Nuclear chemistry

Radioactivity:

We learned in previous that there are **isotopes** of almost all the elements, ***isotopes*** can be defined as atoms whose nuclei have the same number of protons but different number of neutrons. Most of these isotopes are **stable**, but some are **unstable**. The nuclei of unstable isotopes undergo spontaneous nuclear reactions that cause particles and energy, called ***nuclear radiation***, to be given off. The emission of these particles and energy by an isotope is called ***radioactivity***. Only a few isotopes found in nature are radioactive.

Radioactive isotope used now days in:

1. Abundant energy. **2**. Nuclear weapons. **3**. Radiation therapy.

Nuclear reactions: Atoms do change from one kind to another when they emit radiation. This change occurs during a nuclear reaction, when nucleus of an isotope emits **α** or **β** particles. When this happens, the nucleus gains or loses positive charge. The radiation from radioactive isotopes and x-rays can form ions in matter by knocking electrons off the atoms and molecules in its path. For this reason, it is called ***ionizing radiation***. The chief effects of radiation on living systems are due to these ionization reaction. Repeated exposure to low levels of radiation seems to have a number of major effects on health. among them are cancer (carcinogenic effects), damage to the fetus, and genetic damage. For example as the following nuclear equation.

Mass no. ----→ 40

atomic no. ----→ 19

$$^{40}_{19}K \longrightarrow\ ^{40}_{20}Ca + ^{0}_{-1}\beta$$

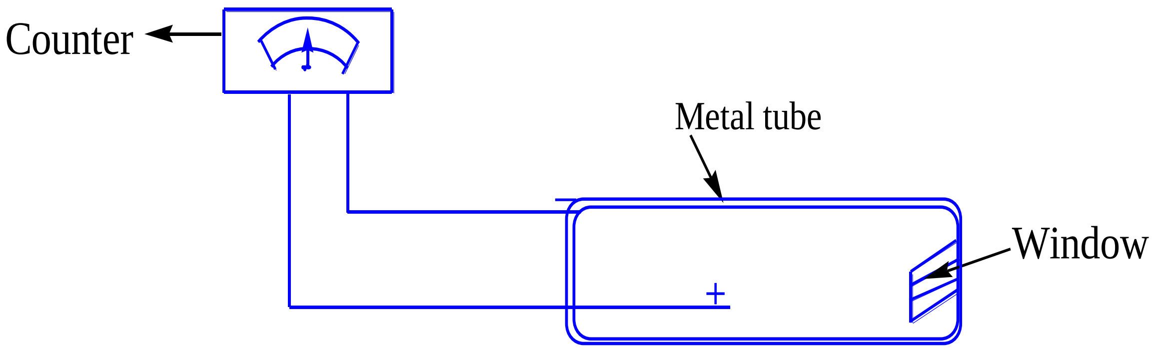
$$^{14}_{6}C \longrightarrow\ ^{14}_{7}N + ^{0}_{-1}\beta$$

Detecting ionizing radiation:

Radiation disturbs the electronic environment of the atoms and molecules that it encounter. There are three methods of detecting ionizing radiation frequently used:

1. photographic method, photographic film and paper shielded from light are exposed by ionizing radiation. This exposure is detected by developing the film in the usual way.
2. Scintillation counter, (liquid and solid), the solid contains a surface coated with a special substance (NaI with Ti) gives off flashes of light when hit ionizing radiation (invisible transformed to visible light).
3. Geiger counter, consist of :

a. Metal tupe
b. Inert gas
c. Large potential difference maintained between metal and wire.



Nuclear stability: nuclear force is a strong force of attraction between nucleons (proton & neutron). Protons and neutrons have energy levels. Nuclei with certain no. of protons or neutrons appear to be stable (Magic no.)

Isotopes with even number of p or n are generally more stable.

Naturally occurring radioactive substances:

All elements of atomic number more than 83 (Bi) are radioactive. There are three series (families) of naturally occurring radioactive substances:

1. Uranium series: $U^{-238} \longrightarrow \underset{decay}{\longrightarrow} \longrightarrow \underset{stable}{Pb^{-206}}$

2. Actinium series: $\underset{actino\ Uranium}{U^{-235}} \longrightarrow \underset{decay}{\longrightarrow} \longrightarrow \underset{stable}{Pb^{-207}}$

3. Thorium series: $Th^{-232} \longrightarrow \underset{decay}{\longrightarrow} \longrightarrow \underset{stable}{Pb^{-208}}$

Tape of radiation:

(1) **Alpha radiation (α):** is a stream of particles moving at about one-tenth of speed light. Each particle is the nucleus of a helium atom ($^{4}_{2}He^{2+}$). They are large and heavy, so they cannot travel very far, they cannot penetrate the skin. If a substance that emits α-particles gets inside the body by being inhaled or swallowed, the α can damage internal organs.

(2) **Beta particle (β):** is a stream of particles, but the particles are electrons. The electrons are produced within the nucleus by the transformation of a neutron into a proton and an electron. The proton stays in the nucleus and the electron is emitted. An electron is smaller than helium nucleus, travels much faster, and can penetrate the skin to a depth of a few centimeters.

(3) **Gamma radiation (γ):** is not a particle, but a form of energy similar to light waves, x-rays.
This radiation has high energy and can penetrate deep within the body and cause serious damage.

Properties of nuclear radiation

*Types of **Radiation***	*Composition*	*Symbol*	*Mass (a.m.u)*	*Charge*	*Penetration (cm)*
Alpha	He nucleus	$(\alpha)^{4}_{2}He$	4	+2	0.01
Beta	electron	$(\beta)\ ^{0}_{-1}e$	1/1837	-1	1
Gamma	energy	(γ)	0	0	100
Neutron	neutron	$(n)^{1}_{0}n$	1	0	10
Positron	positron	$(\beta^{+})^{0}_{1}e$	1/1846	+1	1

Examples:

* $^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$ **-α-**

* $^{16}_{7}N \longrightarrow ^{16}_{8}O + ^{0}_{-1}e$ **-β-**

* $^{99m}_{43}Tc \longrightarrow ^{99}_{43}Tc + \gamma$ **-γ-**

* $^{131}_{53}I \longrightarrow ^{131}_{54}Xe + \beta + \gamma$

Radiation causes cancer, skin cancer, bone cancer, leukemia and other cancers are products of exposure to radiation.
Genetic risk of exposure to radiation is more difficult to determine. Genetic damage is caused by damage to the genes in the nuclei of cells. The damage to the structure of the gene may cause death or variety of physical defects in the following

generation.

Exposure to radiation is dangerous. But is there any level of exposure below which radiation has no effect. According to one theory:

1. **Threshold theory:** no damage is occur below a certain level of radiation, called the threshold value.
2. **Linear theory:** the risk of damage is proportional to exposure, even down to very low levels of radiation.
3. **Current view:** is a compromise of these two theories; there is a risk of damage even at low levels of radiation, but risk is extremely small.

Artificial Radioactivity:

Artificial isotopes can be made when non-radioactive isotope nucleus is bombarded with proton, neutron or Algha particle such as:

$^{197}_{79}Au + ^{1}_{0}n \longrightarrow ^{198}_{79}Au$ tracer in liver

$^{98}_{42}Mo + ^{1}_{0}n \longrightarrow ^{99m}_{43}Tc + ^{0}_{-1}e$ tracer

Half-life ($t_{1/2}$):

Half-life: is the time required for half of given quantity to change to another isotope.

Each radioactive isotop has a characteristic half-life values of the half-lives of naturally occurring isotope range from milliseconds to several billion years. For example:

Element	Isotope	Half-Life
Hydrogen	$^{3}_{1}H$	12.3 Yr
Carbon	$^{14}_{6}C$	5700 Yr
Sodium	$^{24}_{11}Na$	15 Yr

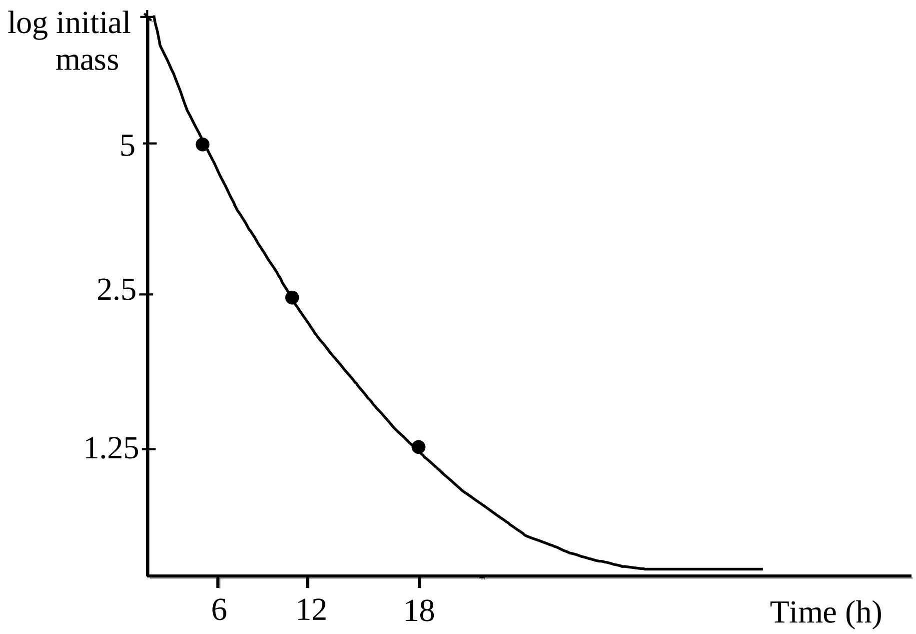
Uranium $\quad {}^{235}_{92}U \quad$ 710 millionYear

The importance of the half-life is that it tell us how long a sample of the isotope will exist. The value of the half-life of a radioactive isotope is independent of sample size.

For example: the size of the sample of thorium-234 is 10gm, 1kg, or 10gm, half of it will decay in 24.1 days.

$$ {}^{234}_{90}\mathbf{Th} \xrightarrow[\text{24.1 days}]{\text{half-life}} {}^{234}_{91}\mathbf{Pa} + {}^{0}_{-1}\beta $$

Ex: The decay scale of **Tc^{-99m}** ($t_{1/2}$ =6h) is :



The remaining mass can be calculated as following:

$$ n = \frac{\text{time elapsed}}{\text{half-life}} $$

n= no. of half-life elapsed

$$ mass_{remain} = \frac{\text{mass initial}}{2^n} $$

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In addition to how long a radioactive isotope will last, we also want to know how much radiation it gives off, for this reason we need units to measure the radiation given off by radioactive isotopes.

Radiation Dosages:

The basic unit of radioactivity:

Curie (Ci): is the level of radioactivity caused by 3.7×10^{10} radioactive disintegrations per second. It is independent of the size of the radioactive sample.
Picocurie (10^{-12} Ci), and millicurie (10^{-3} Ci), are generally used.

Becquerel (Bq): is the SI unit of radioactivity. One Ci is equal to 3.7×10^{10} becquerel.

Ci= 3.7×10^{10} Bq
Rad (D): radiation absorbed dose. The energy absorbed by tissue.
Gray (Gy): the SI unit of absorbed dose.
100 rad = 1 Gy

Rem : No. of rem= RBE X **no. of Rad**

Where: RBE=Factor called relative biological equivalent (effectiveness) .
RBE of $\alpha = 10$ cause more damage
RBE of $\beta = 1$
RBE of $\gamma = 1$
RBE of $n = 5$

LD_{50} Value: the dose, in rem, that is fatal to 50% of the population within 30 days.
The LD50 value for human is estimated to be 500 rem.
The LD50 values of mammals are 250-1000 rem.
The LD50 values of insects are 50000 rem.
Microorganisms can tolerate even more.

Transmutation:

Changing one element into another, either in nature or in the laboratories. This can be done by bombardment reaction, accelerator is needed. The reaction occurs when particles of atomic or subatomic size strike atoms of an element and change them into another.

$$^{9}_{4}\mathbf{Be} + {}^{4}_{2}\mathbf{He} \longrightarrow {}^{12}_{6}\mathbf{C} + {}^{1}_{0}\mathbf{n}$$

target — bombarding particle

Accelerator is a device that increases the speed of a charged atomic or subatomic particle. Circular accelerator (Cycletron) is used and operation is based on:

a) A charged particle is repelled by another of like charge.
b) A charged particle moves in a curved path when magnetic field is applied.

Medical uses of radioactive isotopes:

1. **Treatment of cancer :** Co^{-60} used as external source,

$^{123}_{53}\mathbf{I}$, $^{131}_{53}\mathbf{I}$ used internally to treat thyroid cancer.

$^{32}_{15}\mathbf{P}$ used to treat leukemia.

$^{99}_{43}\mathbf{Tc}$ used to scans Brain, Kidney, and Lung

2. **Tracers:** $^{24}_{11}$**Na** diagnose blockages in circulatory system.

Isotopes must be chosen carefully because:

a. The half-life must be long enough to do job; yet, short enough to disappear without subjecting body to unnecessary radiation.

b. No isotope emit α–particle used.

Magnetic Resonance Imaging (MRI):

Nuclear transition occurs in the microwave region of the electromagnetic radiation under the influence of magnetic field.

An image (based on microwave absorption) is generated, stored and sorted in computer. Differences between normal and malignant tissue may clearly be seen in the final image.

Positron Emission Tomography (PET):

It is a technique for following biochemical processes within the organs (brain, heart, ...) of the human body.

PET scan produces an image of a two-dimensional slice through a body organ of a partient.

Some isotopes used in PET scans are C-11, N-13, O-15 and F-18. All have short half-lives, so the radiation dosage to the patient is minimal.

Energy and nuclear reactions:

Uranium atoms are bombarded with slow neutrons (thermal) cause splitting nucleus. This called ***fission reaction.***

U-235 is the only naturally occurring isotope which undergoes this reaction.

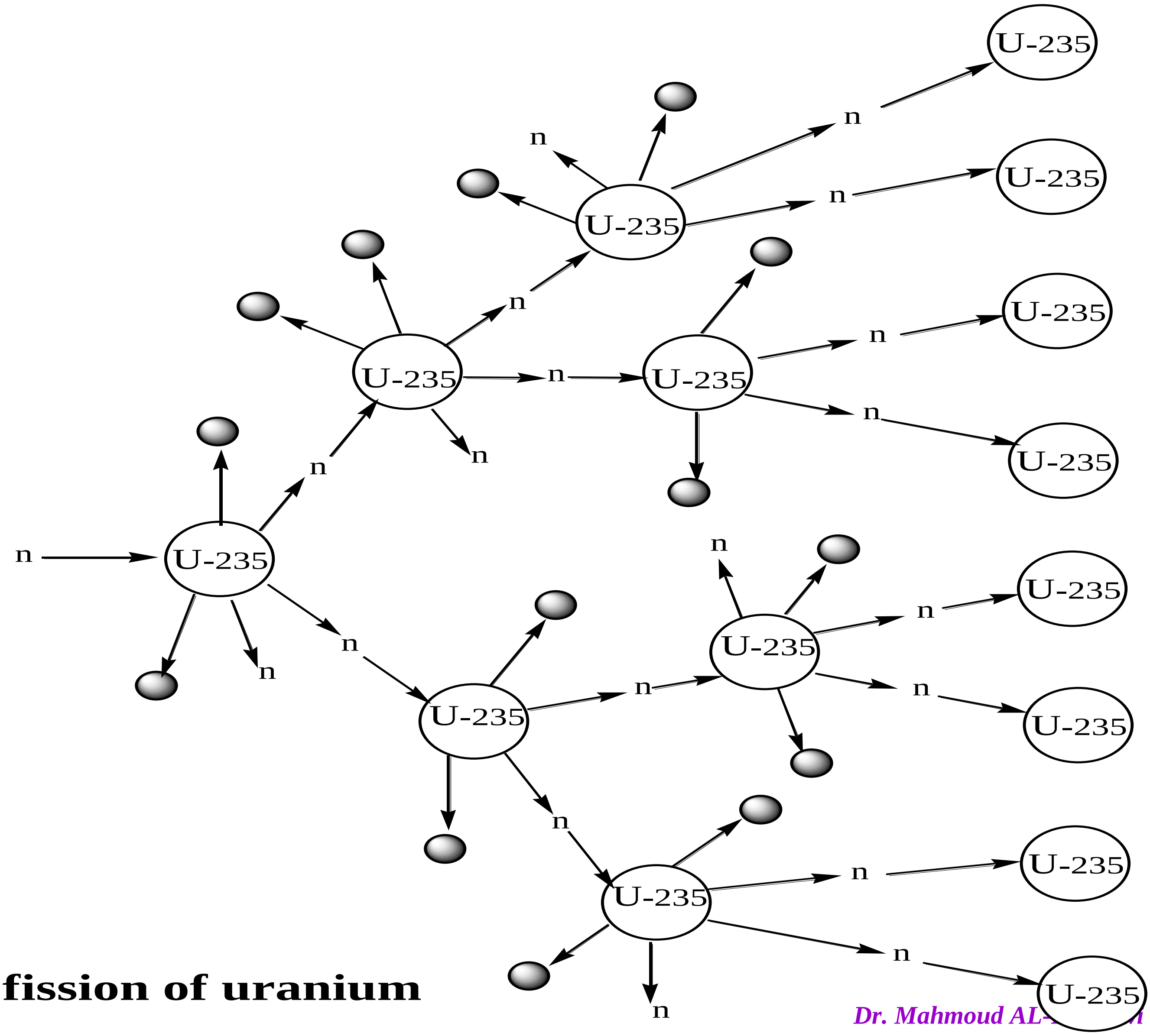
The other two isotopes which undergoes fission reaction are ^{239}Pu and 233U and both are artificial isotopes and produced in breeder reactors. Pu-239 and U-233 are fissionable fuel and can be produced as following:

$$^{238}_{92}\mathrm{U} + \underset{\text{fast}}{^{1}_{0}\mathrm{n}} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[\beta]{} {}^{239}_{92}\mathrm{Np} \xrightarrow[\beta]{} {}^{239}_{94}\mathrm{Pu}$$

$$^{232}_{90}\mathrm{Th} + \underset{\text{fast}}{^{1}_{0}\mathrm{n}} \longrightarrow {}^{233}_{90}\mathrm{Th} \xrightarrow[\beta]{} {}^{233}_{91}\mathrm{Pa} \xrightarrow[\beta]{} {}^{233}_{92}\mathrm{Pu}$$

*In fission reaction, large amount of energy released, neutrons, and γ radiation as well as other elements and heat.

A chain reaction is shown, start by neutron strikes an atom of uranium-235 and causes it to split into two, three, or four neutrons. These neutrons can strike other uranium-235 atoms and cause them to undergo fission reactions. Each fission reaction produces more neutrons, which cause more fission reactions, which cause more fission reactions. It is the emission of neutrons by a fission reaction that keeps the chain reaction going. The amount of material needed for chain reaction to continue is called ((***Critical Mass***)).



fission of uranium