

## Radiochemistry

### Radiochemistry:

Radiochemistry is defined as the branch of chemistry that deals with the study of radioactive elements and their behavior, particularly in analytical applications such as isotope dilution analysis and radiometric titrations. It focuses on understanding the behavior of **actinides and trans uranium elements**, as well as developing methods for handling radioactive waste, manufacturing sources of radioactive emissions, and separating radioactive isotopes.

Radioactivity is a phenomenon that occurs naturally in a number of substances. Atoms of the substance spontaneously emit invisible but energetic radiations, which can penetrate materials that are opaque to visible light. Radioactivity is the release of energy from the decay of the nuclei of certain kinds of atoms and isotopes. The effects of these radiations can be harmful to live cells but, when used in the right way, they have a wide range of beneficial applications, particularly in medicine. Radioactivity has been present in natural materials on the earth since its formation, for example in potassium-40 which forms part of all our bodies. Nowadays we have also found ways of creating new man-made sources of radioactivity; like iodine-131 and molybdenum, for example fluorine-18 are specifically produced for the benefit of their medical use.

### Unites:

The amount of radioactivity in a source is measured by the rate at which atoms undergo radioactive

The curie Ci = level of radioactivity caused by  $3.7 \times 10^{10}$  radioactivity disintegrations per seconds .

$$1 \text{ curi} = 3.7 \times 10^{10} \text{ becquerel}$$

### Isotopes:

- An isotope is a variant of a particular chemical element. They share almost the same chemical properties, but differ in mass and therefore in physical properties. There are stable isotopes, which do not emit radiation, and there are unstable isotopes, which do emit radiation. While all isotopes of a given element have the same number of protons, each isotope has a different number of neutrons. For example, hydrogen has three isotopes (or variants):
- Hydrogen-1 (contains one proton and no neutrons)
- Hydrogen-2, which is called deuterium (contains one proton and one neutron)

- Hydrogen-3, which is called tritium (contains one proton and two neutrons)
  - Another example is uranium-235, which has 92 protons and 143 neutrons, as opposed to uranium-238, which has 92 protons and 146 neutrons.

An isotope is stable when it has a balanced number of neutrons and protons. In general, when an isotope is small and stable, it contains close to an equal number of protons and neutrons

### **Radioisotopes:**

Isotopes that are not stable and emit radiation are called radioisotopes. A radioisotope is an isotope of an element that undergoes spontaneous decay and emits radiation as it decays. During the decay process, it becomes less radioactive over time, eventually becoming stable. Once an atom reaches a stable configuration, it no longer gives off radiation. For this reason, radioactive sources – or sources that spontaneously emit energy in the form of ionizing radiation as a result of the decay of an unstable atom – become weaker with time.

### **Half-life:**

Early investigations by Becquerel and the Curies, Rutherford and Soddy had shown that the activity of a radioactive source reduced over a period of time which was different for each substance. The time taken for the activity to fall to half of its original value is called the half-life of the source. However, the activity does not fall at a steady rate, so it is not the case that the activity will have fallen to nothing after two half-lives. Instead the activity falls at an ever decreasing rate so that in every half -life the activity will halve.

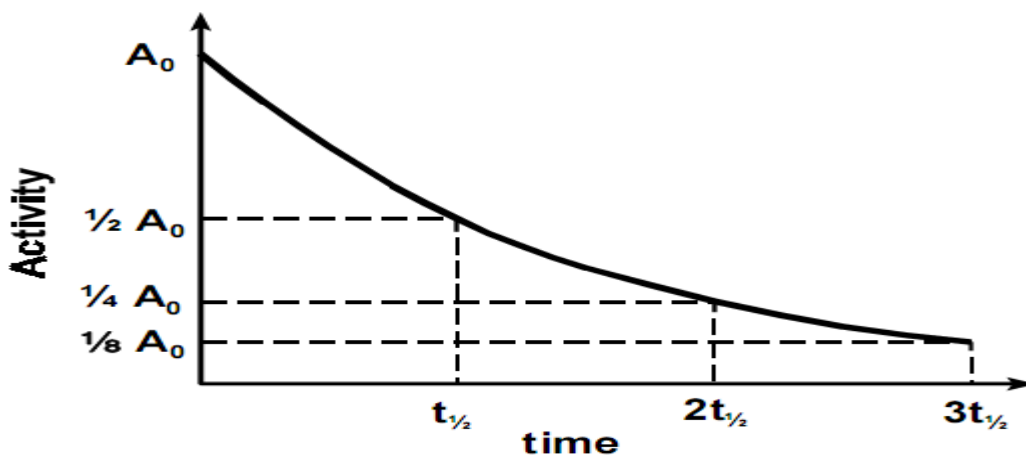


Figure 1 - Exponential decay of activity

## The atom

Atom is the basic building block of all matter and chemistry. Atoms can combine with other atoms to form molecules but cannot be divided into smaller parts by ordinary chemical processes. Each atom consists of a nucleus at its center surrounded by a cloud of orbiting electrons as illustrated in figure -1. Neutral atom has an equal number of protons (in the nucleus) and electrons (surrounding the nucleus). Thus the positive and negative charges are balanced. Ordinary atoms that either gain or lose electrons are called ions. **If a neutral atom loses an electron, it becomes a positive ion. If it gains an electron, it becomes a negative ion.** Most of the atom is empty apart from the very diffuse cloud of orbiting electrons and the nucleus at its center.

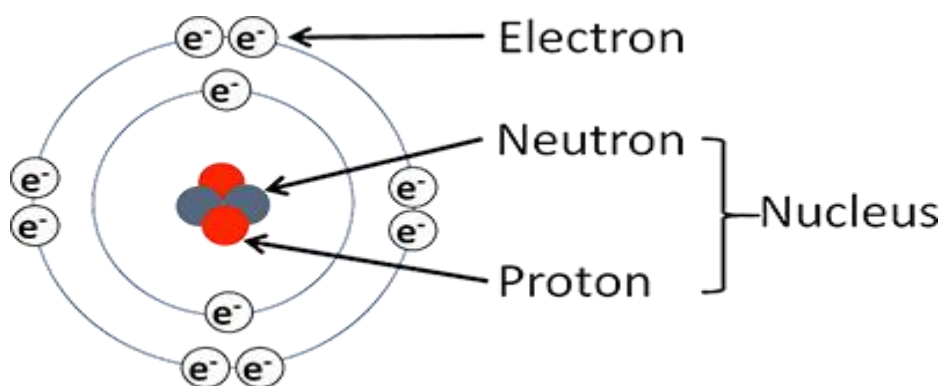


Figure 1: the structure of the atom

The nucleus of an atom is composed of protons and neutrons . **The number of protons in the nucleus is called the atomic number**, and is given the symbol  $Z$  . Because the protons each have a charge of  $+1$  unit and the neutrons have no charge, the total charge of the nucleus is  $+Z$  units . Electrostatic attraction between the positively charged nucleus and the negatively charged electrons holds exactly  $Z$  electrons in orbit around the nucleus when the atom is in its normal state .The overall charge on the atom is then zero. **All atoms with the same  $Z$ , therefore, belong to the same chemically. The protons and neutrons in the nucleus are collectively called nucleon.** Despite its small size the nucleus contains nearly all the mass of the atom because each nucleon is 2000 times heavier than an electron .**Therefore the total mass of the atom is given by the sum of the number of protons,  $Z$ , and the number of neutrons,  $N$ , that it contains . Thus the mass number,  $A$ , of the atom is given by  $A = Z + N$  . The term nuclide is used to describe a particular nuclear species with a given combination of  $A$  and  $Z$  .** The full description of a nuclide is given by writing the chemical symbol for its element

with A as a superscript and Z as a subscript .Thus the normal form of iodine would be written

127

I

53

Where 127 is the mass number, A, and 53 is the atomic number, Z . This nuclide therefore has 53 protons and 74 neutrons (to make a total of 127 nucleons in its nucleus) and 53 orbiting electron.

Types of radiations:

1. **Alpha radiation ( $\alpha$  radiation):** it's a stream of particle moving at about one-tenth the speed of light .Each particle contains two protons and two neutrons and has a charge +2 .
2. **Beta radiations ( $\beta$ ):** it's a stream of electrons, its produces within the nucleus by the transformation of neutron into proton and an electron. Exposure to beta radiation cause skin burned .
3. **Gamma radiation ( $\gamma$ ) :** it's not particles, but a form of energy similar to light waves, radio wave, or x-ray. This radiation has high energy and can penetrate deep within body and cause serious damage .
4. Electron Capture radiation or ionization radiation.

Nuclear reaction:

Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei or one atomic nucleus and a subatomic particle. The nuclides produced from nuclear reactions are different from the reacting nuclei (commonly referred to as the parent nuclei).

**TABLE 2.4** Forms and Properties of Nuclear Radiation

Emission	Symbol	Charge
Alpha	$\alpha$ or ${}^4_2\text{He}$	2+
Beta	$\beta$ or ${}^0_{-1}\text{e}$	1-
Gamma	${}^0_0\gamma$	0
Positron	${}^0_1\text{e}$	1+
Neutron	${}^1_0\text{n}$	0

## Alpha Decay

Nuclei with mass numbers greater than 200 tend to undergo **alpha decay** – a process in which a  ${}^4\text{He}$  nucleus, commonly referred to as an alpha particle ( ${}^4_2\alpha$ ) is liberated from the parent nucleus.

The general equation for alpha decay is:  ${}^A_Z\text{X} \rightarrow ({}^{A-4})_{(Z-2)}\text{X}' + {}^4_2\alpha$

Where A is the mass number and Z is the atomic number. An example of alpha decay is provided below.



Here, the radium-226 nucleus decays into a radon-222 nucleus, liberating an alpha particle in the process.

## Beta Decay

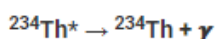
**Beta decay** occurs when a neutron is converted into a proton, which is accompanied by the emission of a beta particle (high-energy electron). An example of this type of nuclear reaction is the beta decay of carbon-14 that affords nitrogen-14:



## Gamma Emission

**Gamma emission** occurs when an excited nucleus (often produced from the radioactive decay of another nucleus) returns to its ground state, which is accompanied by the emission of a high energy photon.

An example of gamma emission is the de-excitation of the excited thallium-234 nucleus (which is produced from the alpha decay of uranium-238). The equation for this nuclear reaction is:



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## Ionization radiation:

The effect of radioactivity also depends on the type and energy of the particles produced during nuclear decay. The process in which an electron is given enough energy to break away from an atom is called ionization. This process results in the formation of two charged particles or ions: the molecule with a net positive charge, and the free electron with a negative charge. Ionizing radiation is the energy produced from natural or artificial sources. It has more energy than non-ionizing radiation, enough to cause chemical changes by breaking chemical bond and such effect can cause damage to living tissue. Radiation in this range has high energy. It has enough energy to strip electrons from an atom or, in the case of very high-energy radiation, break up the nucleus of the atom. Each ionization releases energy that is absorbed by material surrounding the ionized atom. Ionizing radiation deposits a large amount of energy into a small area. In fact, the energy from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms.

## Radiation dose

When ionizing radiation penetrates the human body or an object, it deposits energy. The energy absorbed from exposure to radiation is called a dose. When ionizing radiations (alpha, beta, gamma or X-rays) pass through matter they pass on some or all of their energy to the material by ionizing and exciting the atoms of the material through the processes described above. **The damage done by this depends both on the energy deposited and the amount of material involved.**

The concept of absorbed dose applies to all types of material but, when we need to assess the effect on biological tissues, we also need to take account of the fact that some types of radiation are more harmful than others. For example, because they are so densely ionizing, alpha particles are about twenty times as effective at killing cells as beta particles, gamma rays or X-ray. **Therefore when equivalent dose which is defined as measuring the dose to biological tissues we use a quantity called the absorbed dose multiplied by a radiation weighting factor.** There is one final complication to measuring the effect of radiation on a person; not all tissues in the body are equally sensitive to radiation damage. For example, Different tissues and organs have different radiation sensitivities. For example, bone marrow is much more radiosensitive than muscle or nerve tissue.

RAD: one rad is equal to  $2.4 \times 10^{-3}$  cal of energy absorbed by 1 kg of tissues converted to heat that raise the temperature of tissues only few thousands of degrees.

REM: the rem is 1 rad multiplied by factor called relative biological equivalence (RBE).

*Where the RBE take into account the differences in biological damage causes by different kinds of ionized radiation of the same energy. For example alpha cause 10 times damage by beta of same energy.*

**The REM more accurate and compatible measuring of biological damage.**

**Direct Action: When the atoms of the target itself are ionized by the radiation. It is the dominant process for high energy radiation.**

**Indirect Action: When the radiation interacts with other cellular molecules (e.g. water) to produce free radicals that migrate to and damage the target. About 2/3 of x-ray damage is due to indirect action.**

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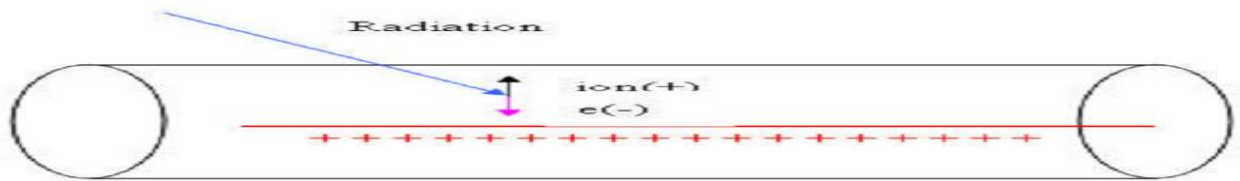
Radiation detectors:

The three methods of detecting ionizing radiation most frequently used are the photographic method, use scintillation counter, and use of the Geiger counter.

**Geiger counter**

Gas-filled detectors are typically utilize an electric potential is set up between a cylindrical detector wall and a center electrode passing through the center of the cylinder.

A gas is used as the detection medium in this cylinder and the negatively charged electrons that are released by ionizing radiation in the gas are collected on the center electrode. Gas-Filled Detector are selectively inexpensive, have good sensitivity, and are used primarily to measure gamma-rays and beta. They are often used in portable applications for assessment and monitoring of radiation levels.



**Geiger counter**

Medical applications of isotopes:

The half-life must be long enough for isotope to do its job and short to diaper from the body .In medical application, no alpha radiation was in use because its cause damage to all tissues . The main mechanism for isotopes application either externally (such as Co-60) or internally I -131 .The below table represent the main isotopes in medical use :

Isotopes	Half life	Application
I -131	8 days	Thyroid cancer
Co-60	5.3 years	Different types of cancer
P-32	143 days	Leukemia
Na -24	15 hrs	Circulation system
Fe -59	456 days	Red blood cells