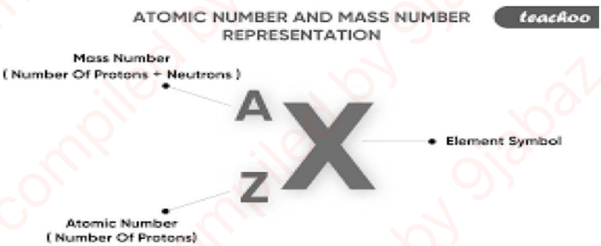
The structure of the Nucleus

The Atomic Structure

What an Atom is? An atom is the smallest unit of matter that retains all of the chemical properties of an element. Atoms combine to form molecules, which then interact to form solids, gases, or liquids.

Atomic Particles: Atoms consist of three basic particles: protons, electrons, and neutrons. The nucleus (center) of the atom contains the protons (positively charged) and the neutrons (no charge). The outermost regions of the atom are called electron shells and contain the electrons (negatively charged). Atoms have different properties based on the arrangement and number of their basic particles.

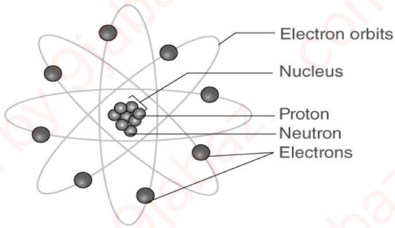


Atomic Mass: Protons and neutrons have approximately the same mass, about 1.67×10^{-24} grams. Scientists define this amount of mass as one atomic mass unit (amu) or one Dalton. Although similar in mass, protons are positively charged, while neutrons have no charge. Therefore, the number of neutrons in an atom contributes significantly to its mass, but not to its charge.

Electrons are much smaller in mass than protons, weighing only 9.11×10^{-28} grams, or about 1/1800 of an atomic mass unit. Therefore, they do not contribute much to an element's overall atomic mass. When considering atomic mass, it is customary to ignore the mass of any electrons and calculate the atom's mass based on the number of protons and neutrons alone.

Atomic Number: Neutral atoms of an element contain an equal number of protons and electrons. The number of protons determines an element's atomic number (Z) and distinguishes one element from another. For example, carbon's atomic number (Z) is 6 because it has 6 protons.

Mass Number: An element's mass number (A) is the sum of the number of protons and the number of neutrons. The small contribution of mass from electrons is disregarded in calculating the mass number.



The atomic structure of an element refers to the constitution of its nucleus and the arrangement of the electrons around it. Primarily, the atomic structure of matter is made up of protons, electrons and neutrons. The **protons and neutrons** make up the nucleus of the atom, which is surrounded by the electrons belonging to the atom. The **atomic number** of an element describes the total number of protons in its nucleus.

Summarily:

An atom is composed of two regions: the nucleus, which is in the center of the atom and contains protons and neutrons, and the outer region of the atom, which holds its electrons in orbit around the nucleus.

Protons and neutrons have approximately the same mass, about 1.67×10^{-24} grams, which scientists define as one atomic mass unit (amu) or one Dalton.

Each electron has a negative charge (-1) equal to the positive charge of a proton (+1).

Neutrons are uncharged particles found within the nucleus

Nuclear Forces

Nuclear forces are the powerful attractive forces that hold protons and neutrons together inside the atomic nucleus. These forces act between nucleons (protons and neutrons) and are responsible for the stability of the nucleus despite the strong electrostatic repulsion between positively charged protons.

Nature of Nuclear Forces

The nuclear force is:

- Very strong
- Short-ranged
- Attractive at moderate distances
- Repulsive at extremely short distances
- It is often called the strong nuclear force or strong interaction.

Nuclear forces are needed inside the nucleus because Protons repel each other due to the similar positive charges on them and because without another force, the nucleus would fly apart. Nuclear force overcomes this electrostatic repulsion and binds nucleons together.

Characteristics of Nuclear Forces

1. Very Strong Force: Nuclear forces are much stronger than electrostatic and gravitational forces within the nucleus.

2. Short Range: They act only over very small distances of about approximately one femtometer (1 fm).

3. Charge Independence: The force between proton–proton, neutron–neutron and proton–neutron is nearly the same after accounting for electrical repulsion.

4. Saturation Property: A nucleon interacts strongly only with nearby nucleons, not with all nucleons in the nucleus.

5. Attractive and Repulsive Nature: Nuclear forces are attractive at intermediate distances to bind nucleons and strongly repulsive at extremely short distances to prevent collapse of the nucleus.

Types of Nuclear Forces

Strong Nuclear Force: which holds nucleons together, a strongest force inside nucleus and very short range

Weak Nuclear Force: Responsible for radioactive decay processes such as beta decay, an example is Neutron transforming into proton

Importance of Nuclear Forces

Nuclear forces are important in:

- Nuclear stability
- Radioactivity
- Nuclear fission
- Nuclear fusion
- Nuclear reactors
- Stellar energy production

Applications

Nuclear Energy: they are responsible for binding protons and neutrons together within atomic nuclei. Changes in nuclear binding during nuclear reactions release enormous amounts of energy. Used in nuclear reactors for electricity generation, this energy release follows Einstein's relation:

$$E=mc^2$$

where: E = energy released, m = mass defect and c = speed of light. A small loss in mass produces a very large amount of energy.

Medicine: Controlled nuclear reactions and radioactive decay processes are widely used in medical diagnosis, treatment, sterilization, and biomedical research, e.g It found applications in Radiotherapy and Nuclear imaging.

Astrophysics: responsible for energy production in stars through fusion reactions.

NUCLEAR REACTIONS

What Nuclear reaction is?

A **nuclear reaction** is a process in which the nucleus of an atom undergoes a change, resulting in the formation of one or more different nuclei and the release or absorption of energy. Unlike ordinary chemical reactions, which involve electrons, nuclear reactions involve changes in the atomic nucleus itself

A nuclear reaction has the following features:

1. Involve the nucleus rather than the electrons.
2. Can transform one element into another.
3. Release or absorb large amounts of energy.
4. May emit particles such as neutrons, protons, alpha particles, beta particles, or gamma rays.
5. Are largely independent of temperature, pressure, and chemical state.

Types of Nuclear Reactions

Nuclear fission: is a process in which the nucleus of an atom splits into two or more smaller nuclei as **fission** products, and usually some by-product particles. An example of **nuclear fission** is the splitting of the uranium-235 nucleus when it is bombarded with neutrons as described in the equations below.

$$
{}^{235}_{92}U + {}^{1}_{0}n \longrightarrow
\begin{cases}
{}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,({}^{1}_{0}n) \\
{}^{138}_{53}I + {}^{95}_{39}Y + 3({}^{1}_{0}n) \\
{}^{140}_{55}Cs + {}^{92}_{37}Rb + 4({}^{1}_{0}n)
\end{cases}
$$

Another important example of **nuclear fission** is the splitting of the plutonium-239 nucleus.

^{235}U is bombarded with slow moving neutron. The neutron is first captured by the uranium which then breaks up into two nuclei of roughly equal sizes which fly apart at great speed. ^{235}U also undergoes fission with fast neutron, the nature of the fragments formed depends on how the neutron collision occurs but it is usually a mixture of particles. Usually, the radioactive isotopes of the element are products. Two important aspect of nuclear fission are as follows:

- It is always accompanied by the release of 2 or 3 fresh neutrons at great speed. This may escape or lead to further collisions with more ^{235}U resulting in a chain reaction if arranged in such a way that a least a neutron brings another fission.
- The fission is always accompanied by the release of a very large amount of energy.

When fission of ^{235}U occurs after neutron bombardment, the total mass of particles after the bombardment is less than before. The balance is converted to energy either as *K.E.* of the particle or partly as g radiation according to

$$E = mc^2$$

Therefore, the energy release from the lost of 1 gm (1×10^{-3} kg) is $E = mc^2 = 1 \times 10^{-3} \times (3 \times 10^8)^2$ J $= 9 \times 10^{10}$ KJ.

Energy from nuclear fission is put to two uses:

- Used in making atomic bomb
- Used to generate electricity in nuclear power plants.

In the first use, the energy output is uncontrolled due to chain reactions. The first atomic bomb was dropped on Japan, a town known as Eroshima in 1945 from a few grams of 235U.

In the second case, the energy is controlled and it is used to produce steam which turns turbines which generates electricity. The first nuclear power plant was built by Great Britain in 1956.

Some of its applications include:

Atomic Bomb: It is generated as a result of uncontrollable chain reactions during nuclear fission. In this case, more than one neutron per fission causes fission or a branched chain reaction leading to a rapidly increasing release of energy. On the other hand in a nuclear reactor, this is controlled by control rods which are used to absorb some of the neutrons so that on average, only one neutron per fission causes or initiate another fission.

Nuclear reactors: are devices that control chain reactions during fission reactions producing new substances from the fission product and energy. Nuclear power stations use uranium in fission reactions as a fuel to produce energy. Steam is generated by the heat released during the fission process. It is this steam that turns a turbine to produce electric energy. The earliest nuclear reactors were built to irradiate U and produce plutonium for bombs, and for experimental purposes.

Activation analysis: Activation of an unknown sample in a nuclear reactor is used to determine the amount of an element in the sample. The unknown sample and a standard sample containing a known amount of the element are placed in a nuclear reactor where they are bombarded with neutrons. After irradiation for a length of time, the samples are removed from the reactor. The induced radioactivity in both samples is measured. The amount of the element present in the unknown sample is obtained from the ratio of the activities of unknown and standard samples. Using the equation:

$$Wx = \frac{Ax}{As} x Ws$$

Where, Wx and Ws are the weight of the unknown and standard respectively and Ax and As are their respective activities. The method is used to determine trace quantities of elements in a sample.

Nuclear Fussion: It consists of joining or fusing of two light nuclei to form a heavier one. This is the opposite of fission. Usually the fusion is also accompanied by lost of mass which is converted to energy. This energy is known as binding energy.

e.g. $2P + 2n \rightarrow {}^{4}_{2}He$ (nucleus) + Energy.

From mass spectrometer:

Proton has mass of 1.0074 amu; Neutron = 1.0089 amu; Electron = 0.00055 amu

Therefore, 2P + 2n = (2x1.0074) + (2X1.0089) = 4.0326 amu.

Mass lost = Product – Reactant

The actual mass of the helium nucleus is 4.0015 amu, therefore, loss of 0.0311 amu during the formation of the nucleus was obtained. This mass is converted to energy according to $E = mc^2$ which is released as binding energy. Fussion occurs at a very high temperature (about 15 million

^{0}C) because very large energy are required to overcome the strong repulsion in bringing two positively charge nuclei together. Reaction requiring such high temp. are called thermonuclear reaction. Such high temp. required for nuclear fussion can be obtained by explosion of atomic bomb based on Uranium fission. Example, when a mixture of deuterium and tritrium are exposed to such high temp., the different reaction occurs.

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy.}$$

This type of reaction confirms the bases of the hydrogen bomb. The power of the bomb is partly due to enormous amount of energy release and partly due to the large quantity of g radiation produced by the detonating agent. Thermo nuclear reaction occurs in the sun and star producing temp. of up to 15 million ^{0}C. The sun generates its energy by nuclear fusion of hydrogen nuclei into helium. In its core, the sun fuses 620 million metric tons of hydrogen each second. The energy produced is radiated in the earth and used in the formation of coal, oil, water power etc. Therefore, we live indirectly on energy obtained from nuclear fusion process.

Applications of Nuclear fussion includes:

1. Energy production in stars
2. Experimental fussion reactors

Radioactive Decay: An unstable nucleus spontaneously emits radiation and transforms into a more stable nucleus. This decay can be ; an alpha decay, a beta decay or a gamma emission. An excited nucleus releases energy as gamma radiation.

Artificial Transmutation: is the process of deliberately changing one element into another by bombarding the nucleus of an atom with high-energy particles such as alpha particles, protons, neutrons, or other nuclei. In artificial transmutation, the nucleus absorbs the incoming particle and is transformed into a different nucleus, often producing a new element. The whole process is summarized as follows:

1. Selecting a target nucleus.
2. Bombarding it with high-energy particles.
3. The target nucleus absorbs the particle.
4. A nuclear reaction occurs.
5. A new nucleus (and sometimes a new element) is formed

Radioactivity

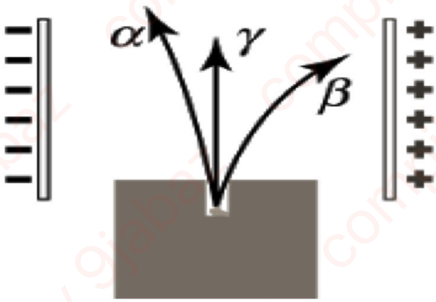
Principle: It is a process through which some elements that do not have a stable nucleus giveoff particles and/or rays to change their nucleus and become a stable element. The nuclei of certain elements disintegrate spontaneously to give two or more simpler one with emission of particles. The process of changing the nucleus to a stable one is called radioactive decay.

Nuclear radioactivity is mostly observed for nuclei of heavy elements e.g. all elements with mass number greater than 209 are radioactive and eventually disintegrate to lead 206 (^{206}Pb). Also, all elements that have an atomic number greater than 82 are radioactive. Some lightweight isotopes are radioactive e.g. carbon 14 (^{14}C), ^{40}K. These are called radium isotope. They all undergo radioactive decay. The change takes place simultaneously and the rate cannot be altered. It is believed to be due to unstable neutron to proton ratio in the nucleus. When the neutron is converted into a proton, a beta (b) particle is emitted as below:

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}b$$

Types of Radioactive decay

Three types of rays are usually emitted by radioactive substances. These are alpha (a), beta (b) and gamma (g) rays.



Radioactive sample in lead block

α particles (rays): This had the least penetrating power and can be stopped by a thin sheet of paper or a few centimeters or layers of air.

- When passed through a magnetic field, they are deflected in a direction expected of positive charge (+ve) particle (see above).
- They have velocity of 1/10 of that of light.
- They are helium atom (42He).
- They are emitted from nucleus within atomic weight greater than 106 e.g uranium, thorium, actinium radium etc.
- When an atom emits an alpha particle in alpha decay, the atom's mass number decreases by four due to the loss of the four nucleons in the alpha particle.
- The **atomic number** of the atom goes down by exactly two, as a result of the loss of two protons – the atom becomes a new element. At the same time, energy is liberated.

▪ For example, in the decay of $^{238}_{92}U$, 4.2 MeV of energy is released.

- Examples of this sort of nuclear transmutation are when **uranium** becomes **thorium**, or radium becomes radon gas, due to alpha decay.

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

$$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He + \text{energy}$$

b particles (rays): These are very small particles produced as a result of the conversion of a neutron to a proton, electron and an antineutrino (the anti-particle of a neutrino).

10n → 11p + ^{0}-1e +

- They pass through thin sheet of Al.
- They are deflected more readily in magnetic field in opposite direction of alpha ray showing negatively charged particles.
- They have velocity about the same size of light.
- They are electrons.
- **g rays:** This requires several centimeters of lead or several meter of concrete to completely absorb them.
- They are not particles at all but rays similar to X-rays of very small wavelength.

- They are extremely dangerous to living creatures because they have damaging effect on living tissues.

Gamma radiation (γ rays)

- High-energy electromagnetic waves.
- Very high penetrating power; requires thick lead or concrete for shielding.
- Weakly ionizing compared with alpha and beta radiation.

Properties of radioactivity

- It is a **nuclear phenomenon** and is not affected by temperature, pressure, or chemical reactions.
- Radioactive decay occurs at a characteristic rate, measured by the **Half-life**, which is the time taken for half of the radioactive nuclei in a sample to decay.
- The process is random but statistically predictable for large numbers of atoms.

Applications

- Medical diagnosis and cancer treatment.
- Generating electricity in nuclear power plants.
- Carbon dating of archaeological remains.
- Industrial quality control and scientific research.

<u>Half Life Period</u>

The time taken for half the radioactive nuclei in a sample to decay is called the half-life period.

It is a characteristic of a particular isotope and differs from others. For a single radioactive decay process, the number of nuclei which disintegrate in a short time period depends only on the relative number of radioactive atoms present and not the size of the samples. Therefore, nuclear decay is a first order reaction. Similarly, change in temperature has no observable effect on the rate of decay. If n is the number of radioactive nuclei and t is the time interval, the rate of decay (i.e, change in the number of radioactive nuclei with time) is given as:

$$\frac{dn}{dt} = -\lambda n$$

where l (units time^{-1}) is the decay constant for the process, which indicates how rapidly the sample is decaying. It is related to the half life time by integrating the equation above to give the relationship:

$$\frac{n}{n_o} = e^{-\lambda t}$$

- where n_o is the original number of nuclei at time 0, and n is the number remaining at time t. Therefore $t_{1/2}$ is the time taken when $n = 1/2n_o$.

The number of counts during the radioactive decay is usually measured as activities in a fixed time using Geiger counter or a scintillation counter. Hence, If A_0 and A represents the activities of the radioactive material at time $t = 0$ and $t = \text{t}$,

Then,
$$\frac{A}{A_0} = \frac{n}{n_0} = e^{-\lambda t}$$

At time $t = t_{1/2}$, then
$$\frac{A}{A_0} = \frac{n}{n_0} = e^{-\lambda t_{1/2}} = \frac{1}{2}$$

Taking logarithms of both side of the equation gives:

$-\lambda t_{1/2} = \ln(1/2)$.

Therefore $t_{1/2} = -\dfrac{\ln(1/2)}{\lambda} = +\dfrac{0.693}{\lambda}$

The SI unit of activity is the Becquerel (Bq), which is defined as the amount of a radioisotope that gives one disintegration per seconds. Thus 1 Bq = 27 x 10^{-12} Ci. Ci means curies which is the traditional unit of radioactivity.

Assignment

The activity of a radioactive isotope was study with the help of a Geiger counter. The number of counts per min (cpm) is a measure of how much of the isotope is present at any given time (Table below). Determine the half-life of the isotope.

t (min)	0	2	4	6	8	10	12	14
CPM	3160	2512	1778	1512	1147	834	603	519

Nuclear Equations

Nuclear equation represents the decay of one element to another. A radioactive element is usually represented as $^{a}_{b}\mathbf{X}$. **X** represents the element, **a**, the superscript represent the mass number, while **b**, the subscript represents the atomic number.

Ex. 1:

$^{1}_{1}H + ^{9}_{4}Be$ ---> $^{6}_{3}Li + ^{4}_{2}He$

For $^{9}_{4}Be$, the 9 represents the **Mass Number**, or the atomic weight of the element while the 4 represents the **Atomic Number**, or number of protons.

Rule: The sum of the mass numbers of the reactants equals the sum of the mass numbers of The products. Using this rule, you can figure out any missing particles in the equation.

Other examples are:

(a) $^{27}_{13}Al + ^{4}_{2}He$ ---> $^{30}_{15}P + ^{1}_{0}N$

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

(c) $^{4}_{2}He \rightarrow ^{1}_{0}n + ^{3}_{2}He$,

(d) $^{6}_{3}Li \rightarrow ^{4}_{2}He + ^{2}_{1}H$.

Mass Energy Relationship

(Binding Energy and Nuclear Stability)

Energy and mass are related by the **Einstein equation $E = mc^2$** where E is the energy liberated,

m the loss in mass (**the mass defect**) and c the velocity of light (2.998×10^8 ms^{-1}). **E and m** are expressed in units of **joules** and **kilograms**, respectively. It can also be represented as:

$$\Delta E = \Delta mc^2$$

The mass defect can be calculated, and converted to the binding energy in the nucleus. The larger

the mass defect, the larger the binding energy, and therefore the more stable the nucleus. The mass of a hydrogen atom $^{1}_{1}H$ is equal to the sum of the mass of one proton and the mass of one electron. For all other atoms the mass of the atom is less than the sum of the constituent neutrons, protons and electrons. The difference is called the mass defect. The mass defect is related to the binding energy holding the neutrons and protons together in the nucleus. A stable nucleus must have less than its constituent particles or it would not form.

Example 1: Using mass-energy relationship, calculate the binding energy for the formation of helium nucleus from neutron and proton as represented below.

$$2n + 2p = {}^{4}_{2}He$$

(Given: mass of $^{1}_{1}p$ = 1.007277 a.m.u., mass of $^{1}_{0}n$ = 1.008665 amu (1 a.m.u = 931 MeV)).

Mass of $^{4}_{2}He$ nucleus = 4.0028 a.m.u

Mass of 2n + 2p = 4.0319

Mass defect $\Delta m = m_{product} - m_{reactant}$ = (4.0028 – 4.0319) amu = -0.0291 amu (the negative indicates loss in mass)

$$\boldsymbol{\Delta E = \Delta mc^2}$$

Binding energy = 0.0291 x 931 = 27.1 MeV or 2.6 x 10^9 $KJmol^{-1}$

Class Notes

Prof. Makinde's Part

CHM 418

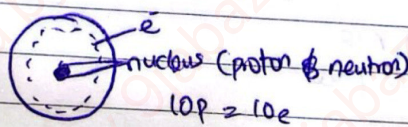
Prof. Makinde

Mo | Tu | We | Th ✓ | Fr | Sa | Su

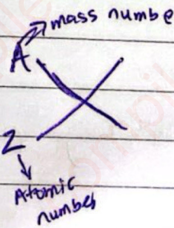
Date 10/06/26

The Atomic Structure

An atom is the smallest indivisible unit of matter that retains all of the chemical properties of an element.



→ Atomic number is the number of electron or proton



Summarily

Nuclear forces

(i) They are very strong force
(ii) Short range
(iii) Independent of charges

Types of Nuclear force

(i) Strong nuclear force
(ii) Weak nuclear force.

Importance of Nuclear forces

(i) nuclear stability
(ii) Radioactivity
(iii) Nuclear fission (iv) Nuclear fusion
(v) Nuclear reactor (vi) stellar energy production

Applications

Give a more page write up of the application of nuclear force in power generation and medicine

*Why are neutron important to nuclear stability

(i) They increase the ~~strong~~ strong nuclear force
(ii) They reduce proton-proton repulsion
(iii) They help in maintain in maintaining the proton-neutron Ratio
(iv) They increase the binding energy

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Force	Strength	Range
Strong Nuclear Force	Strongest	Very short
Electromagnetic	Strong	Infinite
weak nuclear force	weak	Very short
Gravitational force	weakest	Infinite

Scientific Studies
Understanding nuclear force has helped scientist to study topics like nuclear structure, particle physics and matter at atomic level

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Nuclear Reactions

Nuclear forces are short ranged.
Nuclear reactions are reactions that occurs in the nucleus caused either by weak nuclear force for reactivity or by strong nuclear force for stability

Nuclear reaction is different from chemical reaction
Factors affecting nuclear reaction is different for chemical reaction eg P/N ratio (balance) = stability

Example; nucleus of nitrogen being bombared by α-particle

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Features of Nuclear reaction
(i) It involves a nucleus
(ii) It changes an element from the old oil
(iii) Particles are liberated with energy

Types of
(i) Radioactivity (ii) Fusion

$^{235}_{92}U + ^{1}_{0}n \rightarrow$

$\rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2\,^{1}_{0}n$

$\rightarrow ^{138}_{53}I + ^{95}_{39}Y + 3(^{1}_{0}n)$

$\rightarrow ^{140}_{55}Cs + ^{92}_{37}Rb + 4\,^{1}_{0}n$

Energy is also generated in nuclear fission because there is ~~loss of water~~ always a mass difference

$E = mc^2$

Chain reaction

$^{239}_{93}Pu \rightarrow$

$\rightarrow ^{144}_{56}Ba + ^{16}_{38}S + 2\,^{1}_{0}n$

$\rightarrow ^{140}_{54}Xe + ^{98}_{40}Zr + 2\,^{1}_{0}n$]

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✓ Effect of Atomic Boomb

(1) The is a blast ~~waste~~ of intense pressure that destroys tree etc.

(2) There is an extreme heat that cause fire
(3) A nuclear radiation ~~from~~ harming radiation that affects living orgnisms
(4) There is radioactive fallout that can contaminant the environment.

Another application of fission: nuclear reactor
A huge amount of energy or heat generated can be converted to generate electricity
The reaction can be used to carry out activation analysis.
In medicine,
(i) It is used in the production of radio isotopes from nuclear reactors in hospitals and medical research.
(ii) Radioisotopes are used in imaging techniques for diseases detection and monitoring of organ function

(iii) Radiation from isotopes are used to kill cancer cells, eg chemotherapy.

iv) Gamma rays from radio isotopes are used in sterilizing ~~hospital~~ medical equipment

Nuclear Fusion

Coming together of two lighter nucleus into a new big one. It involves the use of large amount of ~~It involved~~ heat.

$$2p + 2n \longrightarrow {}^{4}_{2}He + E$$

The energy comes from the difference in the mass.

$$\Delta m = m_p - (m_p + m_n) \quad \text{called mass defect}$$

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

Calculate the energy released when a mass of 1.0×10^{-3} kg is converted ~~easily~~ completely to energy

A mass defect of 0.02 kg occurred during a nuclear reaction, calculate the energy released

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Application of Nuclear Fusion

(i) Formation of hydrogen bomb.

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He + E$$

This cause the use of hydrogen bomb.

ii) It can be used to generate electricity

iii) In nature, it is responsible for the conversion the things in the soil to coal.

iv) Transmutation: change of one element to another by radioactive decay, nuclear bombardment or similar processes

$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}\beta$$

Causes of transmutation

(i) nuclear bombardment

* Discuss thermonuclear reaction and its usefulness in nature

* Define transmutation. State the differences between natural and artificial transmutation

Natural Transmutation

It happens naturally, an unstable nuclei naturally decay into another element. It starts with one element and ends up with a new element and a particle generated.

$$X \longrightarrow Y + P$$

Example

$$^{42}_{19}K \longrightarrow ^{42}_{20}Ca + ^{0}_{-1}\beta$$

Artifical Transmutation

It is as a resut of instability of the nucleus in which spontaneous ~~destination~~ degradation of the of

2/07/26

Nuclear force is the force that prevent the nucleus from falling apart because proton-proton is supposed to repel each other but because of nuclear force

Radioactivity arises as a result of imbalance in P/N ratio resulting in instability. Chemical reaction can be affected by temperature and pressure which nuclear reaction is not affected. This is the difference between nuclear rxn and chemical rxn

~~Radioactivity is a result of instability of the nucleus~~

~~when degradation~~ of the

* Difference between nuclear and chemical reaction

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Properties of Radioactivity

(1) It is a nuclear phenomenon
Application: Energy generation

Half Life Period: find ½ life for each cpm, then add together or.
Plotting the graph & find the slope, radioactive element is usually ~~Example~~ written as $^{a}_{b}X$.

Example
$$^{1}_{1}H + ^{9}_{4}Be \longrightarrow ^{6}_{3}Li + ^{4}_{2}He$$

Binding Energy

$E = \Delta mc^2$ ~~Δm = Mass defect~~

E → energy liberated
Δm → loss in mass (mass defect)
c → speed of light

E in J
m in Kg

e.g
$$2p + 2n \longrightarrow ^{4}_{2}He$$

m_p
m_n => then we can find mass defect

Δm = mass defect = mass of product − mass of reactant

$$\Delta E = \Delta mc^2$$

The more the binding energy, the more stable the nucleus

Questions

1) Calculate the energy released when a mass of 1.0×10^{-3} kg is converted completely to energy. Find the energy ($c = 3 \times 10^{8}$ m/s)

(2) A mass defect of 0.02 kg occurs during a nuclear reaction. Calculate the energy released

(3) Compare nuclear fission and fusion under the following.
(i) definition (ii) fuel used (iii) energy produced
(iv) application

~~Study;~~

Imbalance of Proton-Neutron ratio is responsible for radioactivity
⇒ Nuclear stability
All the nuclear reaction is as a result of imbalance of Proton Neutron ratio

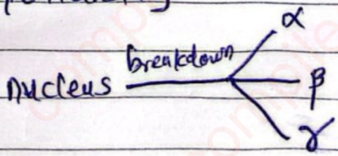
* Study;

* Application of Nuclear force
* Difference between nuclear and chemical reaction (5 points)
* Use of carbon dating
* What is binding energy

Radioactivity

It is as a result of instability of the nucleus when spontaneous degradation of the molecule

It is unstable as a result of imbalance of P/N ratio. To become stable, breaking down will occur to become stable. When they break down the produce α, β and γ - rays
Break down happens either by bombardment or Spontaneity



* features of α, β and γ rays.

Prof. Adenuga's Part

Quditative Application of Radiochemistry

(1) * Direct analysis: It has to do with materials that are naturally radioactive
* Carbon dating
(2) * The use of neutron activation analysis: radioactivity is induced
(3) * The use of radiactive isotopes as tracers in isotope dilution: It is a situation whereby radioactive material is introduced into an anaylyte of interest

(1) Direct Analysis of Radioactive Analyte: We look at the rate of decay and it follows first order kinetics

$$A = \frac{-dN}{dt} = \lambda N$$

λ = radioisotope decay constant
N = number of radioisotope

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

A = activity of radioactive decay

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

t = time

$$= A_0 e^{-\lambda t}$$

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

If the half life can be determined, we can know the quantity of the original material.

Example

In the activity in a 10ml sample of radioactive waste water containing $^{90}_{38}Sr$ was found to be 9.07×10^6 disintegration per sec. What is the molar concentration of If;
$t_{1/2}$ = 28.1 years

$$t_{1/2} = \frac{\ln 2}{\lambda} \Rightarrow 28.1 \times 365 \times 24 \times 60 \times 60 = \frac{\ln 2}{\lambda}$$

$$\lambda = 7.82 \times 10^{-10}\ s^{-1}$$

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Neutron Activation Analysis

We are dealing with elements that are not naturally radioactive. Radioactivity is induced which last for a short period.

Neutron activation is a means of inducing radioactivity in to a non-radioactive sample by bombarding the sample with neutrons. And this is applicable to the elements that naturally don't exhibit radioactivity. So, the process of inducing radiactivity using neutron is termed neutro activation analysis. When the element of interest is irradiated with neutron, the radioactive element formed decays to a radioactive isotope by emitting gamma rays and occasionally other nuclear particles, ~~dependi~~

The rate of γ ray emission is proportional to the analyte initial concentration of the analyte sample.

For instance, a non-radioactive aluminium bombarded with neutron

$$^{27}_{13}Al + ^{1}_{0}n \longrightarrow ^{28}_{13}Al$$

$^{27}_{13}Al$ ↓ non radioactive

$^{28}_{13}Al$ ↓ not stable (radioactive isotope)

The radioactive isotope disintegrate; $Q \propto C$ → initial conc.

Q → quantity of the emitted ray

$$^{28}_{13}Al \longrightarrow ^{28}_{14}Si + ^{0}_{-1}\beta + \gamma$$ → Gamma ray

$A_0 \propto W_0$ A_0 = activity
W_0 = quantity /weight of material

$$(A_0)_x = K W_x \quad \text{—— (1)}$$

$$(A_0)_s = K W_s \quad \text{—— (2)}$$

$$\therefore W_x = \frac{(A_0)_x}{(A_0)_s} W_s$$

This can be applied in mining and oter materials for purification

The concentration of Mn is steel can be determined by NAA using the method of external standards.

* External Standard – having various conc. of a sample and then you plot graph and compare to the determine the conc. of the unknown.

* Internal standard, add a known concentration to a standard and then determine the conc. after

A 1g sample ~~of an unknown steel~~ and of 0.95g of standard sample known to contain 0.463%

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A 1g sample of an unknown steel and a 0.95g of standard steel known to contain 0.463% w/w Mn are irradiated with a neutron in a nuclear reactor for 10hrs after a 40mins cooling period, the activity for γ-ray emission was found to be 2542cpm (count per minute) for the unknown and 1984cpm for the standard. What is the percentage w/w Mn in the unknown steel sample?

Solution

$(A_0)_x = 2542 \text{ cpm}$

$(A_0)_s = 1984 \text{ cpm}$

$W_s = \frac{0.463}{100} \times 0.95 = 0.0043985g$

$\simeq 0.0044g$

$W_x = \frac{(A_0)_x}{(A_0)_s} W_s$

$W_x = \frac{2542}{1984} \times 0.0044$

$W_x = 0.0056g$ Mn

$= \frac{0.0056}{1g} \times 100\% = 0.56\%$

Isotope Dilution

It is an important quantitative method of analysis

17/07/26

NAA has a major advantage, i.e it has application to almost all elements in the periodic table unlike natural one which is only limited to radioactive elements

③ Isotope Dilution

It operates by introducing a trace into the sample which will help to quantify similar elements on the same sample. The trace is always a radioactive form of the element of interest with known activity for it radioactive decay.

A measured mass of the tracer is a added to the sample containing an unknown mass of a non radioactive analyte and the material is homogenized The sample is then processed to isolate the total weight of both tracer and the unknown.

The activity of the isolate sample is then measured. If all the analyte (i.e both the radioactive and non-radioactive) is recovered. Then;

The activity of isolated material = that of total

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Activity of

$$A_A = A_T$$

$$A_A = A_T\left(\frac{W_A}{W_x + W_T}\right)$$

$$W_x = \left(\frac{A_T}{A_A}\right)W_A - W_T$$

Example

The concentration of insulin in the production path is determined by

An 1mg sample of insulin labelled with ^{14}C with an activity of 549 cpm is added to a 10ml sample taken from the production path. After homogenizing the sample, a portion of the insulin is seperated and purified yielding 18.3mg of insulin. The activity for the isolated insulin is measured to be 148 cpm. How many mg of insulin are in the original sample.

Sample

10.00mL

Isolated

$W_A = 18.3mg$

$A_A = 148cpm$

$W_x = ?$

Tracer

1mg insulin with ^{14}C, i.e $W_T = 1mg$

$A_T = 549cpm$

$$W_x = \left(\frac{A_T}{A_A}\right) W_A - W_T$$

$$= \frac{549\,\cancel{cmp} \times 18.3\,mg}{148\,\cancel{cmp}} - 1\,mg$$

$$= 66.88\,mg$$

(Conditions under which it can be used are;