

YABELLO IFA BORU SPECIAL BOARDING SECONDARY SCHOOL

PHYSICS SHORT NOTE FOR GRADE 11

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UNIT-7: NUCLEAR PHYSICS

Introduction

- **Nuclear Physics** is the field of physics that studies **atomic nuclei** and their **constituents**, and **interaction** that holds them together. Nuclear interactions include **radioactive decay**, **fission** (the break-up of nucleus), and **fusion** (the merging of nuclei).
- The main driving strong nuclear force produced by the nucleus of an atom acts within a very short distance-just a few femtometers ($10^{-15}m$) across. The strong nuclear force is the force that is responsible for binding of protons and neutrons into atomic nuclei. The strong binding energy will help to produce strong radiation upon different reaction processes and radiation decay.
- A nuclide may be stable or unstable. Unstable nuclides emit radiations spontaneously. These radiations have different forms which are known as α, β, and γ radiation with charges similar to proton, electron, and neutron in the atomic system.

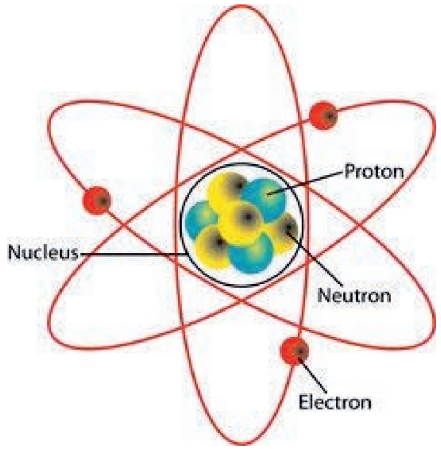
- Through research, nuclear physicists are leading us on a journey of discovery into the nucleus of the atom - the very heart of matter. The goal is a roadmap of matter that will help unlock the secrets of how the universe is put together. Significant efforts have been made from the early 19^{th} century on the observation of different subatomic systems by different scientists.
- Nowadays, the research reactor (RR) and the power reactor (PR) are widely in use globally. Research reactors are small nuclear reactors that are primarily used to produce neutrons, unlike nuclear power reactors, which are larger and used to generate electricity.
- The two reactors are based on the fission processes. However, the fusion is still in progress in laboratories and computer work. In all processes, it is important to aware that the fuel elements for nuclear reactions are heavy unstable nuclei such as **U, Th, K, Pt** ans so on.

- Nuclear radiations have very powerful ionization effects; some of which is fatal to human beings if proper precautions are not in use. It is mandatory to use the nuclear safety rules of the International Atomic Energy Agency (IAEA) for the proper use of nuclear instruments and materials. There should be a separate inspection bodies for both the RR and PR once any country has these reactors in use.
- The purpose of this unit is studying the different properties of nuclei so far have seen above, uses and quantitative measurements of nuclear energy; and precautions to be taken to take care of ionization radiations.

7.1 The Nucleus

About the Atom

- Atoms are the basic building blocks of all matter. An atom consists of a positively charged central nucleus that is surrounded by one or more negatively charged electrons.
  The nucleus contains one or more relatively heavy particles known as protons (positively charged) and neutrons (electrically neutral), which are collectively called **nucleons**. Table below summarizes charges and masses of the three subatomic particles.



Subatomic particles	Charge		Mass	
	(in C)	Relative Charge	(in kg)	(in u)
Electron	-1.602×10^{-19}	-1	9.1094×10^{-31}	0.00054858 u
Proton	$+1.602\times10^{-19}$	+1	1.6726×10^{-27}	1.0072766 u
Neutron	0	0	1.6749×10^{-27}	1.0086654 u

$\Longrightarrow$ amu(u): atomic mass unit ($1amu = 1.660 \times 10^{-27} kg$)

- Since the mass of an electron is comparatively very small, only the nucleus contributes to the mass of the atom, which typically contains more than 99.9% of the mass of the atom. Thus, the sum of the number of protons and neutrons in the nucleus is expressed as mass number (A) and the number of protons is its atomic number (Z) for a neutral element. A neutral element in the periodic table of the chemical symbol X is uniquely designed by:

$$^{A}_{Z}X$$

- Some examples of designation of elements are oxygen ${}^{16}_{8}O$, helium ${}^{4}_{2}He$, carbon ${}^{12}_{6}C$. Although the nucleus contains much of the mass of the atom, it is very dense and occupies only less than $0,01\%$ of the volume of the atom. The atom and the nucleus are assumed to be spherical and the atomic radius is estimated by:

$$R = R_o A^{\frac{1}{3}}$$

Where, A is the mass number of the atom and
$R_o = 1.2fm = 1.2 \times 10^{-15} m$ is the radius of the nucleus.

Isotopes

- An element may have atoms with different number of neutrons. Atoms with the **same** number of **protons** but **different** numbers of **neutrons** are called **isotopes**.
- They share almost the same chemical properties, but differ im mass and therefore in physical properties.
- Examples of isotopes
- Hydrogen isotopes: ${}^{1}_{1}H(protium)$, ${}^{2}_{1}H(deuterium)$, ${}^{3}_{1}H(tritium)$
- Carbon isotopes: ${}^{12}_{6}C$, ${}^{13}_{6}C$, ${}^{14}_{6}C$
- Uranium isotopes: ${}^{232}_{90}U$, ${}^{233}_{90}U$, ${}^{234}_{90}U$, ${}^{235}_{90}U$, ${}^{236}_{90}U$ and ${}^{238}_{90}U$

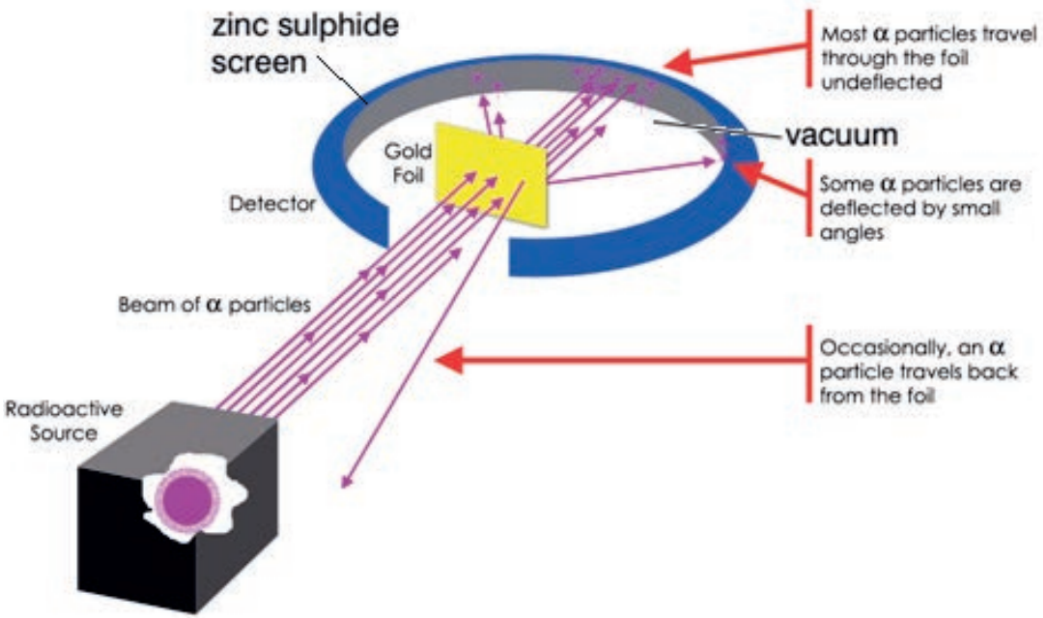
$\Rightarrow$ **Example**

1. Calculate the radii of the smallest isotope of hydrogen $({}^{1}_{1}H)$ and uranium-238.
2. Compare the volume of U-238 atom with the volume of its nucleus.

Historical Origins of the Nucleus ans Constituting Particles

⇒ The Discovery of Nucleus

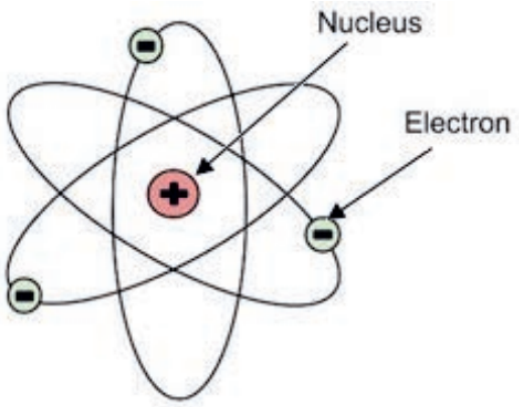
- In 1909, two of Rutherford's students, Geiger and Marsden, aimed positively charged particles (stream of helium nuclei ${}^4_2He$) at an extremely thin piece of gold foil (100 nm thickness). In order to study the deflection caused by the α-particle, they placed a fluorescent zinc sulfide screen around the thin gold foil.



- Rutherford repeated the experiment many times, and up with the same result. His evidences and conclusions are summarized as follows.

Evidences	Conclusions
Most of the -particles passed through the gold sheet with no or small deflection (0°-10°).	Most of the space in an atom is empty.
Some of the particles were deflected by very small angles (10° - 90°)	The positive charge in an atom is not uniformly distributed, but concentrated in a very small volume.
Very few of the -particles were deflected back towards the source (90° - 180°), only very few being at 180°.	Most of the mass of the atom, and all the positive charge, is concentrated in a tiny central space, what Rutherford called the nucleus.

- Based on his observations, Rutherford proposed a new atomic model in 1911, called the **solar system** model as well as the positive charge and most of the mass is concentrated in a tiny central nucleus. Most of the atom is empty space, and electrons orbit at the edge. He also claimed that the electrons surrounding the nucleus revolve around it with very high speed in circular paths. He named these circular paths as **orbits**.



$\Rightarrow$ Drawbacks of Rutherford's atomic

- The Rutherford's atomic model failed to explain the stability of electrons in a circular path. He stated that electrons revolve around the nucleus in a circular path, but electrons in motion would undergo acceleration and causes energy radiation. Eventually, electrons should lose energy and fall into the nucleus.

Discovery of the proton

- Rutherford thought that a hydrogen nucleus must be the fundamental building block of all nuclei, and also possibly a new fundamental particle. Rutherford postulated the hydrogen nucleus to be a new particle in 1920, which he called **proton**. Rutherford named it the proton, from the Greek word "protos", meaning "first".

Discovery of the neutron

- The British physicist James Chadwick discovered the neutron in 1932. He conducted experiments very similar to those of Rutherford. In Chadwick's case, he fired his atomic bullets at the element beryllium, not gold. The resulting collision produced a new kind of particle that was just as massive as the proton, but it penetrated through several inches of lead.
- If you can take a particle and penetrate several inches of lead, it implies, first of all, that the particle is moving very fast; and second, that the particle is electrically neutral, it has neither a positive nor a negative charge. So Chadwick found that the neutron is indeed electrically neutral, and he also found that its mass is slightly greater than that of the proton. Finally, he determined the mass of the neutron using the law of conservation of energy and momentum as well.

What keeps the nucleus together?

- We know that the positively charged protons and electrically neutral neutrons are packed together in the nucleus. Then, what is holding the cluster of nucleons together instead of repelling each other due to the electrostatic force and fly apart?
- This equation takes you to consider the two fundamental forces of nature: the strong and weak nuclear forces.

$\Rightarrow$ **The strong and the weak nuclear forces**

- The strong nuclear force is a very short-range attractive force that acts between nucleons: protons and neutrons. The strong nuclear force is strong enough to withstand the electrical repulsion up within a distance of slightly more than the radius of a nucleon, 10^{-15}. Both nucleons are affected by the nuclear force almost identically.
- At the range of $10^{-15}m$ (slightly more than the radius of a nucleon), the strong force is approximately 100 times as strong as electromagnetism, 10^6 times as strong as the weak interaction, and 10^{38} times as strong as gravitation.

- The weak nuclear force acts inside of individual nucleons, which means that it is even shorter ranged than the strong nuclear force. The weak nuclear force can split the electrically neutral neutron into a proton and an electron. In this process, sub-atomic particles are released near the speed of light. These fast particles allow nuclear fusion reaction-combination of two or more nuclides to form a single nuclide- by then releasing enormous energy.

$\Rightarrow$ **Nuclear Binding Energy**

- This is the energy that holds nucleons together. Also defined as, the minimum energy that is required to disassemble the nucleus of an atom into its constituent nucleons. Now the question is how can we determine the binding energy of a nuclide?
- The mass of an atomic nucleus is less than the sum of the individual masses of the free constituent protons and neutrons. This difference in mass is known as **mass defect (Δm)**.
- Once the mass defect is known, the nuclear binding energy (BE) can be determined using **Einstein's special theory of relativity**, which states that **mass and energy are equivalent**.

- The remarkable equivalence between matter and energy is given in one of the most famous equations given by $E = mc^2$; where m is the mass converted into an amount of energy E and $c = 3 \times 10^8 m/s$ is the speed of light.
- From this theory, we can deduce that the mass defect is an amount of mass released in the form of energy during the formation of the nucleons. This energy is equal to the binding energy, which is given by:

$$BE = \Delta mc^2$$

- Masses of subatomic particles are measured in "atomic mass unit (amu or u)"

$$1u = 1.66 \times 10^{-27} kg$$

- Nuclear energy is measured in "atomic energy unit (aeu)" or "mega electron volt (MeV)"
- The **aeu** is the energy possessed by the subatomic particle of mass **1u** moving at the speed of light **c**.

$$1aeu = 1u \times c^2 = 1.44 \times 10^{-10} J$$

- The **eV** is, energy possessed by electron or proton moving in electric field with a potential difference of **1V**.

$$1eV = qV = 1.602 \times 10^{-19} C \times 1V = 1.602 \times 10^{-19} J$$

$$1MeV = 1eV \times 10^{6} = 1.602 \times 10^{-13} J$$

- Therefore;

$$1aeu = 931.1MeV$$

- The mass defect of an atom can be calculated by;

$$\Delta m = Z(m_p) + (A - Z)m_n - M$$

- Where, $Z(m_p)$ is the total mass of the protons; $(A - Z)m_n$ is the total mass of the neutrons, and M is the mass of the nucleus.
- Using this into the former equation, we obtain

$$BE = \Delta mc^2 = [\Delta m = Z(m_p) + (A - Z)m_n - M]c^2$$

- Therefore, when mass is given in amu, the nuclear binding energy of a nucleus in MeV becomes:

$$BE = [\Delta m = Z(m_p) + (A - Z)m_n - M] \times 931.1MeV$$

- The masses of subatomic particles $m_p = 1.0072766u$, $m_n = 1.0086654u$, and $m_e = \frac{m_p}{1836} = 0.00054858u$
- **Binding energy per nucleon (BEN):** is the average energy required to remove an individual nucleon from a nucleus. It is one of the most important experimental quantities, which is defined by

$$BEN = \frac{BE}{A}$$

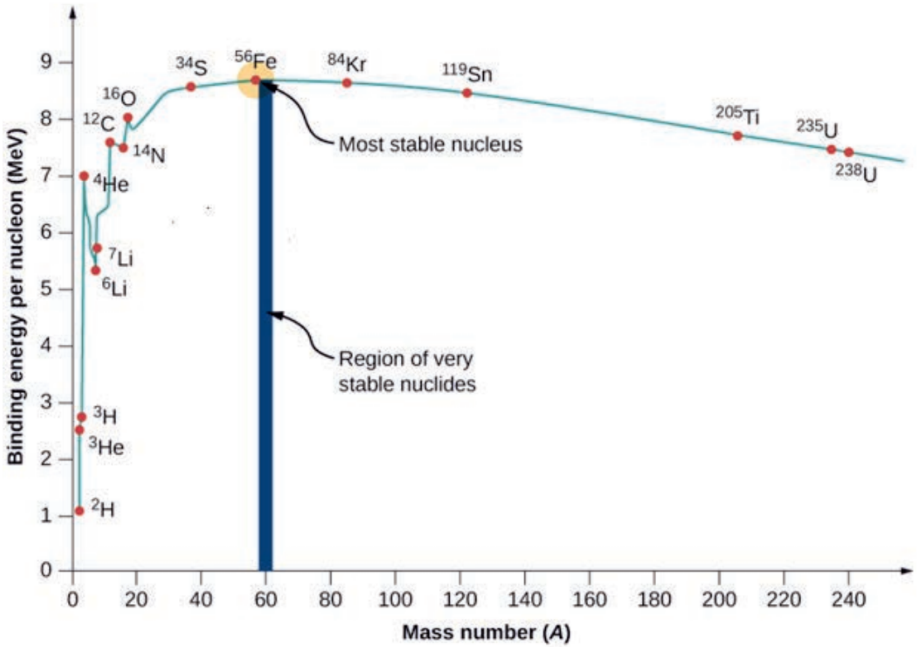
- Where, BE is the binding energy and A is the atomic number of the atom.

Example

1. You know that an atom of oxygen has the form ${}^{16}_{8}O$.
   a) What is the mass defect in oxygen nucleus?
   b) What is the binding energy per nucleon in Oxygen?
2.) a) Find the mass deficit for a carbon-12 nucleus.
   b) Use this mass deficit to calculate the binding energy for a carbon-12 nucleus in joules.
   c) Use this mass deficit to calculate the binding energy for a carbon-12 nucleus in electron-volts and MeV.
   d) calculate binding energy per nucleons

Nuclear Stability

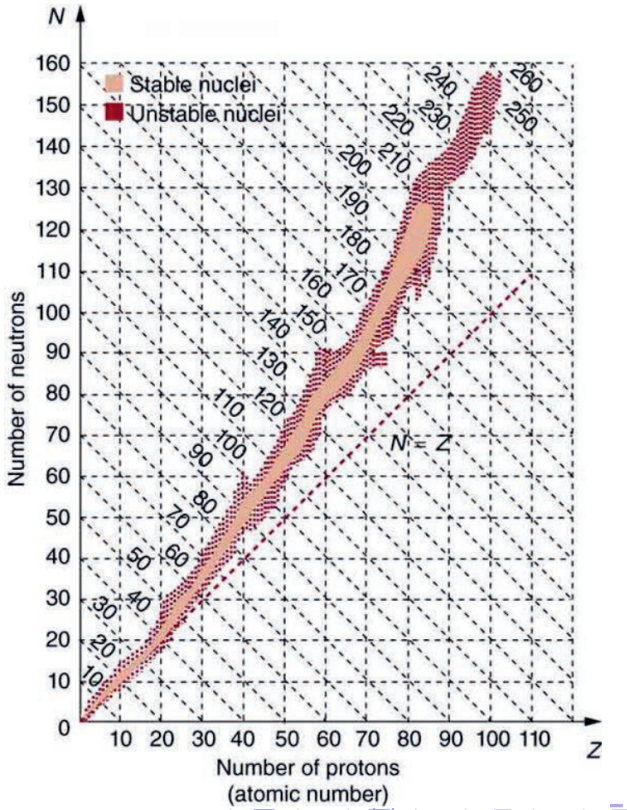
- Nuclear stability refers to the stability of a nucleus of an atom. A stable nucleus does not decay spontaneously. Radioactive elements contain unstable nuclei and decay spontaneously emitting various radiations.
- Nuclear stability is determined by the binding energy per nucleon. The net binding energy of a nucleus is that of nuclear attraction, minus the disruptive energy of the electrostatic force.



- Any system will always try and move to a state of lower energy (or more stable state). As nuclei get heavier than helium, their net binding energy per nucleon grows more and more slowly and reaches its peak at iron (Fe-56), which is 8.8MeV/nucleon, as shown in the above figure.
- As nucleons are added, the total binding energy increases but so does the total disruptive energy of the electrostatic forces and, once nuclei are heavier than that of iron, the increase in disruptive energy has more effect than the increase in binding energy.
- For example, the binding energy per nucleon of uranium, which is at the end of the periodic table, decreases to about 7.6MeV.
- Nuclei of atoms contain protons and neutrons. Positively charged protons repel each other due to electrostatic repulsion between them. This electrostatic repulsion is overcome by the strong nuclear force, the attractive force present between nucleons. Neutrons are important for stabilizing the nucleus. If the attractive force between nucleons is less than the electrostatic repulsion then it makes the nucleus unstable and results in decay. It defines the stability of an isotope of the elements. Nucleons with high binding energy are more stable.

- Stability of an isotope can be determined by calculating the ratio of neutrons to protons present in a nucleus (N/Z). Elements having atomic number less than 20, mostly have proton and neutron ratio 1:1. The number of neutrons increases as the atomic number increases. Most of the stable nuclei have neutrons to protons ratio more than 1. Only 1H and 3He have neutrons to protons ratio less than one but are stable.

- The first 80 elements of the periodic table have stable isotopes. All the elements with the atomic number more than 82 are unstable and radioactive, irrespective of the number of neutrons.



- For many elements with atomic number Z small enough to occupy only the first three nuclear shells, that is up to that of calcium ($Z = 20$), there exists a stable isotope with N/Z ratio of one. The exceptions are beryllium (N/Z = 1.25) and every element with odd atomic number between 9 and 19 inclusive (though in those cases $N = Z + 1$ always allows for stability). Hydrogen-1 (N/Z ratio = 0) and helium-3 (N/Z ratio = 0.5) are the only stable isotopes with neutron–proton ratio under one.
- Uranium-238 has the highest N/Z ratio of any primordial nuclide at 1.587,[2] while mercury-204 has the highest N/Z ratio of any known stable isotope at 1.55. Radioactive decay generally proceeds so as to change the N/Z ratio to increase stability. If the N/Z ratio is greater than 1, alpha decay increases the N/Z ratio, and hence provides a common pathway towards stability for decays involving large nuclei with too few neutrons. Positron emission and electron capture also increase the ratio, while beta decay decreases the ratio.
- Nuclear waste exists mainly because nuclear fuel has a higher stable N/Z ratio than its fission products.

Magic Numbers

- The Octet Rule was formulated from the observation that atoms with eight valence electrons were especially stable (and common). A similar situation applies to nuclei regarding the number of neutron and proton numbers that generate stable (non-radioactive) isotopes. These "magic numbers" are natural occurrences in isotopes that are particularly stable.
- Table below list of numbers of protons and neutrons; isotopes that have these numbers occurring in either the proton or neutron are stable. In some cases there the isotopes can consist of magic numbers for both protons and neutrons; these would be called double magic numbers. The double numbers only occur for isotopes that are heavier, because the repulsion of the forces between the protons. The magic numbers are:
- proton: 2, 8, 20, 28, 50, 82, 114
- neutron: 2, 8, 20, 28, 50, 82, 126, 184

- Also, there is the concept that isotopes consisting a combination of even-even, even-odd, odd-even, and odd-odd are all stable. There are more nuclides that have a combination of even-even than odd-odd. Just like there exist violations to the octet rule, many isotopes with no magic numbers of nucleons are stable.

Proton number (Z)	Neutron Number	# of stable Isotopes
Even	Even	163
Even	Odd	53
Odd	Even	50
Odd	Odd	4

7.2 Radioactivity

- In 1896, the French physicist Antoine Henri Becquerel (1852-1908) accidentally found that uranium-rich mineral called pitchblende emits invisible, penetrating radiations that can darken a photographic plate enclosed in an opaque envelope. Later it was found that there are some unstable isotopes that are emitting particles to be stable.
- Large nuclides tends to have more neutrons than protons to reduce the disruptive energy and stay stable. To reduce the disruptive energy and stay stable. To reduce the disruptive energy by increasing number of neutrons and reducing number of protons, the weak nuclear force converts proton to neutron; or at some stage the only way for the nucleus to reach a lower energy state will be emit particles. All these processes that lead unstable atoms to decay by particle emission are what we call **radioactivity**.

- **Radioactivity** is the phenomenon of the spontaneous disintegration of unstable atomic nuclei to atomic nuclei to form more energetically stable atomic nuclei. Radioactive decay is a highly exoergic, statistically random, process that occurs with a small amount of mass being converted to energy.
- Unstable isotope is said to be a **radioisotope**, and the energy that is released is called **radiation**.
- After an atom expels energy from the nucleus, the composition of the nucleus changes, and we are left with a different element that is more stable.
- All nuclei with 84 or more protons are radioactive. Nuclei with less than 84 protons have both stable and unstable isotopes.

Types of nuclear radiation

Alpha Particles Radiation

- Alpha particles are subatomic fragments consisting of two neutrons and two protons, or helium nuclei (He-4). Alpha radiation occurs when the nucleus of an atom becomes unstable (ratio of neutron to proton is too low) and alpha particles are emitted to restore balance. Alpha decay occurs in elements with high atomic numbers, such as uranium, radium, and thorium. The nuclei of these elements are rich in neutrons, which makes alpha particle emission possible.
- When a radioactive atom decays by α-emission, it leaves a daughter nucleus of atomic number two less than the parent atom of atomic mass number four less than that of the parent atom, i.e the unstable isotope's proton number P is decreased by 2 and its neutron (N) number is decreased by 2, this means that the nucleon number A decreases by 4.

Thus;

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

- Where X and Y are chemical symbol of the parent and daughter nuclei, respectively.
- For example, the abundant isotope of uranium, U-238, decays by alpha emission to give a thorium atom which can be written in a form:

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

- Some source of α radiation are americium-241, plutonium-236, uranium-238, thorium-232, radon-222, and polonium-210.

Beta-particle Radiation

- Unlike alpha radioactivity, beta radioactivity requires the weak nuclear force. There are two beta decay types; beta minus (${}^{0}_{-1}\beta$) and beta minus (${}^{0}_{+1}\beta$).
- Beta minus particle are energetic electrons emitted from a radioactive nucleus. Beta minus particle emission occurs when the ratio of neutron to proton in the nucleus is too high. An excess neutron transforms into a proton and an electron. The proton stays in the the nucleus and the electron is ejected energetically. This process decreases the number of neutrons by one and increases the number of proton by one. Thus,

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

- As we see in this reaction equation, any decay by beta-emission accompanies emission of an antineutrino, $\overline{\nu}$

${}^{234}_{90}Th \rightarrow {}^{234}_{91}\ Pa + {}^{0}_{-1}\ \beta, \qquad {}^{14}_{6}C \rightarrow {}^{14}_{7}\ N + {}^{0}_{-1}\ \beta, \qquad {}^{3}_{1}H \rightarrow {}^{3}_{2}\ He + {}^{0}_{-1}\ \beta$

Some beta negative emitters are tritium, cobalt-60, strontium-90, technetium-99, iodine-129, iodine-131, cesium-137.

- There is also beta plus or positron (${}^{0}_{1}e^{+}$) emission. Like the beta particle, a positron is immediately rejected from the nucleus upon its formation. For example, potassium-38 decays by positron emission, becoming argon-38. Positron emission decreases the atomic number by one, but the mass number remains the same. Thus

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

$${}^{38}_{19}K \rightarrow {}^{38}_{18}\ Ar + {}^{0}_{+1}\ \beta, \quad {}^{23}_{12}Mg \rightarrow {}^{23}_{11}\ Na + {}^{0}_{+1}\ \beta, \quad {}^{11}_{6}C \rightarrow {}^{11}_{5}\ B + {}^{0}_{+1}\ \beta$$

- Some beta positive (positron) emitters are potassium-38, magnesium-23, carbon-11.

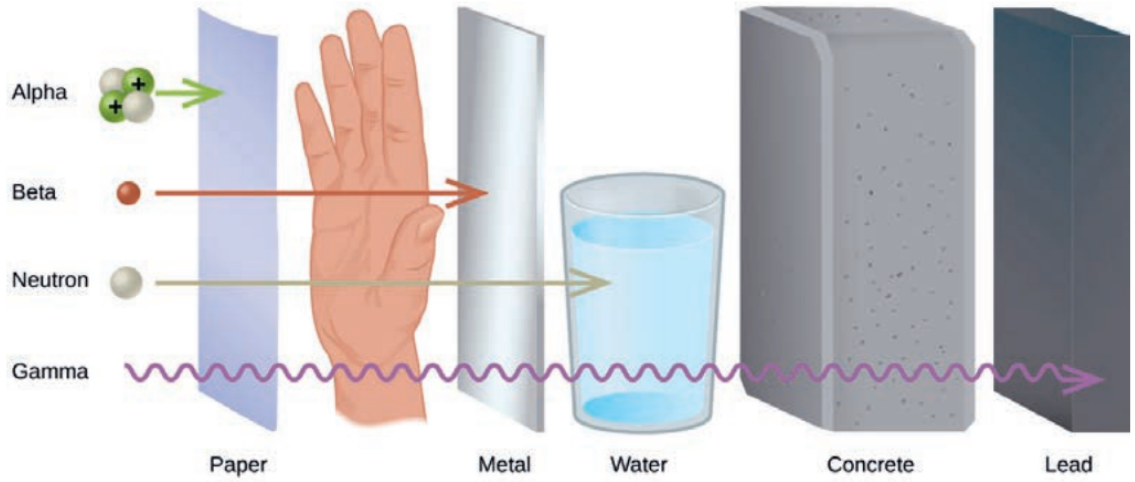
Gamma-particle Radiation

- Gamma rays are high energy, high frequency, electromagnetic radiations. Gamma radiation usually accompanies alpha or beta decay. They have no charge and no mass so they rarely interact with particles in their path, so they have the least ionizing power of the three radiations. They are never completely absorbed, although their energy can be significantly reduced by several centimeters of lead, or several meters of concrete. If energy is reduced to a safe level, gamma rays are often said to have been absorbed.
- Gamma emitting radioisotopes are the most widely used radiation sources. The three radionuclide's by far useful are: cobalt: cobalt-60, cesium-137, and technetium-99m.
- In U-238, 2 gamma rays of different energy are emitted.

$$^{238}_{92}U \rightarrow ^{234}_{90}Y + ^{4}_{2}He + 2^{0}_{0}\gamma$$

Ionization and Penetration Power of Nuclear Radiation

- When alpha, beta and gamma radiations, they produce ions and molecular fragments by knocking electrons from them. The greater mass presents the greater the ionizing power. Thus, alpha-radiation has the highest and gamma radiation has the least ionization powers.
- On the other hand, gamma-radiation has the highest and alpha-radiation has the least penetration powers.
- Alpha-radiations can be stopped by paper and skin, beta-radiation by aluminum sheet and gamma radiation can be blocked by 2 inches thick lead as shown in figure below.



Dangers of Ionization Radiation

- When radiation passes through cellular tissue, it ionizes water molecules which change into free radicals (A free radical can be defined as any molecular species capable of independent existence that contains an unpaired electron in an atomic orbital. The presence of an unpaired electron results in certain common properties that are shared by most radicals.)
- These radicals are highly reactive and can interact with the important genetic material in the cell, the DNA. In addition, the DNA may also be ionized directly. Damage caused by these interactions may be fully repaired, in which case, the cell remains viable. However, if the damage is not successfully repaired and the DNA is not restored completely, they cell may either die or mutate (a change in the DNA sequence of an organism).

- Because the radiations ionize to different extents, the hazard level is also different for each one. The extent of the potential damage depends on several factors, including:
  - the type of radiation
  - the sensitivity of the affected tissue and organs
  - the manner and length of time exposed
  - the radioactive isotopes involved
  - characteristics of the exposed person (such as age, gender and underlying condition)
- The depth of radiation damage is summarized below.

Radiation type	Effect inside body	Effect outside body
Alpha	Highly ionizing – very dangerous radiation poisoning and cancer possible.	Absorbed by surface layer of dead skin cells – no danger
Beta	Moderate ionization and danger should be minimized	Moderate so exposure ionization and danger, close exposure should be minimized
Gamma	Minimal ionization, cancer danger from long-term exposure	minimal ionization –cancer danger from long-term exposure

Effective Dose

- The risk of developing adverse health effects depends on the radiation dose. The higher the dose the higher the risk of adverse effects.
- Absorbed dose describes the amount of energy deposited per unit mass in an object or person.
- The units for absorbed dose are **gray(Gy)**, **sievert(Sv)** and **rad**; where $1Gy = 1J/kg$ and $1rad = 0.01Gy = 0.01J/kg$
- $1Gy$ is the deposit of a joule of radiation energy per kilogram of matter or tissue.
- $1Sv = 1J/kg$; is a biological effect. The sievert represents the equivalent biological effect of the deposit of a joule of radiation energy in kilogram of human tissue.
- Radiation doses above 3 Gy (300 rad) can be fatal and doses above 6 Gy (600 rad) are almost certain to be fatal, with death occurring within several months (in shorter times at higher doses).
- For gamma rays and electrons, above 1Gy, radiation causes a complex of symptoms, including nausea and blood changes, known as radiation sickness. For doses below 1Sv (100 rad), there is little likelihood of radiation sickness, and the main danger is an increased cancer risk.

Safety precautions when using radioactive sources

- Radioactive sources which may be used in schools are usually very weak. They can only be used in the presence of an authorized teacher.
- They are kept in a sealed container except when they are being used in an experiment or demonstration. They are immediately returned to the container when the experiment or demonstration has done.
- When using the radioactive source it should be:
  - handled with tongs or forceps, never with bare hands.
  - kept at arm's length, pointing away from the body.
  - always kept as far as possible from the eyes.
- Hands must be washed after the experiment and definitely before eating.

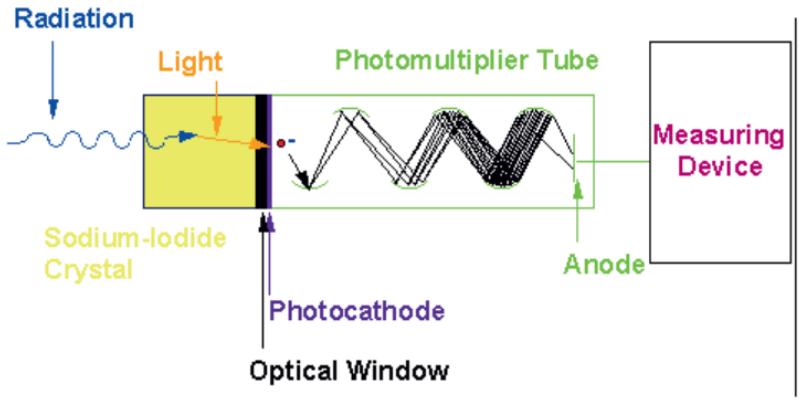
Radiation Detectors

- A radiation detector is a device that measures the ionization of radiations (i.e creating electrons and positively charged ions), such as beta radiation, gamma radiation, and alpha radiation with matter. There are different types of radiation detectors, most widely ones of which are discussed below.

$\Rightarrow$ **Scintillators**

- A scintillator is a general for substances that emit fluorescence when exposed to radiation of high energy- it is type of phosphor. When a radiation collides with this substance, it absorbs its energy and internal electrons move from the ground state (stable state) to the excited state. When this electron returns to the original stable state, it releases its energy in the form of light emission (visible light or ultraviolet light), and this phenomenon called scintillation.

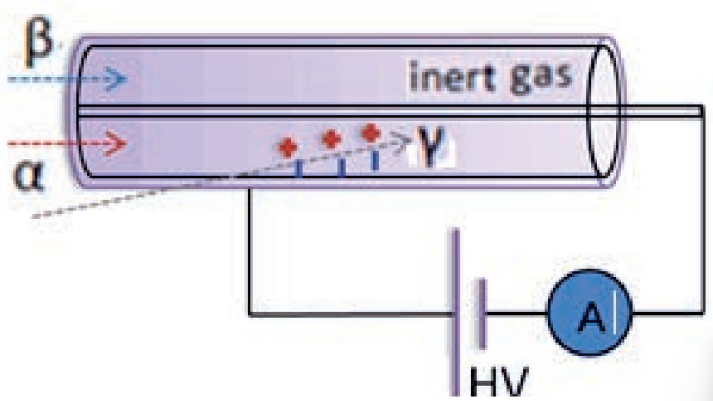
- The incident radiation can be measured quantitatively by photo-electrically converting/amplifying the emitted fluorescence with a photo-multiplier tube (PMT) or the like, figure below shows a type of a scintillator detector.



- Scintillation detectors represent the best means for detecting gamma or x-radiation and are the second most common detector type after G-M tubes. They have the ability to distinguish between alpha, beta, and gamma radiation, and can be configured to produce correspondingly different sounds through a meter.

⇒ Geiger Counter

- A Geiger counter, also known as the Geiger-Muller tube, is used to quickly detect and measure radiation. It exploits the natural process of ionization to detect and measure radiation. When exposed to radioactive radiations, the stable gas within the chamber ionizes. This generates an electrical current that the counter records over a period of 60 seconds.
- When ionization occurs and the current is produced, a speaker clicks and a reading is given-often in millisievert (mSv). The central wire in between a gas-filled tube at high voltage is used to collect the ionization produced by incident radiation. Geiger counters can detect alpha, beta, and gamma radiation. However, they cannot differentiate which one is beta, or gamma or alpha radiation.



The Half Life

- Here, we consider a system containing many nuclei of the same species at some initial time. The number of any radioactive parent nuclei decreases with time since it emits radiation in the form of α, β, or γ emissions. The decay of a particular nucleus cannot be predicted and is not affected by physical influences like temperature. The rate of isotope decay depends on two factors.
  - The total number fo undecayed nuclei present in the system. That is, on doubling the average of undecayed nuclei must double the rate of decay.
  - The stability of the isotopes decay more rapidly than others. The rate of decay gives the number of nuclei that decay per second.
- In general, the decay rate, called the **activity (A)**, is given by

$$A = \frac{\Delta N}{\Delta t} = -\lambda N$$

Where

- The negative sign shows the decrease in the number of the radioactive nuclei with time
- N is the number of undecayed nuclei at the subsequent time t.
- The decay constant λ of a radioactive nuclei is defined as its probability of decay per unit time; having SI unit s^{-1}. It is a positive rate also called the exponential decay constant, disintegration constant, rate constant, or transformation constant.
- The SI unit of activity, A, is **becquerel (Bq)**; $1Bq = 1$ decay per second. We can also use the unit **curie (Ci)**, where

$$1Ci = 3.7 \times 10^{10} Bq$$

.

- The quantity of the parent radioactive nuclei is subject to exponential decay since it decreases at a rate proportional to its current value. This exponential decay law is given by

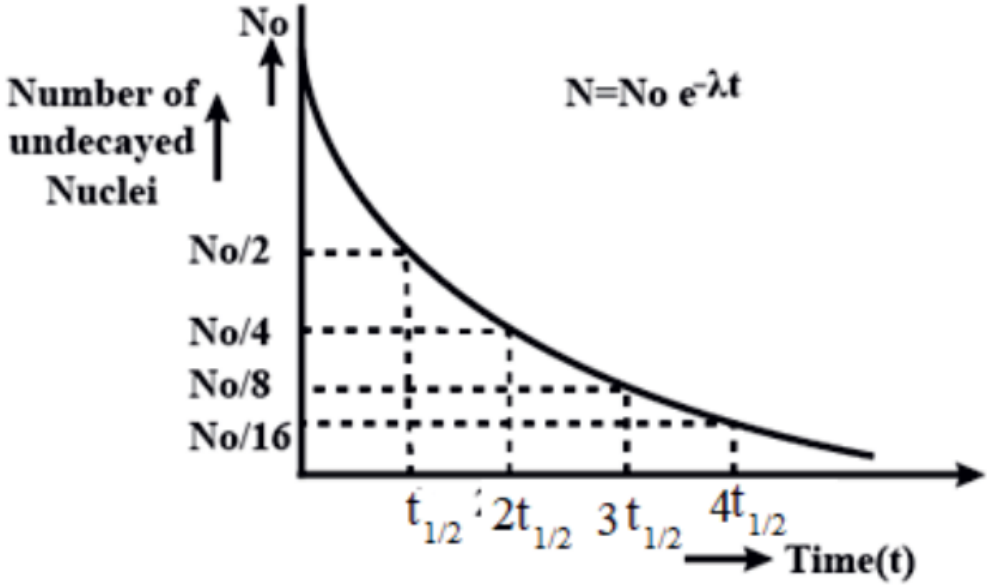
$$N = N_0 e^{-\lambda t}$$

- Where, N_0 is the number of undecayed nuclei at an initial time t_0.

- In practice, the stability of radioactive nuclei against decay and the decay rate are most often estimated in terms of the half-life, $t_{\frac{1}{2}}$, rather than the decay constant λ. The half-life is defined as the time at which half of the original nuclei have decayed. Or,it can also be stated somewhat differently as the time after which one half of the original number of nuclei remains untransformed. Since nuclear decay is an example of a purely statistical process, a more precise definition of half-life is that each nucleus has a 50% chance of living for a time equal to one half-life, $t_{\frac{1}{2}}$.
- The half-life of a certain decay can be determined by using $N = N(t_{\frac{1}{2}})$, in to exponential decay law as:

$$t_{\frac{1}{2}} = \frac{ln2}{\lambda} = \frac{0.693}{\lambda}$$

- Scientist predicted that the half-lives of naturally occurring nuclear reactions fall in a very wide range-vary from fractions of milliseconds like Radium, to billions of years like Uranium-235 (billion years).
- For some induced radioactive elements (initially stable made radioactive by exposure to specific radiation), the half-life is a few millionths or even hundred millionths of second.
- **Why do we use a term like half-life rather than lifetime?**
- The answer can be found by examining figure below, which shows how the number of radioactive nuclei in a sample of initial value N_0, decreases with time. The number of radionuclide's left at $t_{\frac{1}{2}}$ is $\frac{N_0}{2}$. Half of the remaining nuclei decay in the next half-life $(2t_{\frac{1}{2}})$, is $\frac{N_0}{4}$. Then, it becomes $\frac{N_0}{8}$ in the third half-life and so on. For n integral numbers of half-lives, the number of original nuclides left, N, can be calculated by $N = 2^{-n}N_0$



⇒ **Example**

1. The half-life of radium is equal to 1590 years. What is the activity of 1 g of radium-226? Solution:
2. The radioisotope strontium-90 has a half-life of 38.1 years. If a sample contains 400 mg of Sr-90, how many milligrams will remain when the age of the sample is 190.5 years?

7.3 Use of Radioactive Radiation

I. Medical applications of nuclear radiation (Nuclear Medicine)

- Nuclear medicine uses radioactive material inside the body to see how organs or tissue are functioning (for diagnosis) or to destroy damaged or diseased organs or tissue (for treatment/ therapy).

A) Diagnostic Nuclear Medicine

- For diagnosis, nuclear medicine can show how the organs or tissues are functioning. For most diagnostic procedures, a **tracer**, which contains the radioactive material, is injected, swallowed, or inhaled. Then, a radiation detector is used to see how much of the tracer is absorbed or how it reacts in the organ or tissue. The nuclear diagnostics are more often used in imaging.
- Some radioactive nuclides in use for diagnosis include fluorine-18, gallium-67, krypton-81, rubidium-82, nitrogen-13, technetium-99, indium-111, iodine-123, xenon-133, and thallium-201.

- To diagnose cancer, positron emitting nucleotides (PET) are used to scan for a short period. In this type of nuclear medicine, the tracer is used to show the natural activity of cells, providing more detailed information on how organs are working and if there is damage to the cells. Some common uses of PET scans include diagnosing heart disease, Alzheimer's disease, and brain disorders. PET scans are often combined with computed tomography (CT) scans or magnetic resonance imaging (MRI) which provides three-dimensional images of the organ.

B) **Therapeutic Nuclear Medicine**

- For treatment (Nuclear radiation therapy) is a type of cancer treatment that uses high energy beams to destroy cancer cells and shrink tumors. Cancer cells grow and divide faster than most normal cells. The radiation works by making small breaks in the DNA inside cells. These breaks keep cancer cells from growing and dividing and causes them to die. The radiation may injure noncancerous cells, but most are able to recover. There are two broad types of radiation therapy that doctors use to treat cancers: **internal** and **external**.

⇒ **External beam radiation (teletherapy)**

- In this type of treatment, the energy beams come from a machine outside of the body. The beam is precisely aimed and it penetrates the body to reach the cancer site. For example, such treatment can be carried out using a gamma beam from a radioactive cobalt-60 source.

⇒ **Internal radiation therapy**

- **Brachytherapy**: in this therapy, a doctor places usually a **gamma(γ)** or **beta(β)** emitter, in or near the cancer site. The implants come in different shapes, which include: tube, wire, capsule, and pellets. For example, iodine-131 is commonly used to treat thyroid cancer and non-malignant thyroid disorders. It is produced in wire form.
- **Systematic radiation therapy**: in this therapy, the patient requires swallowing a radioactive substance, which travels throughout the body to find and kill the cancerous cells. Alternatively, a healthcare profession may inject the radioactive substance into a person's vein.

⇒ **Nuclear treatment in Ethiopia**: Based on the basics of medical application, in Ethiopia, there are Nuclear Technology activities. Previously, the Black Lion Specialized Hospital (a teaching hospital under Addis Ababa University) uses radioisotope for the treatment of cancer.

II. Radioactive Dating

- Radioactive dating or radioisotope dating is a technique which is used to date materials by use of naturally occurring radioactivity.
- That is, radioactive dating, scientists count the number of parent isotopes and daughter isotopes formed from the nuclear decay to determine how many half-lives have passed and provide a suggestion of the age of an object. Thus, once the isotopic abundances of each parent/daughter elements is determined using the mass spectrometer, the age (t), of the object can be calculated using the formula $N = N_0 e^{-\lambda t}$.

Carbon-14 Dating

- Its most famous application is **carbon-14** dating. Carbon-14 has a half-life of 5730 years. Radioactive carbon has the same chemistry as stable carbon, and so it mixes into the ecosphere, where it is consumed and becomes part of every living organism.

Carbon-14 has an abundance of 1.3 parts per trillion of normal carbon. Thus, if you know the number of carbon nuclei in an object (perhaps determined by mass and Avogadro's number), you multiply that number by 1.3×10^{-12} to find the number of C-14 nuclei in the object. When an organism dies, carbon exchange with the environment ceases, and C-14 is not replenished as it decays. By comparing the abundance of C-14 in an artifact with the normal abundance in living tissue, it is possible to determine the artifact's age (or time since death).

- Carbon-14 dating can be used for biological tissue as old as 50 or 60 thousand years, but is most accurate for younger samples, since the abundance of C-14 nuclei in them is greater. Very old biological materials contain no of C-14 at all. There are instances in which the date of an artifact can be determined by other means, such as historical knowledge or tree-ring counting. These cross-references have confirmed the validity of carbon-14 dating and permitted us to calibrate the technique as well. Carbon-14 dating revolutionized parts of archaeology.

- $N = N_0 e^{-\lambda t}$
- The half life of C-14 is 5730 years

$$\lambda = \frac{-0.693}{5730\ years}$$

$$t = \frac{ln\left(\frac{N}{N_0}\right)}{-0.693} * 5730\ years$$

Example

1. An archaeologist digs up a human skull at a dig site. It was found that concentration of carbon-14 is 25% of its initial concentration. What is the age of the skull?
2. A museum is testing the authenticity of a Leonardo da Vinci (1452-1519) manuscript. They send a paper sample to a lab and learn that it has 97.4% of its initial carbon-14 concentration. Is this manuscript authentic?

3. How far back can carbon dating reliably date?
   A. 10,000 years B. 50,000 years
   C. 100,000 years D. 5,000 years
4. Why is carbon-14 used instead of carbon-12?
   A. Carbon-14 is in a steady supply, while carbon-12 isn't
   B. Carbon-12 is too abundant
   C. No reason, carbon-12 can also be used
   D. Carbon-14 will start to decay when a species dies, while carbon-12 is stable and will therefore not decay
5. What is the half-life for carbon-14?
   A. 57,300 years B. 537 years
   C. 5,730 years D. 5,370 years

Localized Applications of radioactive dating

- Dinkenesh or Lucy was discovered in 1974 in Ethiopia, at Hadar, in Afar by paleo-anthropologist Donald Johnson. After all her fragments were collected and reconstructed, Lucy was taken to USA so that her age is measured precisely. Which method was used to measure the age of Lucy? Can carbon dating be applicable?
- Carbon-14 has the same chemistry as stable carbon, and so it mixes into the ecosphere, where it is consumed and becomes part of every living organism. When the organism dies, carbon exchange with the environment ceases, and as a result C-14 is not replenished as it decays. Since the ratio of C-14 to total carbon nuclei is very small (1.3×10^{-12}), C-14 concentration falls nearly to zero after about nine half-lives (about more that 50 thousand years). This implies that Lucy is too old for radiocarbon dating and hence other methods were employed to find her age.

- The appropriate method used was argon-argon ($^{40}Ar - ^{39}Ar$) dating on tiny crystal in layers of volcanic ash sandwiching the sediments where Dinkenesh was found. In this measurement, her age was found to be 3.18 million years.

- The figure below shows several hundred fossils of Lucy 40% pieces of female found in Afar region Ethiopia.



7.4 Nuclear Reaction and Energy Production

- Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei or from the collisions between a nucleus and a subatomic particle. In general, there are two types of nuclear reactions, namely;
  - Nuclear fission reaction
  - Nuclear fusion reaction

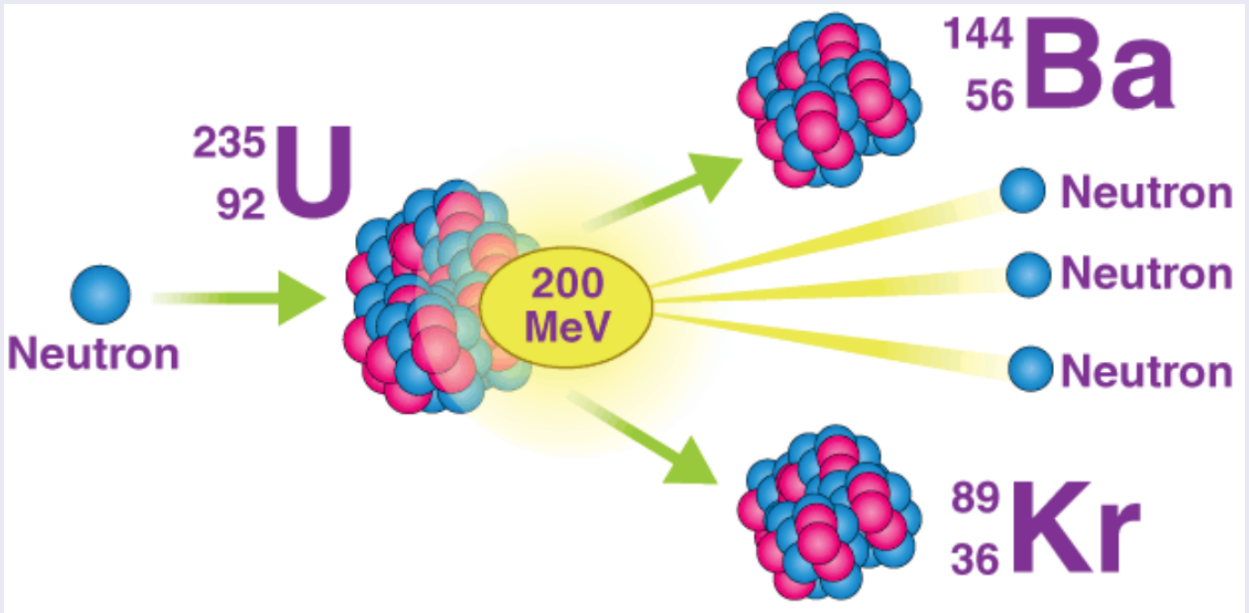
7.4.1 Nuclear fission reaction

- Nuclear fission is the splitting of a heavy atomic nucleus such as uranium-235, into two fragments of roughly equal mass.
- Nuclear fission is a form of nuclear transmission, meaning that the starting atoms are not the same elements as the resultant or daughter as product atoms.
- In nuclear reactors, nuclear fission usually takes place by inducing neutrons into the parent nuclei.
- In neutron induced fission reactions, two additional neutrons released per incident neutron.

Nuclear fission is accompanied by the release of a large amount of energy. Part of this energy is converted into the kinetic energy of the fission fragments and the remaining energy is converted into different forms such as heat and sound. For example, consider the fission reaction equation on U-235 given by

$$^{235}_{92}U + ^{1}_{0}n \implies ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n + 200MeV$$

- The reaction is described pictorially as shown in figure below



- In this reaction, the sum of the nuclear binding energy U-235 and the kinetic energy of the incident neutron (n-1) is equal to the sum of kinetic energy of the two daughter nuclides (Ba-144 and Kr-89); the kinetic energy of the three neutrons and the $200MeV$ energy, which is directly released.

Example

- A nuclear fission reaction is given below. Complete the equation, find the value of X and determine the type of the element, Y. Calculate the amount of energy.

$$^{235}_{92}U + ^{1}_{0}n \Longrightarrow {}^{x}Y + {}^{139}Cs + 2^{1}_{0}n + energy$$

- **Solution:**

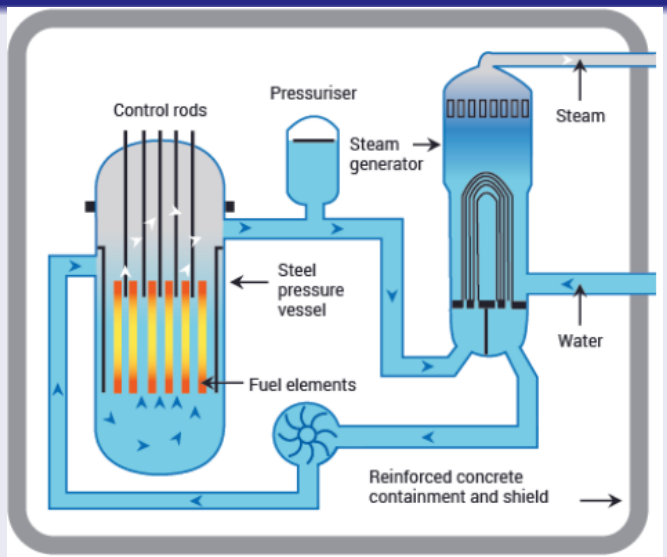
The equation is balanced on both sides so the total mass number on the left side must be the same as the total mass number on the right side. Thus, 235 + 1 = X + 139 + 2, or X = 95, which corresponds to Rb-95. [m(U-235)=235.0439299u, m(Rb-95)=94.929263u, m(Cs-139)=138.913364u, m(n) = 1.00867u]

Applications of fission reaction

- Fission reaction has several applications. Its application in nuclear reactors is the concern of this section. There are two types of nuclear reactors: power reactor and research reactor.

Power Reactor (PR)

- Power Reactor are used to generate electricity by the process of nuclear fission. In a chain nuclear reaction, undertaking in nuclear reactor, the kinetic energy of fission fragments and the energy released will be converted to heat. The heat produces steam which is used to drive the turbine of a generator to produce electricity.



- There are several components common to most types of reactors:
  - **Fuel:** Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.
  - **Moderator:** Material in the core which slows down the neutrons released from fission so that they cause more fission. It usually water, but may be heavy water (a form of water whose hydrogen atoms are all deuterium) or graphite.
  - **Control rods or blades:** These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from core to control the rate of reaction, or to halt it.
  - **Coolant:** A fluid circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant.
  - **Pressure vessel or pressure tubes:** Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

- **Steam generator:** Part of the cooling system of pressurized water reactors where the high-pressure primary coolant bringing heat from the reactor is used to makes steam for the turbine, in a secondary circuit.
- **Containment:** The structure around the reactor and associated steam generators which is designed to protect it form outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside. It is typically a meter-tick concrete and steel structure.

Research Reactor (RR)

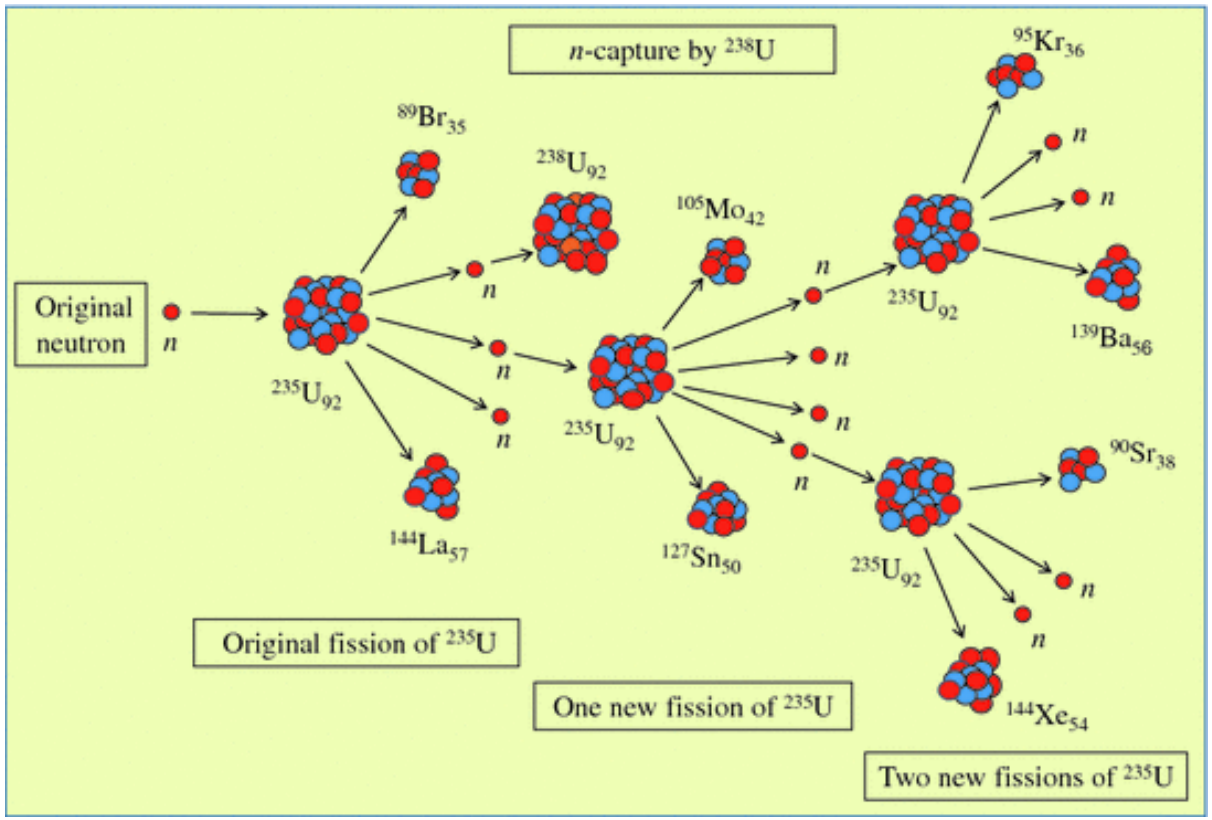
⇒ **Research Reactor (RR)** are nuclear fission-based nuclear reactors that serve primarily as a neutron source. Research reactors are simpler than power reactors and operate at lower temperatures. They need far less fuel, and far less fission products build up as fuel is used. They are also called non-power reactors, in contrast to power reactors.

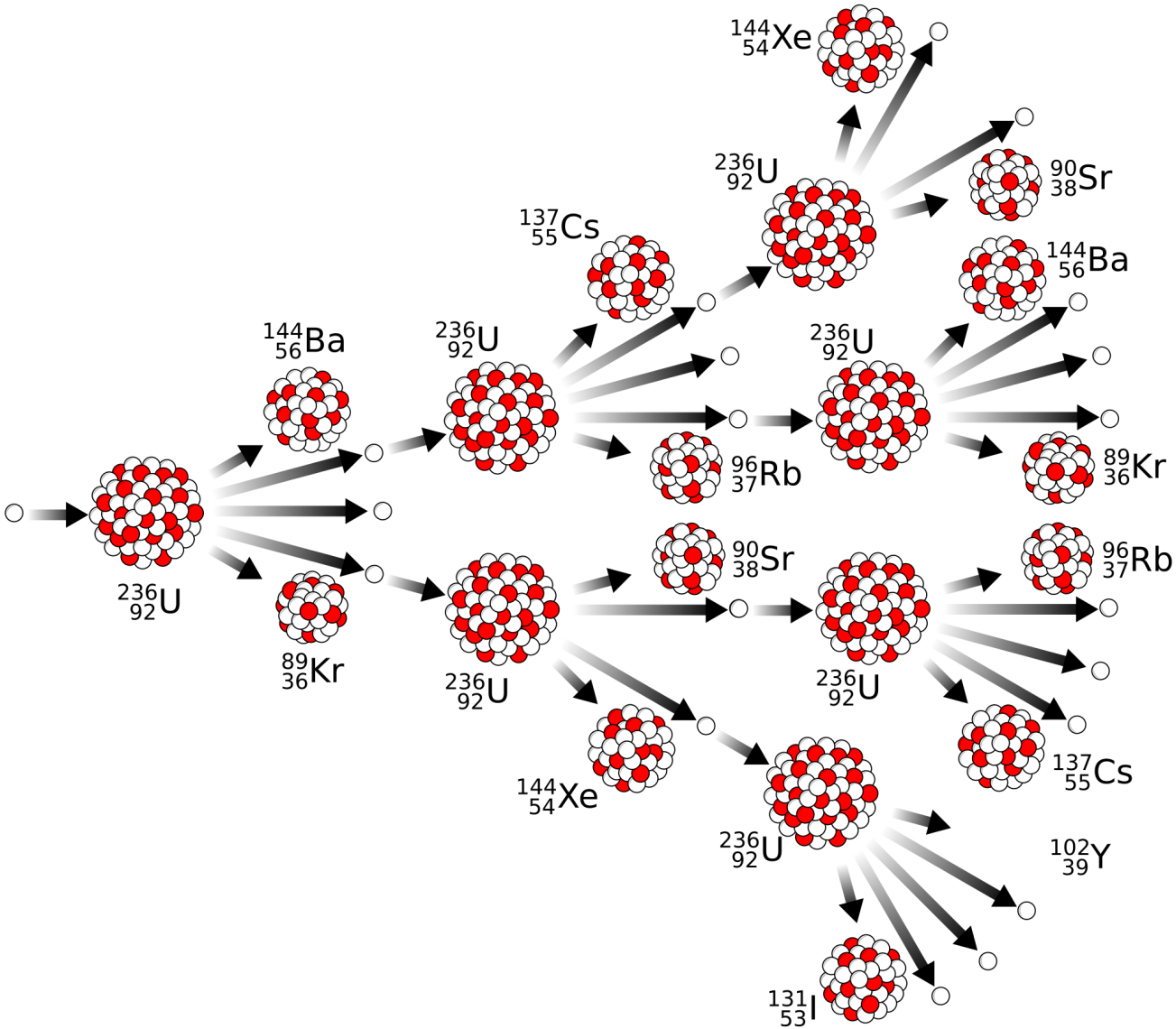
- The neutrons produced by a research reactor are used for different purposes such as neutron scattering, analysis and testing of materials, production of radioisotopes, research and public outreach, and education.

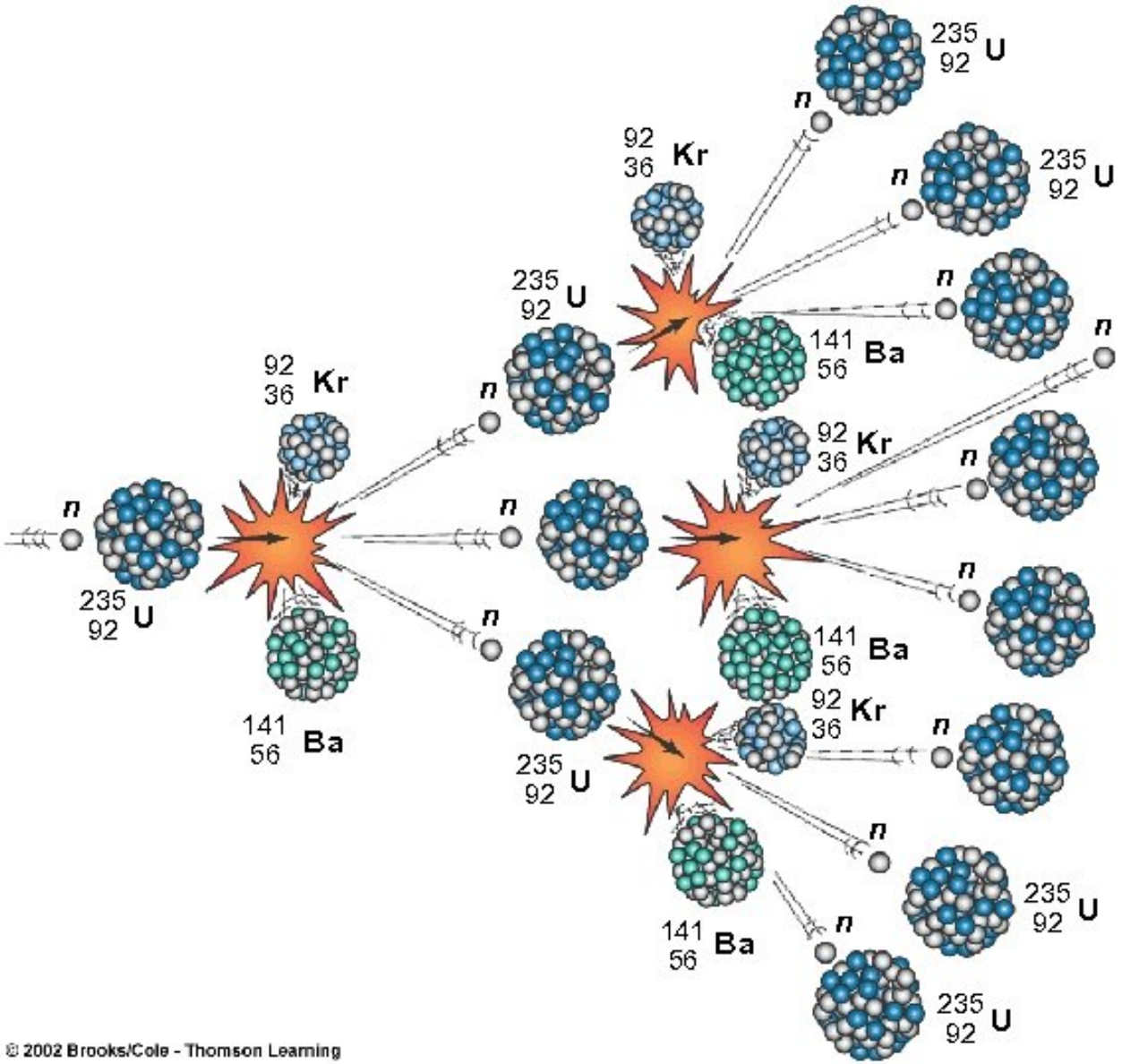
- Radioisotopes can be produced in research reactors by exposing suitable target materials to the intense neutron radiation for an appropriate time. The quality and specific activity of the radioisotopes produced depends on both the target and the irradiation conditions. A wide range of isotopes are made at reactors, from elements as light as carbon-14 to as heavy as mercury-203, with irradiations ranging from minutes to weeks.
- For example, Mo-99 the parent to the widely used medical diagnostic radioisotope, Tc-99m is usually produced via neutron-induced fission of targets with U-235 using a 4-to-8 day irradiation time.

Chain nuclear reaction:

- In a chain reaction, neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons). Chain reaction occurs only above a certain mass called critical mass.




$^{144}_{54}Xe$
$^{236}_{92}U$
$^{90}_{38}Sr$
$^{137}_{55}Cs$
$^{144}_{56}Ba$
$^{144}_{56}Ba$
$^{236}_{92}U$
$^{236}_{92}U$
$^{96}_{37}Rb$
$^{89}_{36}Kr$
$^{236}_{92}U$
$^{89}_{36}Kr$
$^{90}_{38}Sr$
$^{96}_{37}Rb$
$^{236}_{92}U$
$^{236}_{92}U$
$^{144}_{54}Xe$
$^{137}_{55}Cs$
$^{236}_{92}U$
$^{102}_{39}Y$
$^{131}_{53}I$



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Figure 3-12
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Slide 18

The problems posed by nuclear waste of reactors

- Nuclear waste refers to the byproducts of nuclear reactors. One of the main difficulties is that the isotopes used in nuclear power stations typically have very long half lives. Plutonium-239 has a half-life of 24100 years; in contrast plutonium-238 has a half life of 88 years. Spent nuclear fuel is the most important source of waste from nuclear power stations and is mainly unconverted uranium. About 3% of it is fission products from nuclear reactions. The actinides (uranium, plutonium, and curium) are responsible for the bulk of the long-term radioactivity, whereas the fission products are responsible for the bulk of the short-term radioactivity.
- After about 5% of a nuclear fuel rod has reacted inside a nuclear reactor, it will no longer able to be used as fuel due to the high build up of fission products.
- Scientists are experimenting on methods for reusing these rods in order to reduce waste and use the remaining actinides as fuel.

7.4.2 Nuclear fusion reaction and its uses

- Nuclear fusion reaction is a process of making a single heavy nucleus form the combination of two or more lighter nuclei. In most cases, fusion reaction releases more energy than fission reaction. The process releases energy because the total mass of the resulting single nucleus is less than the mass of the two original nuclei. The leftover mass becomes energy.

Use of nuclear fusion as source of energy in the sun

- The principal source of energy in the sun is a fusion reaction in which four hydrogen nuclei fuses and produce a helium nucleus and two positrons. This is a net reaction of a more complicated series of events:

$$4\,{}^{1}_{1}H \implies {}^{4}_{2}He + 2\,{}^{0}_{+1}\beta$$

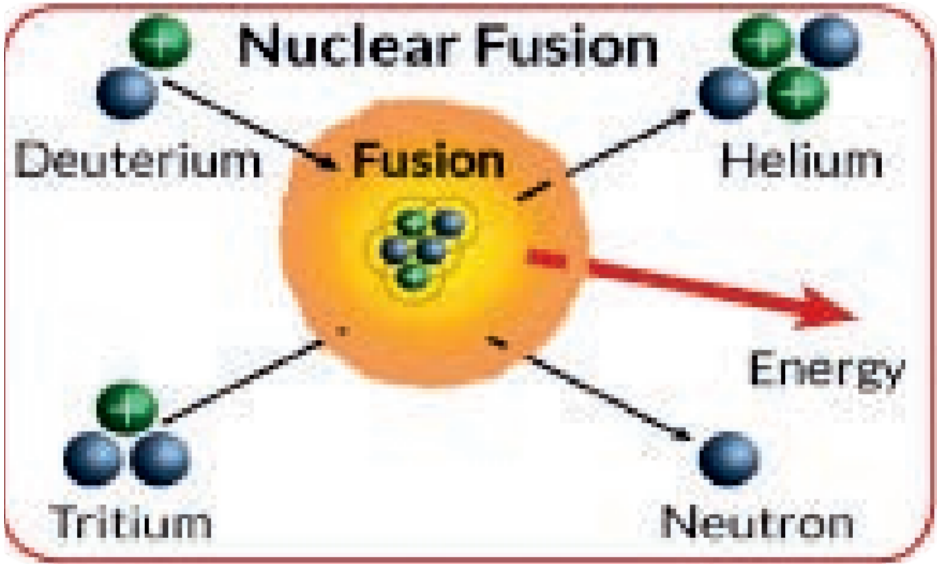
- The mass of the resulting helium nucleus has a mass that is 0.7% less than that of the four hydrogen nuclei. This lost mass (the mass defect) is converted into energy during the fusion. The energy produced in this reaction is about $3.6 \times 10^{11} kJ$ of energy per mole of He-4 produced.

- This energy is greater by 20 fold than the energy produced by the nuclear fission of one mole of U-235, and over 3 million times larger than the energy produced by (chemical) combustion of one mole of octane.
- The heavy isotopes of hydrogen, a deuterium, and a tritium, also undergo fusion at extremely high temperatures. They form a helium nucleus and a neutron:

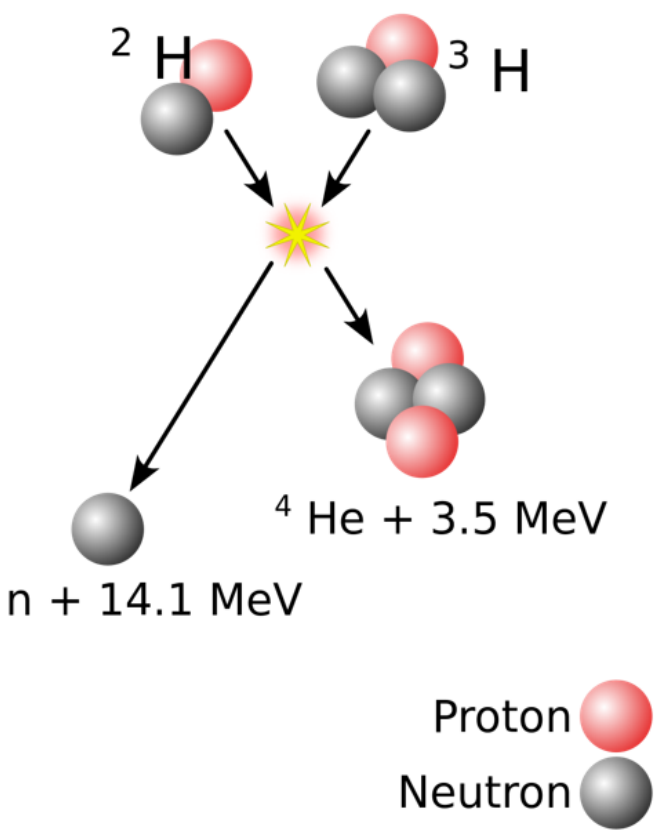
$$ {}^{2}_{1}H + {}^{3}_{1}H \implies {}^{4}_{2}He + {}^{1}_{0}n $$

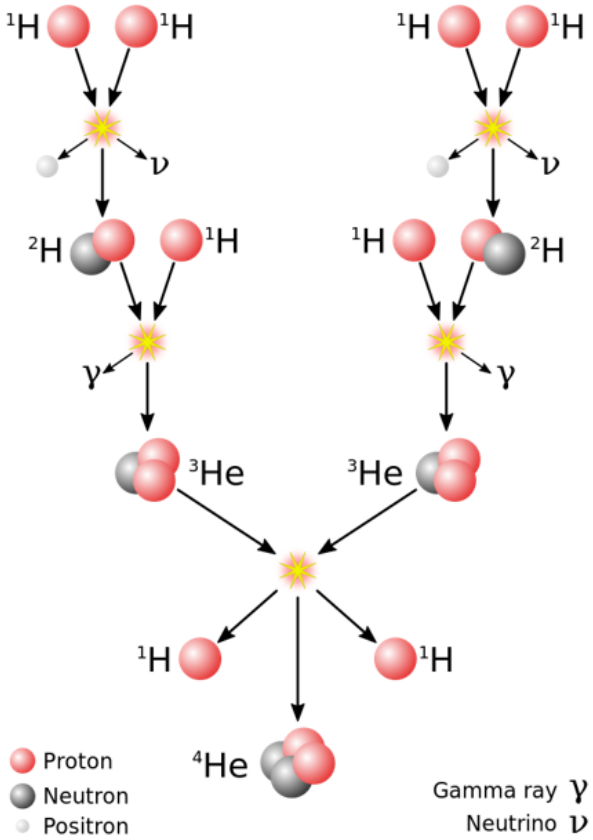
- This change proceeds with a mass loss of 0.0188amu, corresponding to the release of He-4 formed. The very high temperature is necessary to give nuclei enough kinetic energy to overcome the very strong repulsive forces resulting from the positive charges on their nuclei so they can collide.

- Figure below shows the cyclic sun fusion reaction to form a very strong release in the electromagnetic radiation.



- **Hydrogen bomb:** One of the misuses of nuclear fusion reaction is its application for hydrogen bomb, which has higher destructive power and greater efficiencies than atomic bombs. Fusion weapons are also referred to as thermonuclear bombs.


2 H
3 H
4 He + 3.5 MeV
n + 14.1 MeV
Proton
Neutron


1H
1H
ν
2H
1H
γ
3He
1H
2H
4He
Proton
Neutron
Positron
Gamma ray γ
Neutrino ν

(1)	$^{2}_{1}D$	+	$^{3}_{1}T$	→	$^{4}_{2}He$	(3.52 MeV)	+	n^{0}	(14.06 MeV)			
(2i)	$^{2}_{1}D$	+	$^{2}_{1}D$	→	$^{3}_{1}T$	(1.01 MeV)	+	p^{+}	(3.02 MeV)			
(2ii)				→	$^{3}_{2}He$	(0.82 MeV)	+	n^{0}	(2.45 MeV)			
(3)	$^{2}_{1}D$	+	$^{3}_{2}He$	→	$^{4}_{2}He$	(3.6 MeV)	+	p^{+}	(14.7 MeV)			
(4)	$^{3}_{1}T$	+	$^{3}_{1}T$	→	$^{4}_{2}He$		+	2 n^{0}			+	11.3 MeV
(5)	$^{3}_{2}He$	+	$^{3}_{2}He$	→	$^{4}_{2}He$		+	2 p^{+}			+	12.9 MeV
(6i)	$^{3}_{2}He$	+	$^{3}_{1}T$	→	$^{4}_{2}He$		+	p^{+}	+ n^{0}		+	12.1 MeV
(6ii)				→	$^{4}_{2}He$	(4.8 MeV)	+	$^{2}_{1}D$	(9.5 MeV)			
(7i)	$^{2}_{1}D$	+	$^{6}_{3}Li$	→	2 $^{4}_{2}He$	+ 22.4 MeV						
(7ii)				→	$^{3}_{2}He$	+	$^{4}_{2}He$	+ n^{0}			+	2.56 MeV
(7iii)				→	$^{7}_{3}Li$	+	p^{+}				+	5.0 MeV
(7iv)				→	$^{7}_{4}Be$	+	n^{0}				+	3.4 MeV
(8)	p^{+}	+	$^{6}_{3}Li$	→	$^{4}_{2}He$	(1.7 MeV)	+	$^{3}_{2}He$	(2.3 MeV)			
(9)	$^{3}_{2}He$	+	$^{6}_{3}Li$	→	2 $^{4}_{2}He$	+	p^{+}				+	16.9 MeV
(10)	p^{+}	+	$^{11}_{5}B$	→	3 $^{4}_{2}He$						+	8.7 MeV

Example

1. Find the energy produced in the following reaction.
   $[m_n = 1.00867u,\ m(H-1) = 1.0078250322u,$
   $m(H-2) = 2.0141017781u,\ m(H-3) = 3.01604928132u,$
   $m(He-4) = 4.002603254u,\ m(He-3) = 3.0160293u]$

$$ {}^{2}_{1}H + {}^{3}_{1}H \implies {}^{4}_{2}He + {}^{1}_{0}n + E $$

7.5 Safety Rules Against Hazards of Nuclear Radiation

Nuclear Safety rules

- Nuclear safety is defined by the International Atomic Energy Agency (IAEA) as **"The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards"**.
- The IAEA defines nuclear security as **"The prevention and detection of and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear materials, other radioactive substances or their associated facilities"**.
- This covers nuclear power plants and all other nuclear facilities, the transportation of nuclear materials, and the use and storage of nuclear materials for medical, power, industry, and military uses.
- The nuclear power industry has improved the safety and performance of reactors and has proposed new and safer reactor design.

- However, a perfect safety cannot be guaranteed. Potential sources of problems include human errors and external events that have a greater impact than anticipated. The designers of reactors at Fukushima in Japan did not anticipate that a tsunami generated by an earthquake would disable the backup systems that were supposed to stabilized the reactor after the earthquake. Catastrophic scenarios involving terrorist attacks, insider sabotage, and cyber-attacks are conceivable.
- Nuclear safety therefore covers at minimum:
  - Extraction, transportation, storage, processing, and disposal of fission-able materials
  - Safety of nuclear power generators
  - Control and safe management of nuclear weapons, nuclear material capable of use as a weapon, and other radioactive materials
  - Safe handling, accountability and use in industrial, medical and research contexts
  - Disposal of nuclear waste
  - Limitations on exposure to radiation

Protecting yourself from radiation

- **Radiation** is part of our life. Background radiation, coming primarily from natural minerals, is around us all the time. Fortunately, there are very few situations where an average person is exposed to uncontrolled sources of radiation above background. Nevertheless, it is wise to be prepared and know what to do if such a situation arises.
- One of the best ways to be prepared is to understand the radiation protection principles of time, distance and shielding.
  - **Time:** For people who are exposed to radiation in addition to natural background radiation, limiting or minimizing the exposure time reduces the dose from the radiation source.
  - **Distance:** Just as the heat from a fire reduces as you move further away, the dose of radiation decreases dramatically as you increase your distance from the source.
  - **Shielding:** Barriers of load, concrete, or water provide protection from penetrating gamma rays and X-rays. This is why certain radioactive materials are stored under water or in concrete or lead-lined rooms, and why dentists place a lead blanket on patients receiving X-rays of their teeth. Therefore, inserting the proper shield between you and a radiation source will greatly reduce or eliminate the dose you receive.

Safety precautions when using radioactive sources in schools

- Radioactive sources which are used in school are usually very weak. They can only be used in the presence of an authorized teacher. They are kept in a sealed container except when they are being used in an experiment or demonstration. The container can be designed based on the appropriate shields. They are immediately returned to the container when the experiment or demonstration is finished.
- When using the radioactive source it should be:
  - Handle with tongs or forceps, never with bare hands. Moreover, hands must be washed after the experiment and definitely before eating.
  - Kept at arm's length, pointing away from the body.
  - Always kept as far as possible from the eyes.

The End