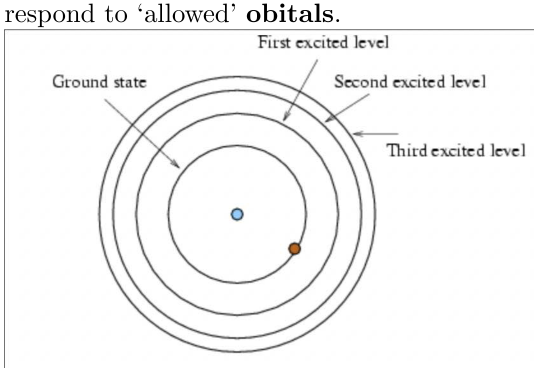
7.1 Discreen Energy and Radioactivity

1. Key points to know

You must know:
-what is meant by discrete energy and discrete energy levels
-what is meant by a transition between two energy levels
-that radioactive decay is a random, spontaneous process during which radioactive emissions occur and the nucleus of an atom changes
-that there are four fundamental forces: electromagnetic, gravitational, strong nuclear and weak nuclear
-the properties of alpha and beta particles and gamma radiation and the decay equations that describe the changes to the nucleus
-what is meant by background radiation.
-dangers of radioactivity
-half life calculations

2. Structure of atom and energy levels

Atoms, as we know have a central dense Nucleus and are mostly empty space with electrons around the nucleus.
Electrons can only occupy given energy levels – the energy of the electron is said to be **quantized**. These energy levels are fixed for particular elements and correspond to 'allowed' **obitals**.



Hydrogen atom, with the four lowest energy levels marked

Note above: the gap between the first level and 2nd is greater than the subsequent differences of energy levels.

3. energy absorption and emission concept

- The electrons of an atom can occupy certain **discrete atomic energy levels**.
- As an electron makes a jump from one energy level to another, energy is absorbed or released in the form of a photon. The amount of energy absorbed or released is equal to the difference between the discrete atomic energy levels and is also **quantized.**
- The energy of a photon is dependent on its frequency. Therefore, only photons with frequencies which correspond to the differences between the atomic energy levels can be absorbed or released by an atom. These frequencies appear as spectral lines in the **emission and absorption spectra**.

The energy of a photon is given by

$E = hf$

- energy in joules (E)
- frequency of light in Hz (f)
- Planck's constant (h) 6.63×10^{-34} J s

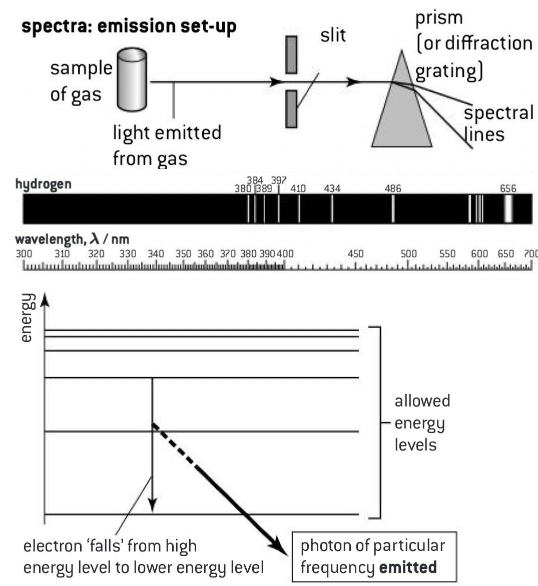
Since $c = f\lambda$

$\lambda = \frac{hc}{E}$

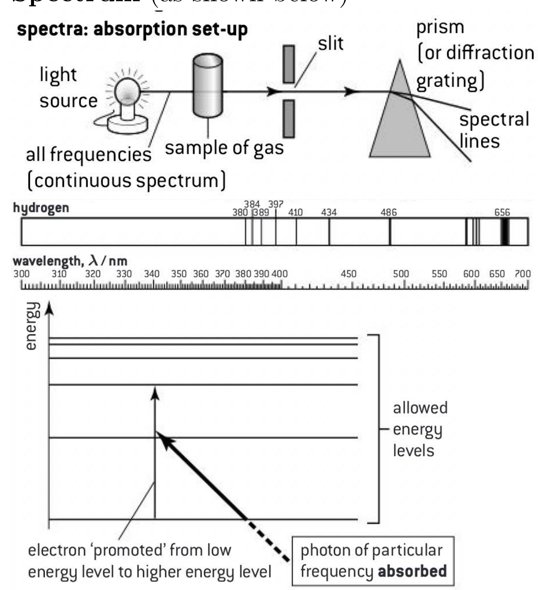
- Speed of light in m s^{-1} (c)
- Wavelength in m (λ)

4. Emission and Absorption Spectrum

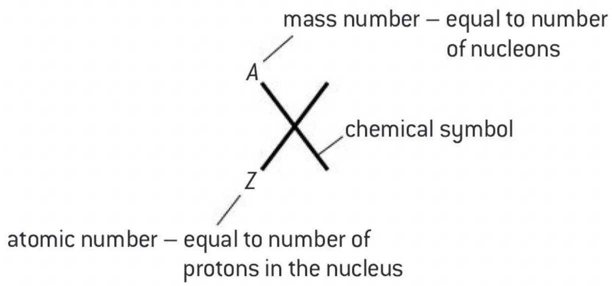
Coloured Discreet lines on black background= **Emission Spectrum** (as shown below)



Black lines on coloured background: **Absorption Spectrum** (as shown below)



5. Isotopes and Nuclear Stability



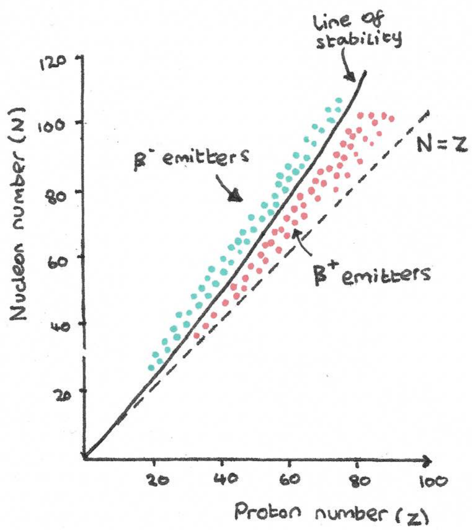
Nuclide notation

Isotopes - Mass number is different but proton number is same.

NUCLEAR STABILITY:

Many atomic nuclei are unstable. The process by which they decay is called radioactive decay.

It involves emission of **alpha** (α)**, beta** (β) **or gamma** (γ) **radiation.** The stability of a particular nuclide depends greatly on the numbers of neutrons present. The graph below shows the stable nuclides that exist.

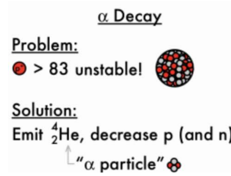


- For small nuclei, the number of neutrons tends to equal the number of protons.
- For large nuclei there are more neutrons than protons.
- Nuclides **above** the band of stability have 'too many neutrons' and will tend to decay with either **alpha or beta decay**.
- Nuclides **below** the band of stability have 'too few neutrons' and will tend to emit **positrons**

6. Alpha beta and gamma emission

All decay reaction must be balanced in terms of mass and atomic numbers on both sides.

Alpha particles:



An alpha particle is a **helium nucleus.**

-It has a relative charge of +2.

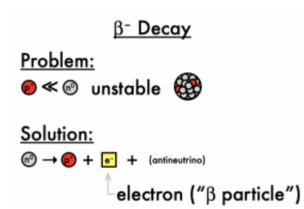
-Its penetration power is the lowest among the three types of particles and can be blocked by a piece of paper or a few cm of air.

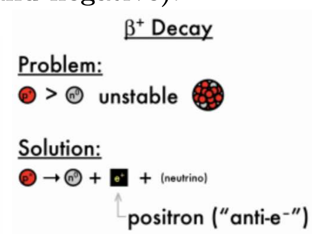
-Its ionizing power is the highest among the three types of particles.

$$^{A}_{Z}\mathbf{X} \rightarrow {}^{(A-4)}_{(Z-2)}\mathbf{Y} + {}^{4}_{2}\alpha$$

e.g. ${}^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{ Np} + {}^{4}_{2}\alpha$

Beta Decay (positive and negative):





A beta particle is an **electron or a positron.**

-It has a relative charge of -1 or +1.

-Its penetration power is in the middle among the three types of particles and can be blocked by a thin sheet of aluminum.

-Its ionizing power is in the middle among the three types of particles.

${}^{0}_{1}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\beta + \bar{\nu}$

$$^{A}_{Z}\text{X} \rightarrow {}_{(Z+1)}^{\;\;\;A}\text{Y} + {}^{0}_{-1}\beta + \bar{\nu}$$

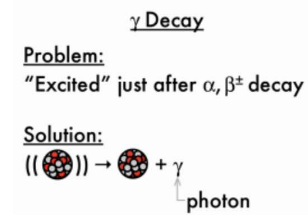
e.g. ${}^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\beta + \bar{\nu}$

$$^{1}_{1}\text{p} \rightarrow {}^{1}_{0}\text{n} + {}^{0}_{+1}\beta^{+} + \nu$$
$$^{19}_{10}\text{Ne} \rightarrow {}^{19}_{9}\text{ F} + {}^{0}_{+1}\beta^{+} + \nu$$

the positron, β^{+}, emission is accompanied by a neutrino. The **antineutrino is the antimatter form of the neutrino.**

6. More decay concepts

Gamma particles (Decay):



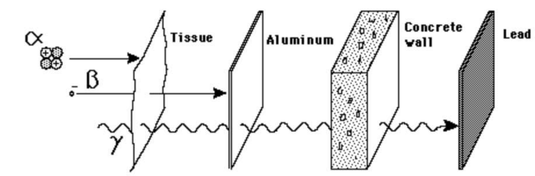
-Gamma rays are photons.

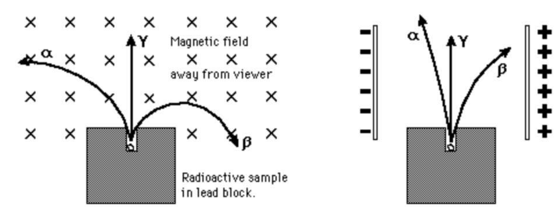
-It does not have a charge.

-Its penetration power is the highest among the three types of particles and can be blocked by several cm of lead.

-Its ionizing power is in the lowest among the three types of particles.

${}^{A}_{Z}\mathbf{X}^{*} \rightarrow {}^{A}_{Z}\mathbf{X} + {}^{0}_{0}\gamma$ (Excited state to Lower energy state)





Absorption characteristics of decay particles:

-Short-term effects: Radiation burn Nausea and vomiting Diarrhea Headache

-Long-term effects: Cancer Genetic mutations

Background radiation:

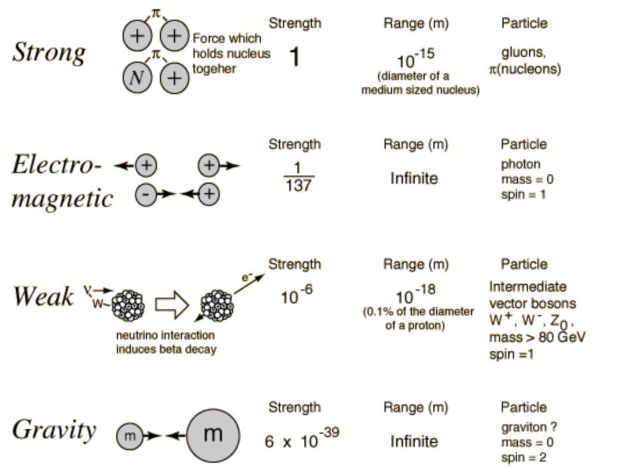
Background radiation comes from natural sources and artificial sources.

Natural sources: cosmic rays from space, radioactive rocks and soil, living organisms that have consumed radioactive substances in the food chain

Artificial sources: radioactive waste from nuclear power plants, radioactive fallout from nuclear weapons, medical x-rays

7. Fundamental Forces

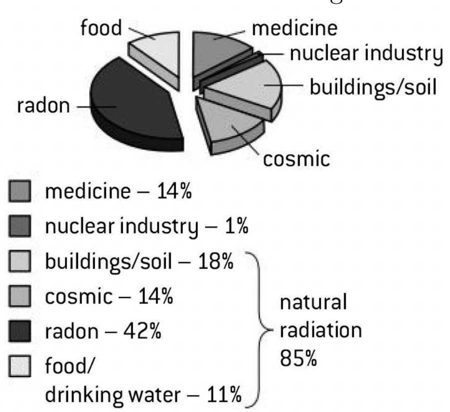
Nuclear properties are governed by the **fundamental forces** that act between particles in the nucleus. In order of increasing strength, where 1 is the strongest force, these are:



8. Nuclear activity

The **activity** of any given source is measured in terms of the number of individual nuclear decays that take place in a unit of time. This information is quoted in **becquerels** (Bq) **with** 1 Bq = 1 **nuclear decay per second.**

Experimentally this would be measured using a **Geiger counter**, which detects and counts the number of ionizations taking place inside the GM tube. A working Geiger counter will always detect some radioactive ionizations taking place even when there is no identified radioactive source: there is a background count as a result of the background radiation.



9. Half Life

Radioactive decay refers to the **spontaneous** random process by which particles or electromagnetic radiation is emitted from an unstable nucleus.

The product nucleus from a radioactive decay is called a **daughter nucleus**.

The daughter nucleus is energetically unstable.

The activity of radioactive decay can be shown by **half-lives**.

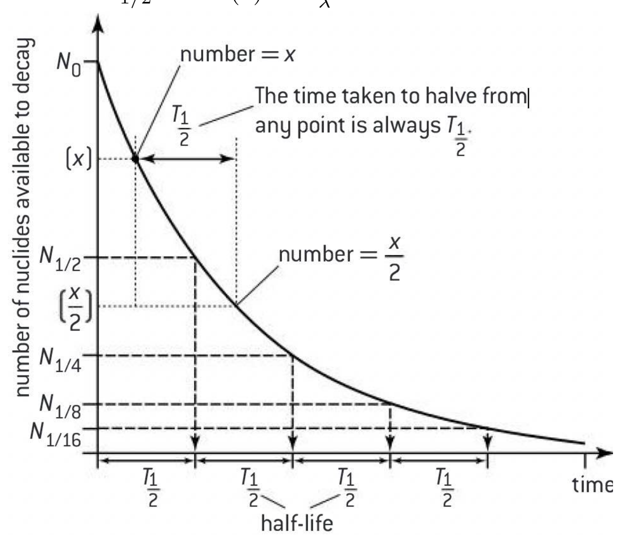
Radioactive decay is a random process and is not affected by external conditions. For example, increasing the temperature of a sample of radioactive material does not affect the rate of decay. This means that is there no way of knowing whether or not a particular nucleus is going to decay within a certain period of time. All we know is the chances of a decay happening in that time.

-The half-life of a nuclide is the time taken for half the number of nuclides present in a sample to decay. An equivalent statement is that the half-life is the time taken for the rate of decay (or activity) of a particular sample of nuclides to halve.

Activity (half-life decay)

$R(t) = R_0 \left(\frac{1}{2}\right)^{\left(\frac{t}{T_{1/2}}\right)}$ [[decays/s]

half-life $T_{1/2} = \tau \ln(2) = \frac{\ln(2)}{\lambda}$



Half-life of an exponential decay

10. Artifical Transmutation

There is nothing that we can do to change the likelihood of a certain radioactive decay happening, but under certain conditions we can make nuclear reactions happen. This can be done by bombarding a nucleus with a nucleon, an alpha particle or another small nucleus.

Such reactions are called **artificial transmutations.**

In general, the target nucleus first 'captures' the incoming object and then an emission takes place.

$$^4_2\text{He}^{2+} + ^{14}_7\text{N} \rightarrow ^{17}_8\text{O} + ^1_1\text{p}$$

The mass numbers $(4 + 14 = 17 + 1)$ and the atomic numbers $(2 + 7 = 8 + 1)$ on both sides of the equation must balance.