Course: CHEM 3232
Nuclear Chemistry
Chapter: Radiation Detection and Measurements

Dr. M. Abdul Latif

Associate Professor
Department of Chemistry
Begum Rokeya University, Rangpur

Review

Nuclear radiation: refers to the particles and photons emitted during reactions that involve the nucleus of an atom. Nuclear radiation is also known as ionizing radiation. The particles emitted by nuclear reactions are sufficiently energetic that they can remove electrons from atoms/molecules and ionize them.

Nuclear radiation includes gamma rays, x-rays, and the more energetic portion of the electromagnetic spectrum. Ionizing subatomic particles released by nuclear reactions include alpha particles, beta particles, neutrons, muons, mesons, positrons, and cosmic rays.

Nuclear Radiation Example

During the fission of U-235 the nuclear radiation that is released contains neutrons and gamma ray photons.

They are also called ionizing radiations because they are capable of causing ionization, either directly or indirectly.

Formation of ion-pair

There is a strong electric field in its immediate neighborhood, a rapidly moving charged particle, such as an alpha or beta particle has the ability to eject orbital electrons from the atoms or molecules of a gas through which it passes, thus converting them into positive ions.

Meanwhile the expelled electrons usually remain free for sometime, although a few many attach themselves to other atoms or molecules to form negative ions. Thus the passage of charged particles through a gas results in the formation of a number of ion-pairs consisting mainly of positive ions and free electrons.

When ionizing radiation passes through living tissue, electrons are removed from neutral water molecules to produce H_2O^+ ions. Between three and four water molecules are ionized for every 1.6×10^{-17} joules of energy absorbed in the form of ionizing radiation.

$$H_2O \longrightarrow H_2O^+ + e^-$$

Definition of some terms

Specific ionization: The intensity of ionization produced by a moving particle in its path through a gas is expressed by the specific ionization; this is the no. of ion-pairs formed per centimeter of path.

For particles of the same mass and energy (or velocity) the specific ionization increases with the magnitude of the charge, and for the particles of the same energy and charge it increases with the mass, that is decrease the speed.

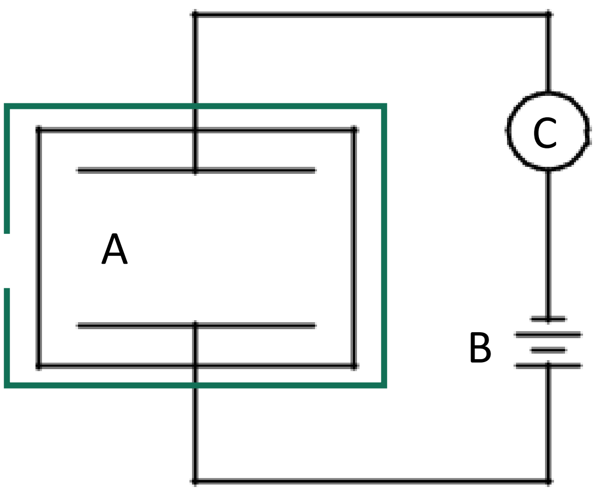
The more slowly moving particle spends more time in the vicinity of an atom or molecule of the gas through which it passes, and so the chances of ionization occurring are thereby increased.

For example: alpha particle $\left({}_{2}^{4}He\right)$from radio active sources produce 50000-100000 ion-pairs per cm of normal air

Beta $\left({}_{0}^{-1}e\right)$ $\longrightarrow$ few hundreds ion-pairs per cm

Behavior of ion-pairs in electric fields

Consider a simple electric circuit where two electrodes (A) are connected with positive and negative ends of a battery. In order to understand the behavior of the ions, it is convenient to consider an apparatus consisting of vessel , containing a gas , e.g., air in which are fixed with two parallel metal plates to act as electrodes. The electrodes are connected with to a battery 'B' so that voltage can be increased steadily from zero to high values. An ammeter 'C' connect in the circuit which is capable of measuring electric current.



Normally, the air in the vessel does not conduct electricity and no current will be observed in the ammeter C until the voltage becomes high enough to several hundreds/thousands.

Suppose now a single alpha or beta particle or any ionizing radiation is permitted to enter the vessel A, while a small voltage is applied to the plates by the battery B. A number of ion-pairs will be produced, and the applied potential will cause the positive ions to travel toward one electrode and negative electron towards the other electrode.

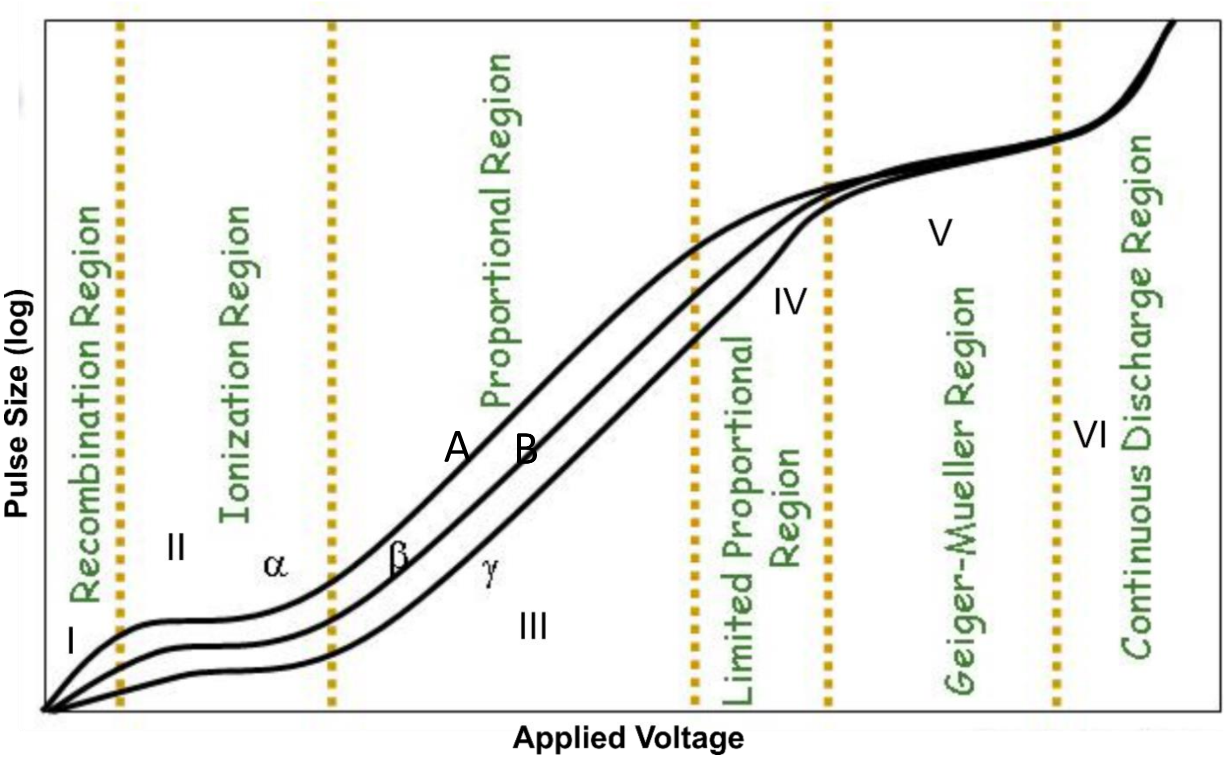
As a result, a charge will collect on the electrodes, and ammeter indicate a pulse of electric current.

Behavior of ion-pairs in electric fields

The size of the current pulse will depend on two factors-

(i) the no. of ion-pairs produced bet^n the electrodes by radiation

(ii) The applied voltage by battery



Curve 'A' refers to a case In which radiation produces 10 (log10 = 1) primary ion-pai

Curve 'B' refers to a case In which radiation produces 1000 primary ion-pairs

Fig. Variation of signal with applied voltage for particles of different energies (α>β).

Behavior of ion-pairs in electric fields

In region I, when the voltage is small, the size of the electrical pulse produced by a single α or β particle increases with the applied voltage.
When the applied voltage is small, the charged particles constituting the ion-pairs move slowly towards the respective electrodes. As a result, there is a ample time for many to recombine, i.e., positive ions and negative electrons meet and neutralize each other. The size of the current pulse registered will consequently be less than if all ion-pairs originally formed succeeded in reaching the electrodes.

In region II, when voltage is increased, electric pulse attains a constant value. Gradually, less number of ions recombine and at a certain period of time almost all ions are collected at the electrode. Recombination is diminished here and pulse size is increased. Ultimately a point is reached, at the beginning of region II, when the charged particles move to the electrodes so rapidly that virtually all ion-pairs produced by alpha or beta reaches the electrodes. Since further increase in the applied voltage cannot cause any increase in the number of ion pairs, the pulse size remains unchanged throughout region II. In region II pulse size is independent of the voltage. This is the range relevant to the ionization chamber. Here all the ions are collected, hence voltage saturates. The voltage needed for saturation is higher for α than for β. Here, the pulse size is also small and large amplification is needed for measuring the same.

Behavior of ion-pairs in electric fields

In region III, the pulse size commences to increase to again with increasing voltage , and this behavior continues through regions IV, V, and VI. Because with the increment of applied voltage kinetic energy of ion-pairs also increases. Electrons are very light in mass, its kinetic energy is very high making collisions with other charge neutral molecules and creates extra ion-pairs. In this region, pulse size is strictly proportional to the number of primary ions produced between the electrodes. For this reason, the region III is called the **proportional region.**

In region V, the curves A and B coincide, so that the pulse size , for a given voltage is same regardless of the number of ion-pairs initially produced between the electrodes. **Geiger-Muller counter** is introduced depending on this region.

GAS-FILLED DETECTORS

Nuclear detector are kinds of instrument that can detect nuclear particle, e.g., alpaha, beta , gama ; And can also determine their energy, momentum, direction etc.

- One of the oldest and most widely used radiation detectors
- Gas-filled detectors sense the direct ionization created by the passage of charged particles caused by the interaction of the radiation with the chamber gas
    - Ion Chambers
    - Proportional Counters
    - Geiger-Mueller Counters

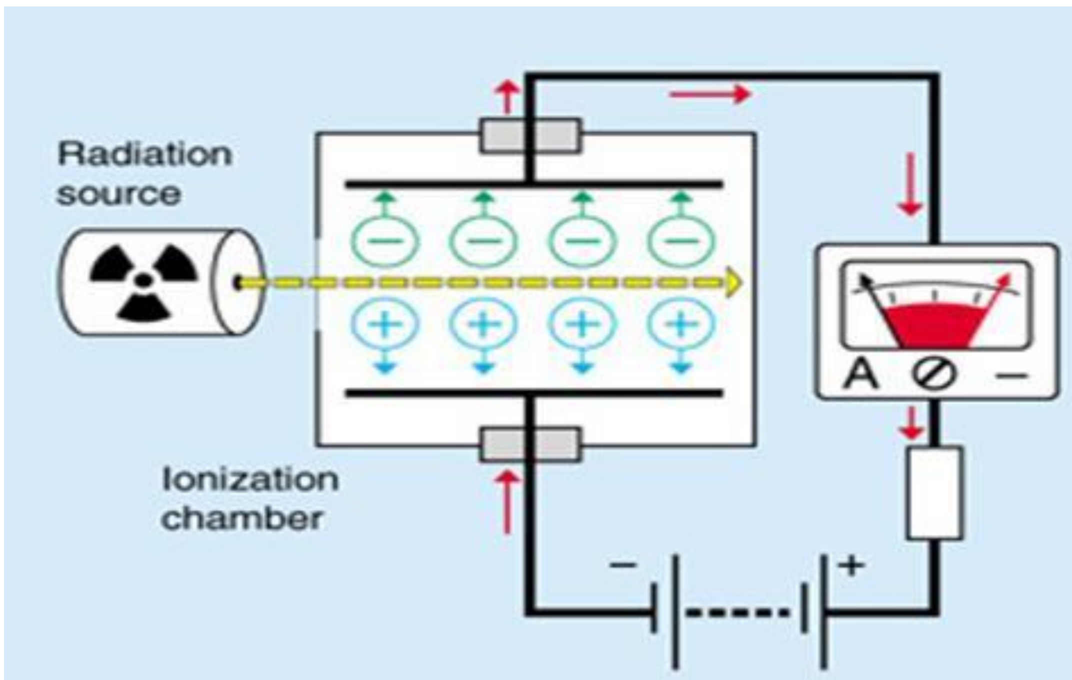
The ionization chamber is the simplest of all gas-filled radiation detectors, and is widely used for the detection and measurement of certain types of ionizing radiation; X-rays, gamma rays and beta particles. Conventionally, the term "ionization chamber" is used exclusively to describe those detectors which collect all the charges created by direct ionization within the gas through the application of an electric field.

Ionization Chamber is an ionization detector which main function is to measure the ion pairs created when ionization mediation through the gas. The ion pairs are attached either in the positive or negative electrodes which are then connected the battery therefore reading measurement of ionizing radiation. Applied potential is (100-400) V.

For the detection and measurement of nuclear radiation two types of instruments are introduced depending on the purpose;

i) Chambers- main objective to observe individual ray

ii) Counters- to count the number of ionizing particles



35 eV is required to form an ion pair. How much current will be produced by an alpha particle of 3.5 MeV, 10^7 particles entering an ionization chamber?

Energy of alpha particle = 3.5 MeV = $3.5*10^6$ eV

Energy required for the production of one ion pair is = 35 eV
Hence the ion-pair produced by alpha particle = 10^5

1 alpha particle produce= 10^5 ion pair
10^7 alpha ……………………= 10^7*10^5 ‘’

Total no. of ion-pairs produced by a single ion-pair is called the gas amplification factor.

A **Geiger counter** is an instrument used for detecting and measuring ionizing radiation. Also known as a **Geiger–Müller counter.** It is widely used in applications such as radiation dosimetry, radiological protection, experimental physics, and the nuclear industry.

It detects ionizing radiation such as alpha particles, beta particles, and gamma rays using the ionization effect produced in a Geiger–Müller tube, which gives its name to the instrument.[1] In wide and prominent use as a hand-held radiation survey instrument, it is perhaps one of the world's best-known radiation detection instruments.

History: The original detection principle was discovered in 1908 in Manchester University. The development of the Geiger–Müller tube in 1928 that the Geiger–Müller counter became a practical instrument. It has been popular due to its robust sensing element and relatively low cost.

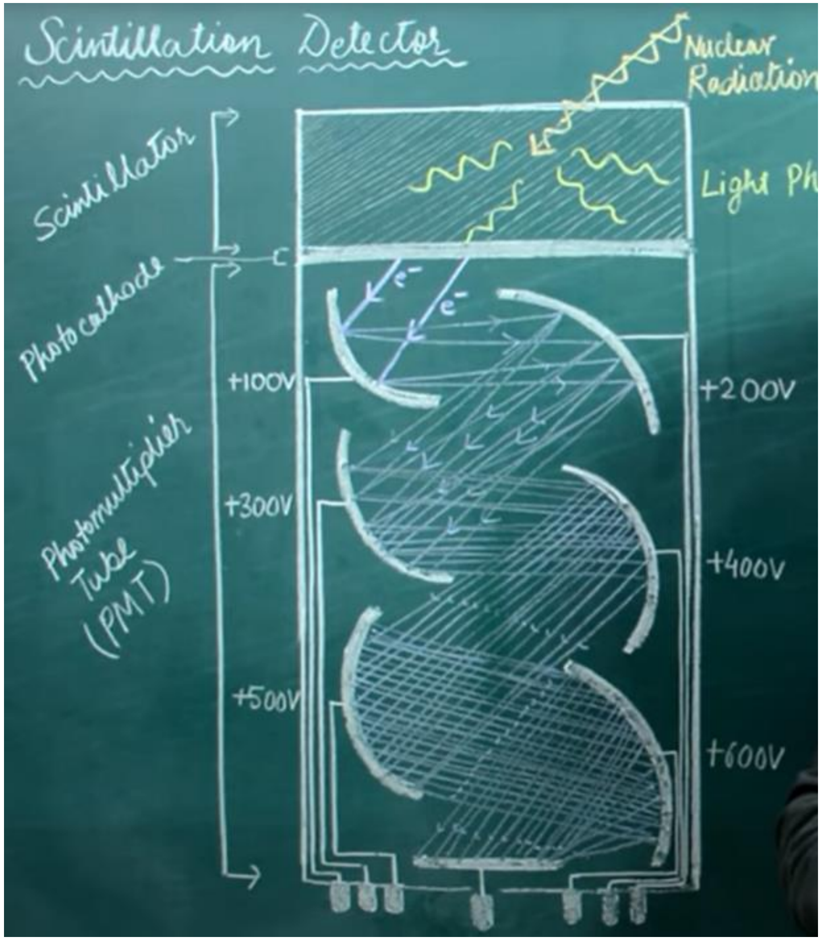
History: The original detection principle was discovered in 1908 in Manchester University. The development of the Geiger–Müller tube in 1928 that the Geiger–Müller counter became a practical instrument. It has been popular due to its robust sensing element and relatively low cost.

Operating Principle: Geiger Muller Counters, or GM Counters, are very common and easily available nuclear particle detectors. It works on the principle that in the presence of a strong potential difference, a nuclear particle which causes ionization in gaseous molecules can lead to an avalanche of secondary ionizations that results in a sudden discharge, and therefore detection of the particle. Such an avalanche is known as Townsend Avalanche.

- A Geiger Muller Counters, or GM Counter consists of a Geiger Muller tube, a sensing elements which detects the radiation and the processing electronics.
- Geiger-Muller tube is filled with an inert gas such as helium, neon or argon at low pressure to which a high voltage is applied.
- The value of applied voltage is 800-1500 volts.
- Tube briefly conducts electrical charge when a particle of incident radiation makes the gas conductive by ionization.
- The ionization is considerably amplified within the tube by a Townsend avalanche effect to produce an easily measured detection pulse.
- The value of applied voltage is 800-1500 volts.
- Dead Time (200-400 us) is time period the detector kind of dead. Within this time the counter is incapable of detecting any further nuclear particle.
- Quenching

Scintillation Detector

Scintillation counter is an instrument for detecting and measuring ionizing radiation by using the excitation effect of incident radiation on a scintillator material, and detecting the resultant light pulses.



Structure of Scintillation counter:

It consists of

- a scintillator is material medium in which when a charged particle enters it absorbs that energy and leads to generate photons in response to incident radiation.
- a sensitive photomultiplier tube (PMT) which converts the light to an electrical signal and electronics to process this signal.
- Sciontillator consists of a transparent crystal, e.g., NaI, CsI, ZnI usually a phosphor, plastic or organic liquid.

Working principle:

- When an external nuclear radiation, let suppose an alpha particle enter into scintillator, then the external nuclear particle that basically collide with the material and material medium absorb the energy of the incident radiation and converts it into low energetic photon. Now all of the photons are focused to the photocathode (A photocathode is simply a material that can experience photoelectric effect).
- The photon from the scintillation strikes a photocathode and emits an electron which accelerated by a pulse and produce a voltage across the external resistance.
- Now the photoelectron enters the photomultiplier tube (PMT). Its purpose to increase initial photoelectron to a very high value of photoelectron. Inside the PMT photoelectron are directed towards the 1st dynode which causes secondary photoelectrons. The photoelectrons are then accelerated by potential difference between the two dynodes. This process ends up with successive multiplication of photoelectrons.
- This voltage is amplified and recorded by an electronic counter.

Application Important: There are variants of scintillation counters mounted on pick-up trucks and helicopters for rapid response in case of a security situation due to dirty bombs or radioactive waste. ▯ Scintillation counters are used to measure radiation in a variety of applications including hand held radiation survey meters, personnel and environmental monitoring for radioactive contamination, medical imaging, radiometric assay, nuclear security and nuclear plant safety. ▯ scintillation counters designed for freight terminals, border security, ports, weigh bridge applications, scrap metal yards and contamination monitoring of nuclear waste.