Problem 2

Detection of Alpha Particles

We are constantly being exposed to radiation, either natural or artificial. With tha advance of nuclear power reactors and utilization of radioisotopes in agriculture, industry, biology and medicine, the number of man made prepared (artificial) radioactive sources is also increasing every year. One type of the radiation emitted by radioactive materials is alpha (α) particles (doubly ionized helium atom having two units of positive charge and four units of nuclear mass).

The detection of α particles by electrical means is based on their ability to produce ionization when passing through gas and other substance. For α particle in air at normal (atmospheric) pressure, there is an empirical relation between the mean range R_α and its energy E

$$R_\alpha = 0.318\ E^{3/2} \qquad (1)$$

Where R_α is measured in cm and E in MeV.

For monitoring α radiation, one can use an ionization chamber, which is a gas-filled detector that operates on the principle of separation of positive and negative charges created during the ionization of gas atoms by the α particle. The collection of charges yields a pulse that can be detected, amplified and then recorded. The voltage difference between anode and cathode is kept sufficiently high so that there is a negligible amount of recombination of charges during their passage to the anodes.

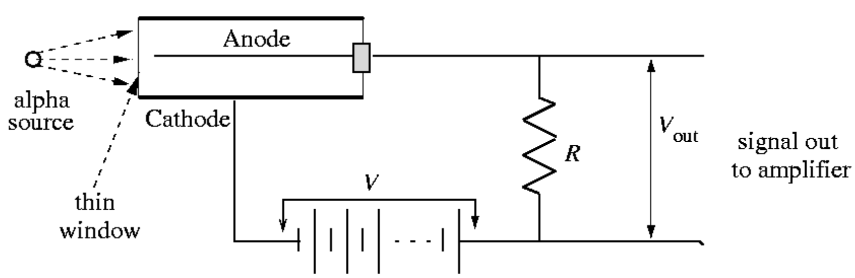

Figure 1 : Schematic diagram of ionization chamber circuit.

a. An ionization chamber electrometer system with a capacitance of 45 picofarad is used to detect α particles having a range R_{α} of 5.50 cm. Assume the energy required to produce an ion-pair (consisting of a light negative electron and a heavier positive ion, each carrying one electronic charges of magnitude e = 1.60 x 10^{-19} Coulomb) in air is 35 eV. What will be the magnitude of the voltage produced by each α particle?

b. The voltage pulses due to the α particle of the above problem occur across a resistance R. The smallest detectable saturation current (a condition where the current is more or less constant, indicating that the charge is collected at the same rate at which it is being produced by the incident α particle) with this instrument is 10^{-12} ampere. Calculate the lowest activity A (disintegration rate of the emitter radioisotope) of the α source that could be detected by this instrument if the range R_{α} is 5.50 cm assuming a 10 % efficiency for the detector geometry.

c. The above ionization chamber is to be used for pulse counting with a time constant $\tau = 10^{-3}$ seconds. Calculate the resistance and also the necessary voltage pulse amplification required to produce 0.25 V signal.

d. Ionization chamber has geometry such as cylindrical counter, the central metal wire (anode) and outer thin metal sheath (cathode) have diameter d and D, respectively. Derive the expression for the electric field $E(\tau)$ and potential $V(\tau)$ at a radial distance $\tau \left(with \frac{d}{2} \leq \tau \leq \frac{D}{2} \right)$ from the central axis when the wire carries a charge per unit length λ. Then deduce the capacitance per unit length of the tube. The breakdown field strength of air E_b is 3 MV m^{-1} (breakdown field strengths greater than E_b , maximum electric field in the substance). If d=1 mm and D = 1 cm , calculate the potential difference between wire and sheat at which breakdown occurs.

Data : 1 MeV = 10^6 eV ; 1 picoFarad = 10^{-12} F ; 1 Ci = 3.7 x 10^{10} disintegration/second = 10^6 μ Ci (Curie, the fundamental SI unit of activity A); $\int \frac{dr}{r} = \ln \tau + C$