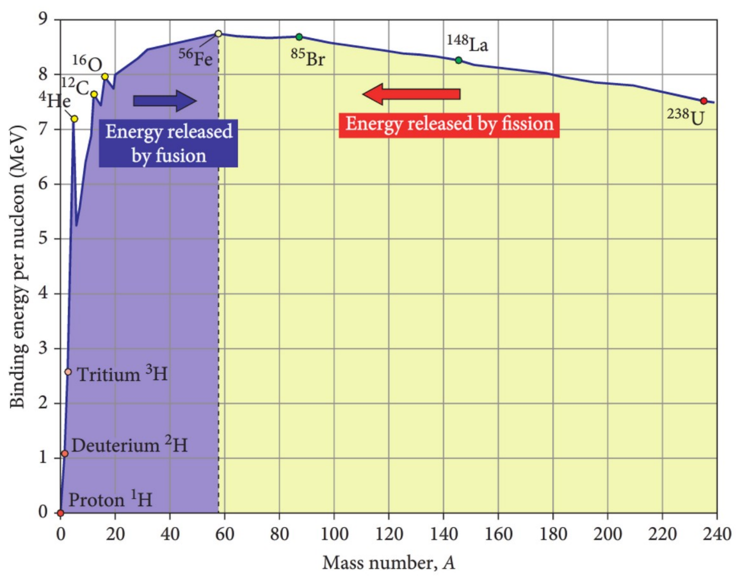
Is the splitting of a heavy nucleus (Z>56) into fragments with lower atomic numbers.

-the nuclei, called fission fragments, are more stable than the original nuclide because of their lower binding energy

Binding energy per nucleon governs stability. The higher the binding energy per nucleon the more stable the nuclide.

- Fusion is favoured for light nuclides (Z<56)
- Fission if favoured for heavy nuclides (Z>56)

More energy is released per nucleon in nuclear fusion than in nuclear fission because a greater percentage of the mass is transformed into energy



<u>Nuclear Energy: Fission</u>

Is the process by which a nucleus splits into two fragments.

In general, the fragments are rarely the same size.

Nuclear fission is triggered by the absorption of a neutron

In the process, neutrons are released and energy stored as binding energy is released

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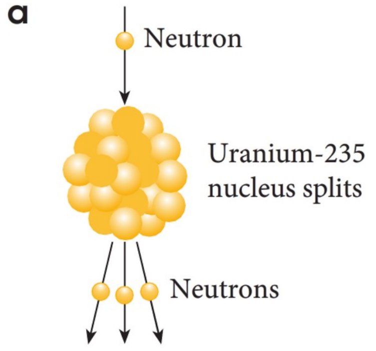
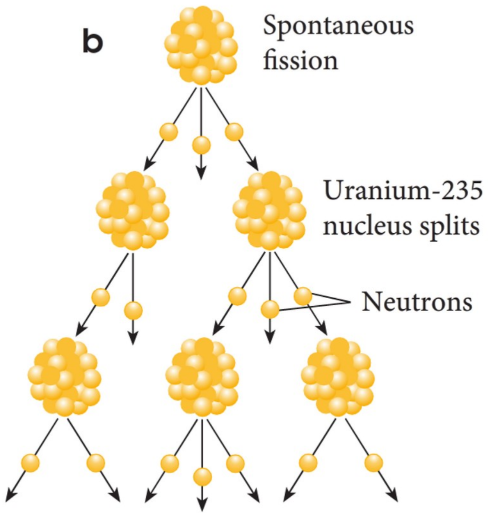


<u>Fission Chain Reactions:</u>

Occurs when more than one of the neutron released from the initial fission event cause new events to occur.

-This rapidly multiples to huge numbers of fission events. Unless this is carefully controlled, a runaway explosion will occur.



<u>Fissile:</u>

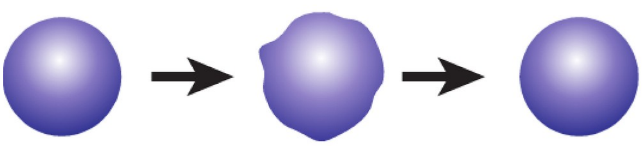
Nuclides that are capable of undergoing nuclear fission after absorbing a neutron

<u>Fission Fragment/ Product:</u>

Nucleus produced in a fission event

<u>Neutron Poison:</u>

Nuclei including fission products that absorb a neutron, thus making that neutron unable to cause further fission events



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Mass defect in fission:

The mass difference is what is converted into energy

-the energy is transferred via the fission products

-the daughter nuclei carry most of this energy as kinetic energy

e.g.

For example, when uranium-235 undergoes fission to produce krypton-92 and barium-141, three neutrons are released:

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n$$

There are 236 nucleons before and after this fission event, yet the mass of the products is less than the mass of the original neutron and uranium-235 nuclide. This is the mass defect.

Rather than use the mass of a nucleon, 1.660×10^{-27} kg, we shall use its equivalent in unified atomic mass units, u (Table 4.4). 1 u is defined as the mass of $\frac{1}{12}$ of the mass of a neutral carbon-12 atom. This is almost the same value as the mass of one nucleon. Why? Because the mass is a common factor for each calculation. If we want to convert back to units of kilogram at the end, we need only multiply our answer by the conversion factor:

$$1\,u = 1.660 \times 10^{-27}\,kg$$

Table 4.4 Particles in a fission event involving uranium-235

Particle	$^{1}_{0}n$	$^{235}_{92}U$	$^{92}_{36}Kr$	$^{141}_{56}Ba$
Mass ($\div 1.660 \times 10^{-27}$ kg)	1.009	235.044	91.926	140.914

In atomic mass units:

Initial mass = 1.009 u + 235.044 u = 236.053 u

Final mass = 91.926 u + 140.914 u + 3 × 1.009 u = 235.867 u

Mass defect = 236.053 u − 235.867 u = 0.186 u

It is this mass defect, Δm, that is converted into energy, ΔE:

$$\Delta E = (\Delta m)c^2$$

At this point, it is necessary to convert back to SI units:

$\Delta m = 0.186\,u \times 1.66 \times 10^{-27}\,kg\,u^{-1} = 3.090 \times 10^{-28}\,kg$

$\Delta E = 3.090 \times 10^{-28}\,kg \times (3.0 \times 10^{8}\,m\,s^{-1})^2$

$\Delta E = 2.78 \times 10^{-11}\,J$

This is a very small amount of energy; however, 250 gram of pure uranium contains more than 10^{23} nuclides. If all of these were to undergo fission, the effect would be enormous:

$$\Delta E = 2.78 \times 10^{-11} \times 10^{23}\,J = 2.78 \times 10^{12}\,J\ (2.78\,TJ)$$

Nuclear Reactors:

Is a device in which controlled fission is used to produce both new substances and release energy

Controlled Chain Reaction:

A chain of nuclear reactions that are controlled to limit the rate at which reactions occur. In steady state (reaction rate held constant), an average of one neutron from each reaction goes on to cause another reaction. This is the case for a nuclear power reactor running at constant power outlet.

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Parts of a Reactor:

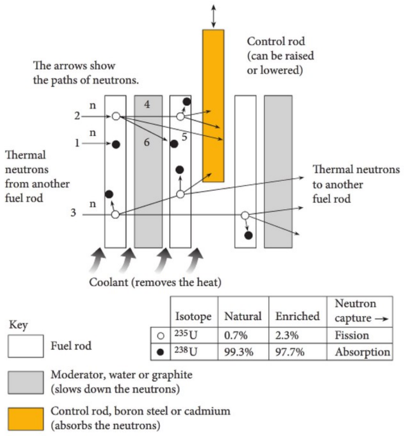
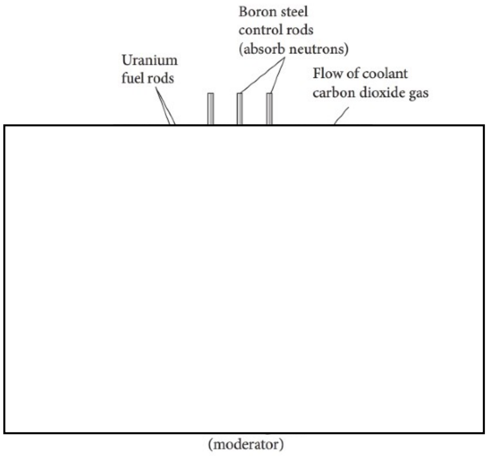


Table 4.5 Components of a thermal nuclear reactor and their functions

Component	Function
Nuclear fuel	Usually 1–4% enriched uranium-235 is used as the nuclear fuel, which is placed in airtight containers and located in the reactor core.
Moderator	It is used to slow down the high-energy, fast-moving neutrons produced by the splitting of the uranium atom to continuously cause fission in uranium-235. It must have a low mass number, readily gain kinetic energy from collisions with neutrons, and be a weak absorber of neutrons.
Control rods	In order to control the chain reaction, some neutrons must be absorbed. This is done by means of control rods that are inserted in the reactor. These rods are made of substances that readily absorb neutrons (neutron poisons), such as cadmium or boron steel.
Coolant	As a large amount of energy is produced in each fission reaction, and this is carried as kinetic energy by the fission products, the temperature of the reactor would increase unless a coolant was used. The coolant material is used to absorb this heat so that it can be used for energy purposes outside the reactor.
Radiation shield	A nuclear reactor is enclosed in a thick concrete vessel. The nuclear reactor must be shielded to protect workers and nearby communities from the large quantities of γ-radiation and penetrating neutrons that are released.



<- Is a advanced gas-cooled reactor (AGR) but u can also get a pressurised water reactor

Pr

Cons:

1. Environmental Impact
2. Radioactive Waste Disposal
3. Nuclear Accidents
4. High Costs
5. Uranium is Finite
6. Hot Targets for Militants

Fusion :

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Occurs when two light nuclei join to produce a nucleus with a lower binding energy per nucleon

Mass Defect in Fusion:

For light nuclides the energy per nucleon is greater when there are more particles in their nucleus. The nucleus is more stable.

$$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$$

$$^{13}_{7}N \rightarrow ^{13}_{6}C + ^{0}_{+1}e + v$$

$$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N$$

Effect of Radiation on Humans:

Absorbed Dose (D):

Is the energy arriving at the body unit off mass

$$D = \frac{E}{m} \text{ (Unit: joule per kilogram or gray, Gy)}$$

Equivalent Dose (*H*)

Is a measure able of the biological effects of different radiations.

$$H = D \times W_R \text{ (Unit: joule per kilogram; sievert, Sv)}$$

Ionising radiation	Radiation weighting factor (no unit)
Beta particles	1
Gamma rays	1
Slow (thermal) neutrons	3
Alpha particles	20

Dose, E: energy arriving at a body

Absorbed dose, D: $D = \frac{E}{m}$ (joule per kilogram; Gy)

Radiation weighting factor, W_R: relative biological effect of different ionising radiations

Equivalent dose, H: $H = D \times W_R$ (joule per kilogram; Sv)