IMPORTANT TERMS

Chemical reactions are the processes that lead to the formation of new substances by making and/or breaking chemical bonds

- All actions in a chemical reaction do not mess with the nuclei
- They work by moving electrons

Nuclear Chemistry is all about changing the nucleus and it has no business with the chemical reactions "moving electrons"

a **Nucleon** is a particle that's part of the nucleus, either a proton (**p**) or a neutron (**n**)

Atomic number (z) is the number of protons in a nucleus

Mass number (a) is the sum of the protons and neutrons

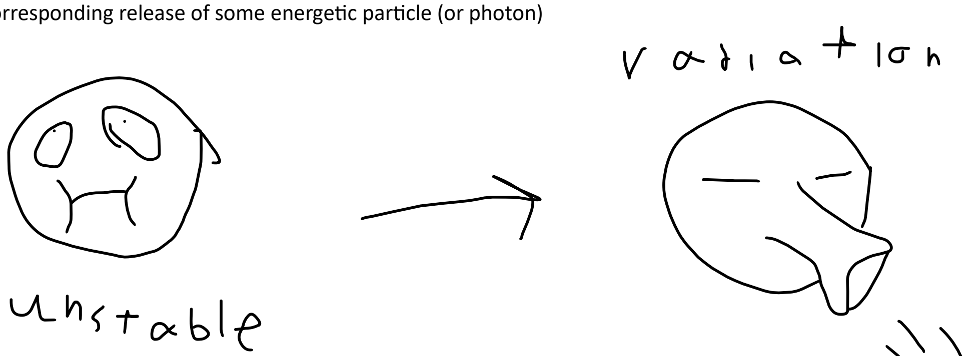
Isotopes (of an element) are variations of the same element, they have the same proton count but different neutron count, an example is carbon-12, carbon-13, carbon-14

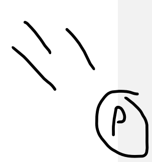
a **Nuclide** is a nucleus with a specified number of neutrons (almost synonymous to "isotope")

Isotope refers to a type of matter

Nuclide refers to a thing

a **Radioactive Nuclide** is an unstable nuclide that undergoes a spontaneous nuclear decay process with a corresponding release of some energetic particle (or photon)





Radiation is the general historic term for the kind of energetic particles that are emitted from a sample containing radioactive material, it has types like **alpha, beta, gamma, positron**

Stable Nuclide is a nuclide that does not undergo any spontaneous nuclear decay processes

Spontaneous nuclear decay it's the process where a radioactive (reactant) nuclide turns into another "more stable" nuclide, and it is **spontaneous,** it does not need previous steps to work, it just happens

There are other reactions that include initiation and more than a single nuclide like **Fission** and **Fusion** and **Transmutation (bombardment) reactions**

Radioactive

It is the characteristic behavior of the nuclei of unstable atoms

The first one who observed the radioactivity phenomenon was **Antoine Henri Becquerel**

And the first one to use the word RADIOACTIVITY to describe this phenomenon was **Marie & Pierre curie**

Commented [SD1]: It means "what we call"

Commented [SD2]: It's highlighted because this is the unit of activity

Activity is the rate at which a radioactive substance undergoes decay

- Its SI unit is **Becquerel (Bq)**, it means "1 decays per second (dps)"
- 1 liter of air has ~ -.04 Bq due to ^{14}C in CO_2
- It had an older unit called **Curie (Ci)** which is equal to 3.7×10^{10} **Bq**

It will be discussed later

STABILITY

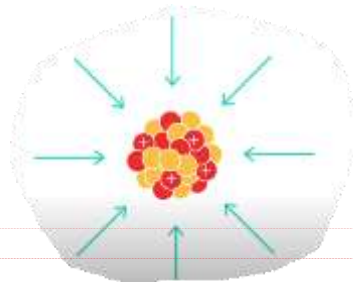
It has two kinds

Kinetic stability refers to whether a nuclide **will undergo spontaneous nuclear decay**, if the nuclide decays then it is **unstable or radioactive**, and if it doesn't decay then it is **stable**

Thermodynamic stability refers to how stable a nuclide is **compared to another**, in terms of (overall configuration of nucleons), it applies to **all** nuclides, radioactive or not, and it is determined by the amount of energy required to split a nucleus into 2 "binding energy per nucleon"

It is going to be discussed later, in more detail

There are **two nuclear** forces in nature

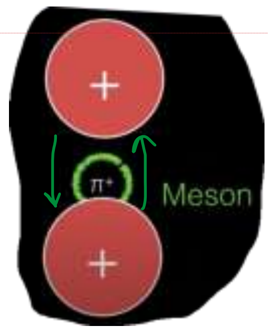


Strong Nuclear force

is the force that pulls the positive protons and neutral neutrons together in the nucleus

it is stronger than all the other fundamental forces, and its strength shows in the small scale of femtometers, because in the nucleus, the positively charged protons will repel each other

Mechanism: when Meson bounces between the protons a lot of times, it attracts them to each other

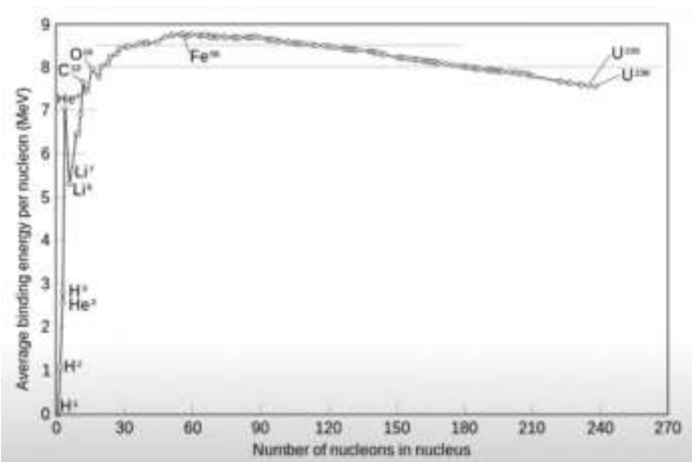


Commented [SD3]: They are gravity – electromagnetism – weak nuclear force

Commented [SD4]: It means 10^{-15}, it's just there to make you imagine the small area the nuclear force is acting on

Commented [SD5]: A quark, a very small particle that makes up nucleons like protons or neutrons, it is not going to be mentioned again, it is just here to make you understand how the nuclear force is working, and no, it is unlikely to pop up in exams

Binding Energy per Nucleon is the amount force pulling an induvial nucleon "proton or neutron" together



As you can see in this graph, at first, the more nucleons we have, the stronger the binding energy, but at a certain point, the amount of protons and neutrons become too much for the nuclear force to handle, and the binding energy is weakened, causing the nucleus to be **unstable**

WEAK NUCLEAR FORCE

It is the force responsible for decays like **beta decay**, we don't have to study it in detail

STABLE AND UNSTABLE NUCLEI

A Nucleus is unstable most of the time when:

- Too much **nucleons** (protons/neutrons)

So to stabilize themselves, they get rid of excess nucleons, this process is what we call **radioactive decay** or **nuclear decay**

alpha decay | beta minus decay | beta plus decay

gamma radiation | electron capture

NOTES

- The nucleus before decay is called a **parent nucleus**
- the nuclei after decay are called **daughter nuclei**
- when a nucleus has too many neutrons, it goes in **beta minus decay**
- when a nucleus has too many protons, it goes in **beta plus decay**

Commented [SD6]: I made it in plural because after some more pages, we are going to take fusion and fission which are splitting the nucleus into multiple nuclei

HOW TO DETERMINE IF A NUCLEUS IS UNSTABLE

We can know if a nucleus is stable or not, and what kind of decay it will have by looking at the **NZ graph**

NZ graph (valley of stability)

It's a graph plotting the **neutron count** and **proton count**

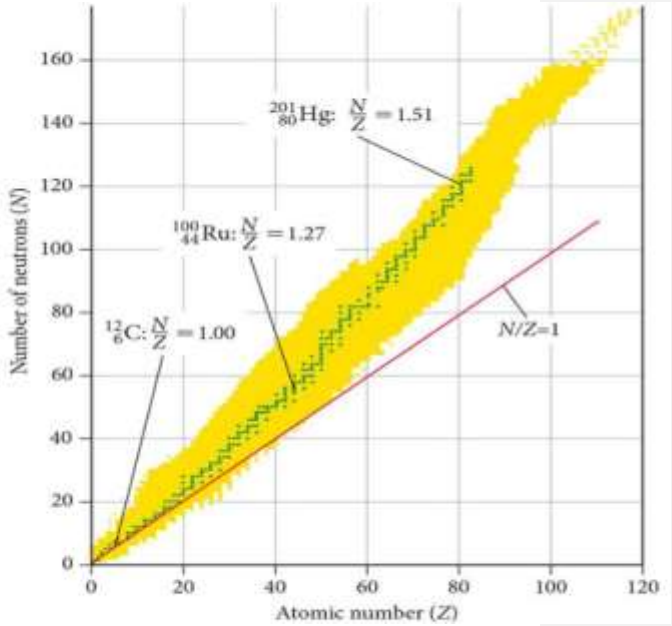
The red line is the **1:1** ratio between **Neutron count (N)** and **Proton count (Z)**

The yellow squares are **unstable**

The green squares are **stable**

OBSERVATION

- the more that the proton count increases, the more neutrons are needed to make it stable, as you can see, the 1:1 ratio will be unstable after sometime
- after the proton count reaches 82 (lead), any other nucleus after that will be unstable as the proton count is too much for the nuclear force to handle



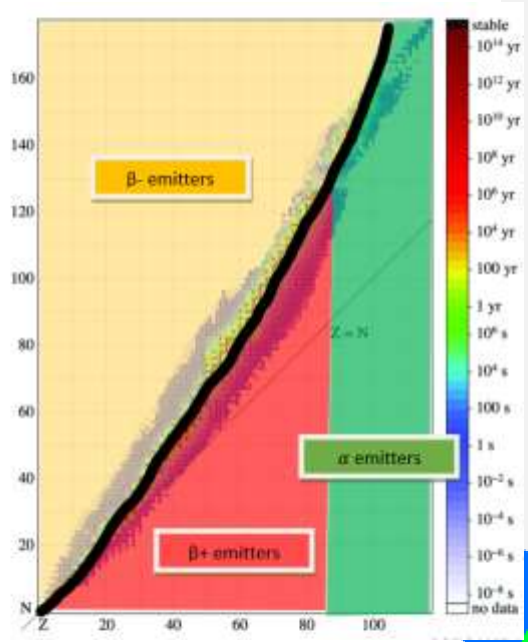
HOW TO GET THE TYPE OF DECAY

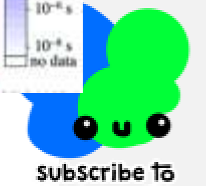
here, the **black line** represents the **stability curve**

red section -> There is a lot of protons and still not many neutrons, so there will be **mostly beta plus decay** to turn the protons into neutrons

yellow section -> There is a lot of neutrons and still not many protons, so there will be **mostly beta minus decay** to turn the neutrons into protons

green section -> There are a lot of protons and neutrons, so **mostly** alpha decay will happen until we are stable





KINDS OF NUCLEAR DECAY (TYPES OF SPONTANEOUS EMISSION)

Alpha decay (α)

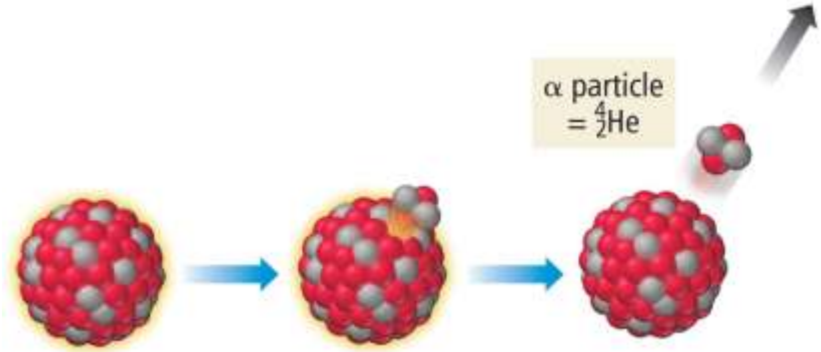
Is the loss of an alpha particle, aka a helium nucleus ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$, the lower left subscript is the **charge (proton count)**, and the upper left is the mass **(mass number)**

-4 ← A

Z

-2 ←

$${}^{238}_{92}U \xrightarrow{\alpha\ \text{decay}} {}^{234}_{90}Th + {}^{4}_{2}\alpha$$



Beta minus decay (β-)

Is when a nucleus turns a neutron turns into a proton by shooting out an electron (negative beta particle) and an antineutrino

Commented [SD7]: It's a small particle like electrons, they do not interact with matter most of the time so you can just ignore them

Neutron -> proton + electron (β-)

A

0 ←

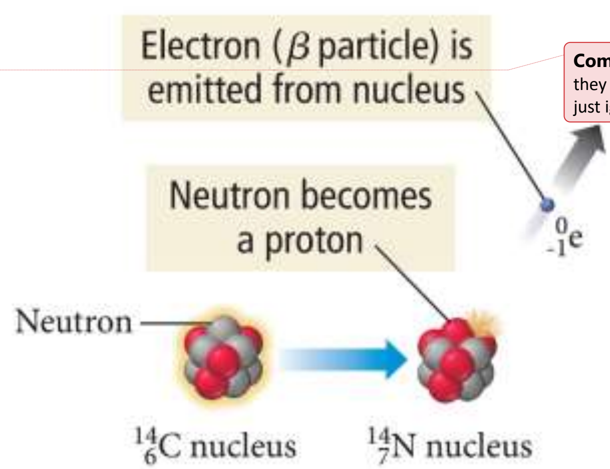
$${}^{1}_{0}n \xrightarrow{\beta\ \text{decay}} {}^{1}_{1}p + {}^{0}_{-1}e$$

Z

+1 ←

$${}^{131}_{53}I \xrightarrow{\beta\ \text{decay}} {}^{131}_{54}Xe + {}^{0}_{-1}e$$

Here you see that a neutron in the nucleus turned into a proton and shot out an electron

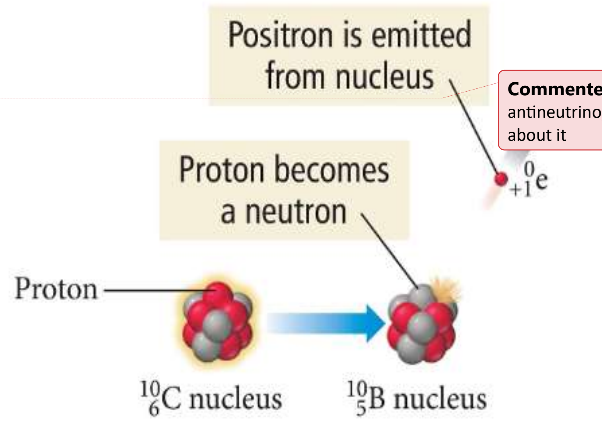


Beta plus decay (β+)

Is when a nucleus turns a proton into a neutron by shooting a positron (positive beta particle) and a neutrino

Commented [SD8]: It is the positive counterpart to an antineutrino, it doesn't react much with matter so forget about it

Proton -> neutron + positron (β+)



A

0 ← $^{1}_{1}p \xrightarrow{\beta\ decay} {}^{1}_{0}n + {}^{0}_{1}e$

Z

-1 ← $^{31}_{54}Xe \xrightarrow{\beta\ decay} 1\ {}^{131}_{53}I + {}^{0}_{1}e$

Here you see that a proton in the nucleus turned into a neutron and shot out an positron

Gamma radiation (γ)

Is when a nucleus emits a high energy photon "particle of light with no mass", it doesn't lose charge or mass, it was just very excited with energy, so it disposes of it, it happens after a nuclear reaction because of the huge amount of energy

0 ← A

0 ← Z

$$^{234}_{90}Th^{*} \xrightarrow{\gamma\ radiation} {}^{234}_{90}Th + {}^{0}_{0}\gamma$$

ANTI MATTER

It's a type of "negative" matter, when matter meets anti-matter, they annihilate each other releasing gamma radiation in the process

A positron is an **antimatter** while an electron is **matter**

$$^{0}_{-1}e + {}^{0}_{+1}e \rightarrow \text{"energy"}$$

Electron Capture

It is when the nucleus grabs an electron (it's a reactant and added to the nucleus, not produced from it) in the inner most shell and uses it to turn a proton into a neutron, this will also produce GAMMA radiation

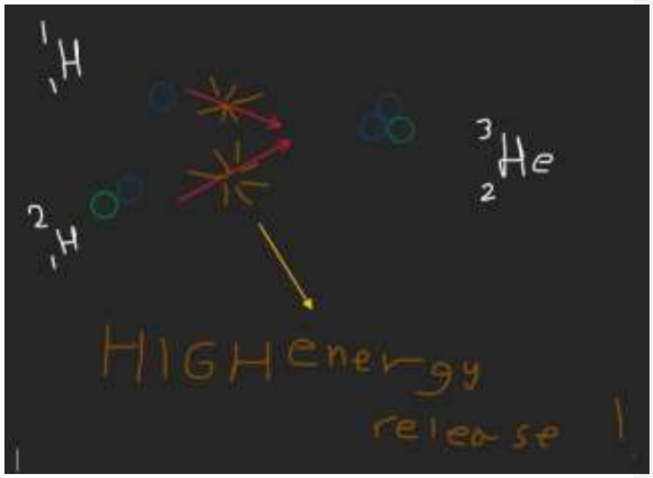
0 ← A

-1 ← Z

$$^{7}_{4}Be + {}^{0}_{-1}e \xrightarrow{E.C.} {}^{7}_{3}Li + {}^{0}_{0}\gamma$$

Nuclear Fusion

It is when two light nuclei, fuse together into a heavier nucleus, imagine elements like ${}_{1}^{1}H$ and ${}_{1}^{2}H$ fuse together to form ${}_{2}^{3}He$



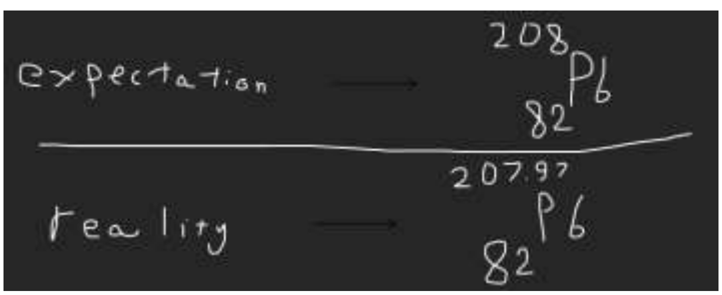
this process is the thing fueling stars, as the huge amount of energy released from nuclear fusion produces a ton of light

and this is why it is said that **hydrogen** was the start of all elements, as all elements were just hydrogens that were fused

why does nuclear fusion produce a lot of energy?

It's because some of the mass of the original nuclei, is being turned into **ENERGY** rather than staying as **mass**, you visibly can't see it in the mass number, but this helium atom is slightly lighter than the nucleus of 2 hydrogen atoms

This shows in elements with big nucleon counts like lead, as its atomic mass is 207.97 even though when you add the proton and neutron numbers you get 208



HOW TO CALCULATE THE ENERGY OF FUSION

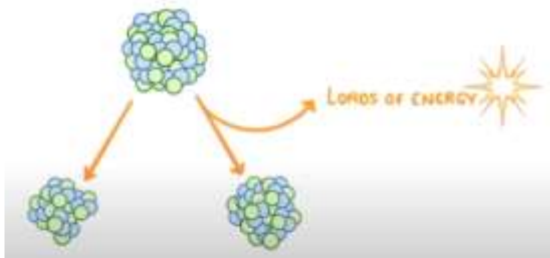
We use the formula $\mathbf{E = mc^2}$

Where

- **E** is energy
- **m** is the amount of mass turned into energy
- **c** is the speed of light or $3\text{x}10^8$m/s

Nuclear Fission

It's splitting an unstable nucleus into 2 more stable nuclei (**daughter nuclei)**, it produces a lot of energy and it's the mechanism we use in **nuclear reactors**



it can happen in two ways

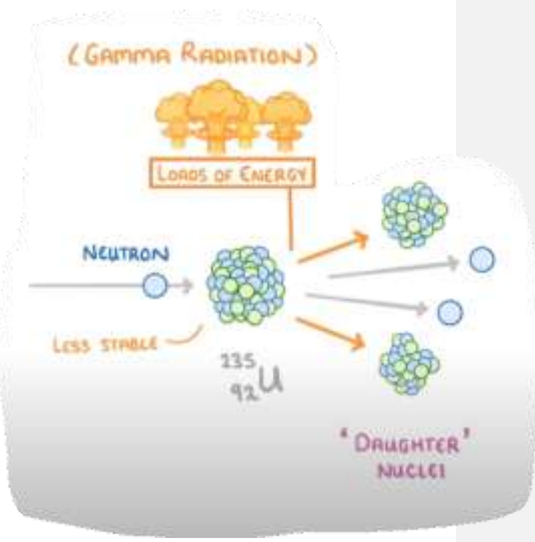
SPONTANEOUS fission

Is when nuclear fission is unforced and happens by itself naturally, it is rare in nature to find a spontaneous fission

ABOSRBING A NEUTRON fission

It is when we hit an unstable nucleus with a neutron to generate energy

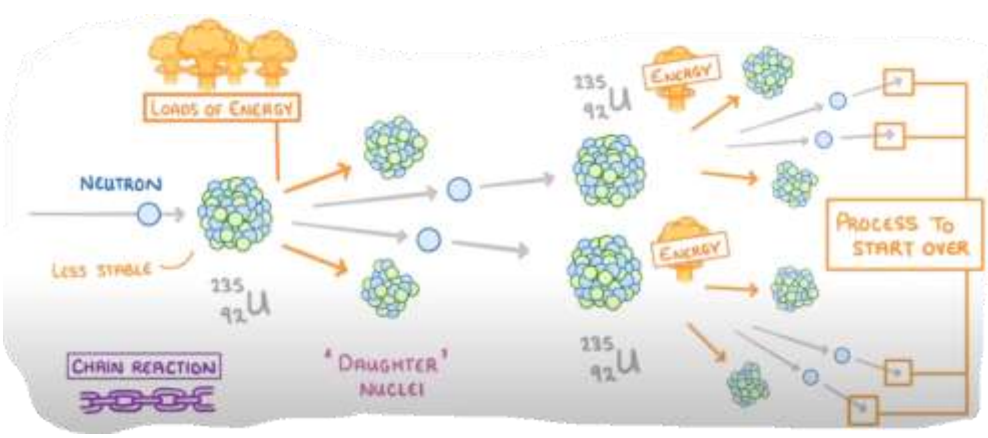
For example, if we throw a neutron at the nucleus of uranium 235, it will split into two nuclei with some extra neutrons, while generating a lot of energy (GAMMA RADIATION)



NUCLEAR FISSION CHAIN REACTION (used in nuclear plants)

The extra neutrons will collide with more nuclei, producing more nuclear fission, producing more neutrons that will lead to more nuclear fission, etc etc.

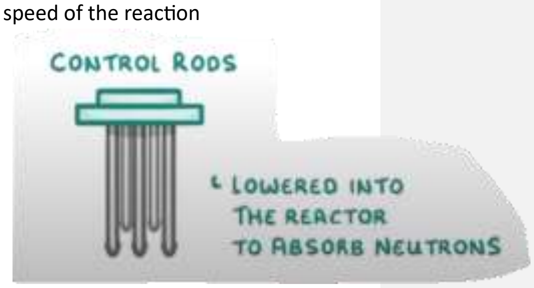
This chain reaction will lead to the production of a lot of energy, and if uncontained, it will lead to the creation of a **nuclear bomb**



NUCLEAR FISSION HANDLING

How do nuclear plants contain this chain reaction?

- **Control rods** are used to absorb neutrons and lower the speed of the reaction
- **The energy** is used to heat up water, generating steam, which is used for generating electricity



1 minute video that summarizes "nuclear fusion, nuclear fission"

https://www.youtube.com/watch?v=2W-GEE6YU4M we know that unstable isotopes of elements become stable by emitting radiation, and we call these materials **radioactive**, if had a single radioactive isotope, we will have no way of knowing when the it will decay, because it is random

but if we had a large enough sample, we can still find out two very useful things

ACTIVITY

The overall rate of decay for all **isotopes/unstable nuclei** in our sample

We measure it in **Becquerels (Bq)**, where 1 **Bq = 1 decay per second**

Activity = number of decays / time

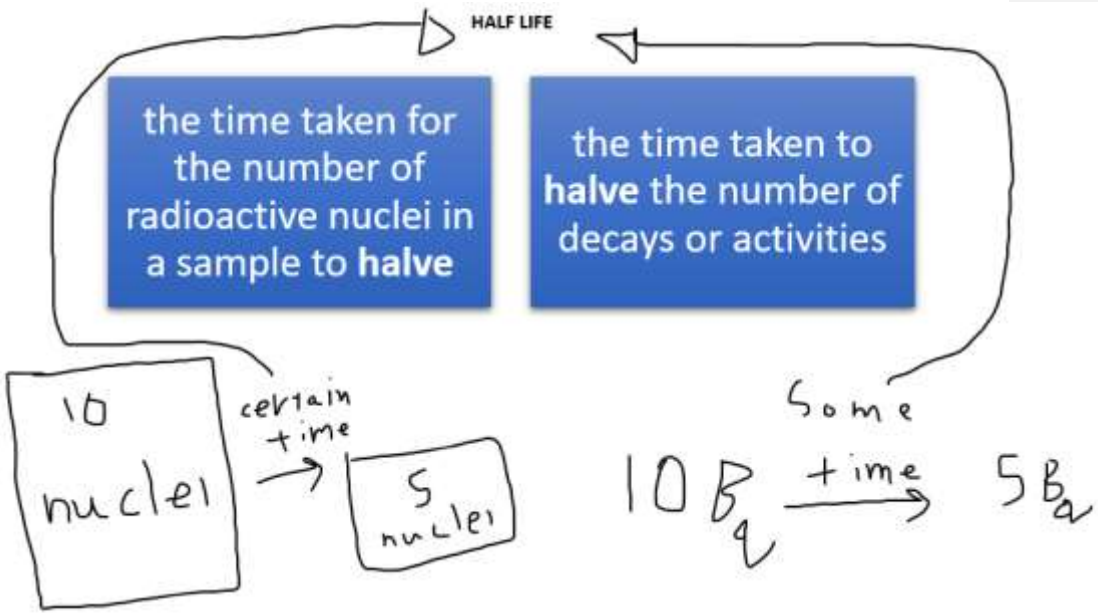
So if said our sample has an activity of 10 Bq, it means that overall, 10 nuclei decay every second
it has a direct relationship with the number of unstable nuclei in the sample, because the decay rate for a single nuclei is random, it is not a constant rate, so the decay is linked to the amount of unstable particles

So let’s say we had 10 nuclei and they all decayed in 10 seconds

We would have an activity of 1Bq

But if we had 5 nuclei and they all still decayed in 10 seconds

We would have an activity of 1/2 Bq

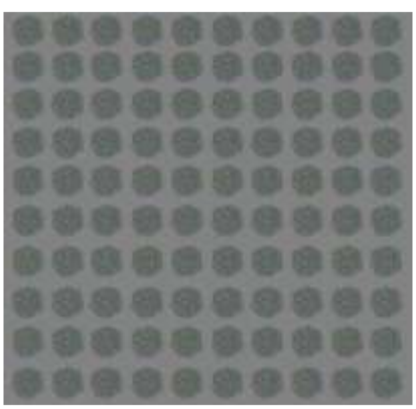


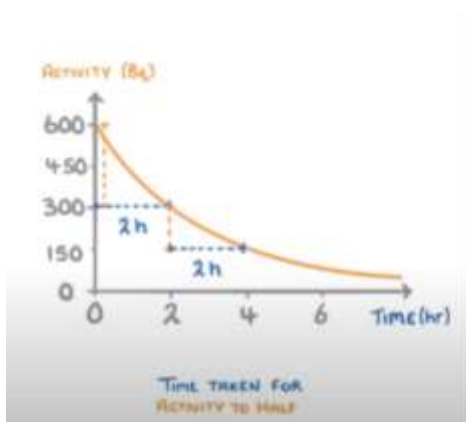
as more time passes, the number of unstable particles **decreases**, and the **activity decreases** with them too

when the number of the unstable particles, or the activity reach **half** what they began with

we call that **half life**

as you can see in this sample, every 2 hours, the activity **halves**, so the half-life is **2 hours**





If we imagined another sample but it is decaying much faster, we would have more activity, but faster half life, as everything is going to be halved more quickly

FINDING THE ACTIVITY

In previous examples, we speculated the activity, but in real life, we use a device called **Geiger-Muller tube**

It measures every decay that reaches it and turns them into a count rate (activity)

GEIGER-MULLER TUBE AND COUNTER

QUESTION

THE HALF-LIFE OF A RADIOACTIVE SOURCE IS 40 HOURS.
THERE ARE INITIALLY 3,000,000 RADIOACTIVE NUCLEI IN THE SAMPLE.
HOW MANY NUCLEI WILL REMAIN AFTER 5 DAYS?

1. Turn the time into hours
   5 * 24 = 120 hours
2. Calculate how many half lives
   half-life count = 120 / 40 = 3 half lives
3. Now for each half-life, you divide the nuclei count by 2
4. **Count = 3,000,000 / 2 = 1,500,000** for half-life 1
5. **Count = 1,500,000 / 2 = 750,000** for half-life 2
6. **Count = 750,000 / 2 = 375,000 nuclei** for half-life 3