Nuclear Physics   Course Code: Phy 6101
Nuclear Radiation Detectors

Nuclear radiation detectors play important role in nuclear physics experiment. Most radiation detectors are based on the production of excited atoms/molecules by a charged particle traversing the medium or by ionizing radiation like gamma ray. A strong electric field exists in the region where a moving charged particle eject orbital electrons from the atoms/molecules of the gas and make them positive ions.

"The number of ion pairs formed per cm of the path of the charged particle is called specific ionization"

The principle of detection of nuclear radiation may be classified as:

(1)Method based on the detection of free charge carriers by the ionization, i.e., ionization chamber, proportional counter, Geiger-Muller counter and semiconductor detectors.
(2)Method based visualization of the tracks of radiation, i.e., Wilson Cloud Chamber, Bubble Chamber, nuclear emulsion plates, spark chamber etc.
(3)Method based on light sensing, i.e., scintillation counter, cerenkov counter etc.

Types of Radiation Detectors
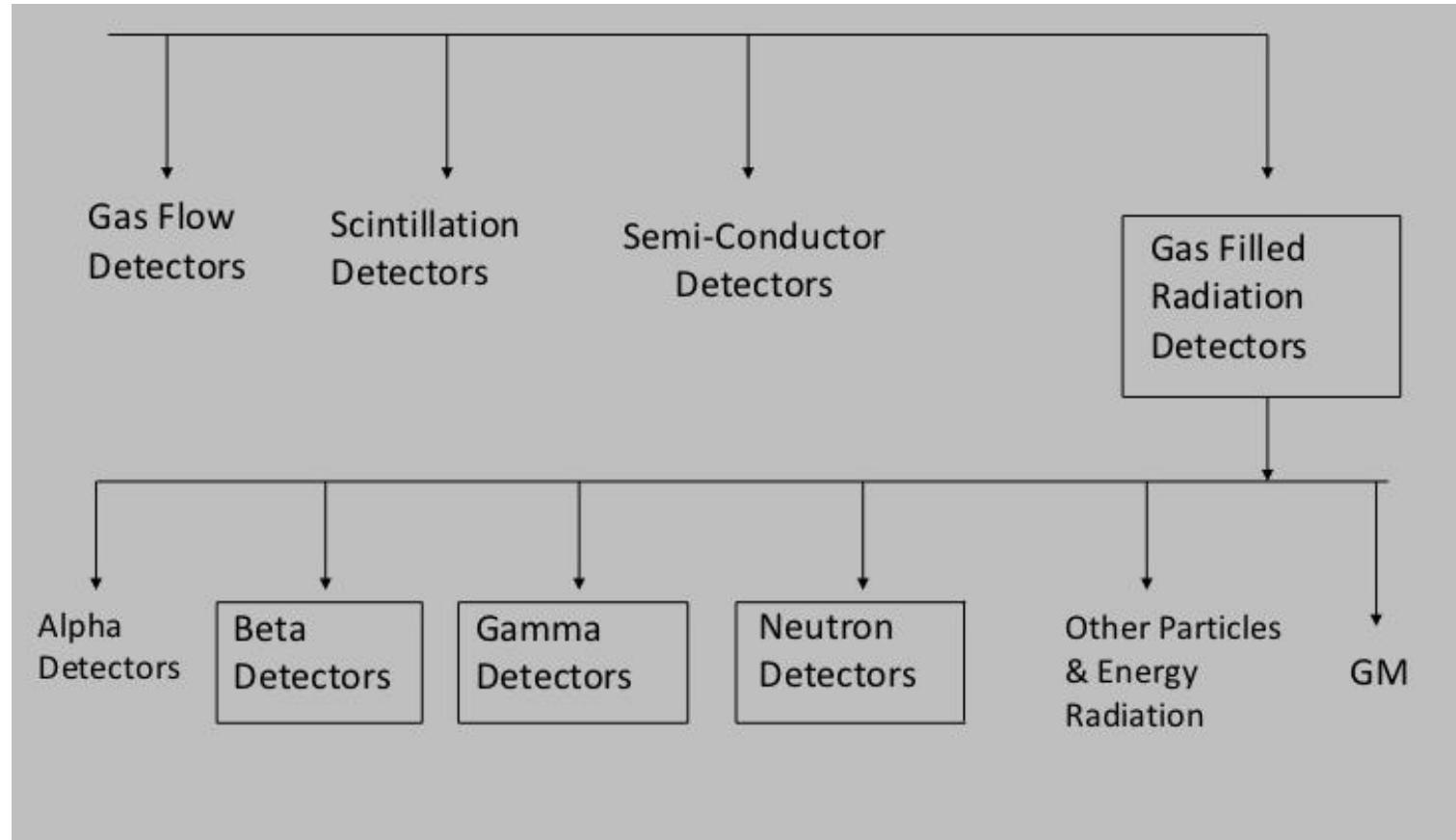
G M Counter

A Geiger counter consists of a Geiger-Müller tube, the sensing element which detects the radiation, and the processing electronics, which displays the result. The Geiger-Müller tube is filled with an inert gas such as helium, neon, or argon at low pressure, to which a high voltage is applied.

The Geiger counter is an instrument used for measuring ionizing radiation used widely 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.

G M Tube

The Geiger-Müller tube is filled with an inert gas such as helium, neon, or argon at low pressure, to which a high voltage is applied. The tube briefly conducts electrical charge when a particle or photon of incident radiation makes the gas conductive by ionization. The ionization is considerably amplified within the tube and fed to the processing and display electronics. This large pulse from the tube makes the G-M counter relatively cheap to manufacture, as the subsequent electronics is greatly simplified. The electronics also generates the high voltage, typically 400–600 volts, that has to be applied to the Geiger-Müller tube to enable its operation.
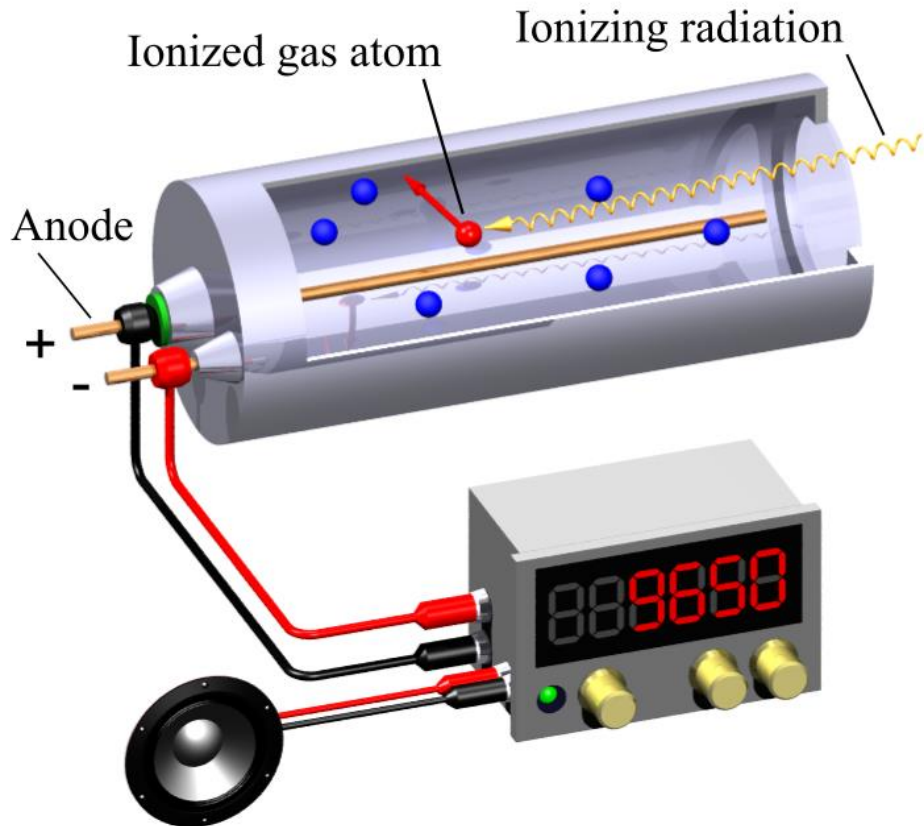
G M Tube
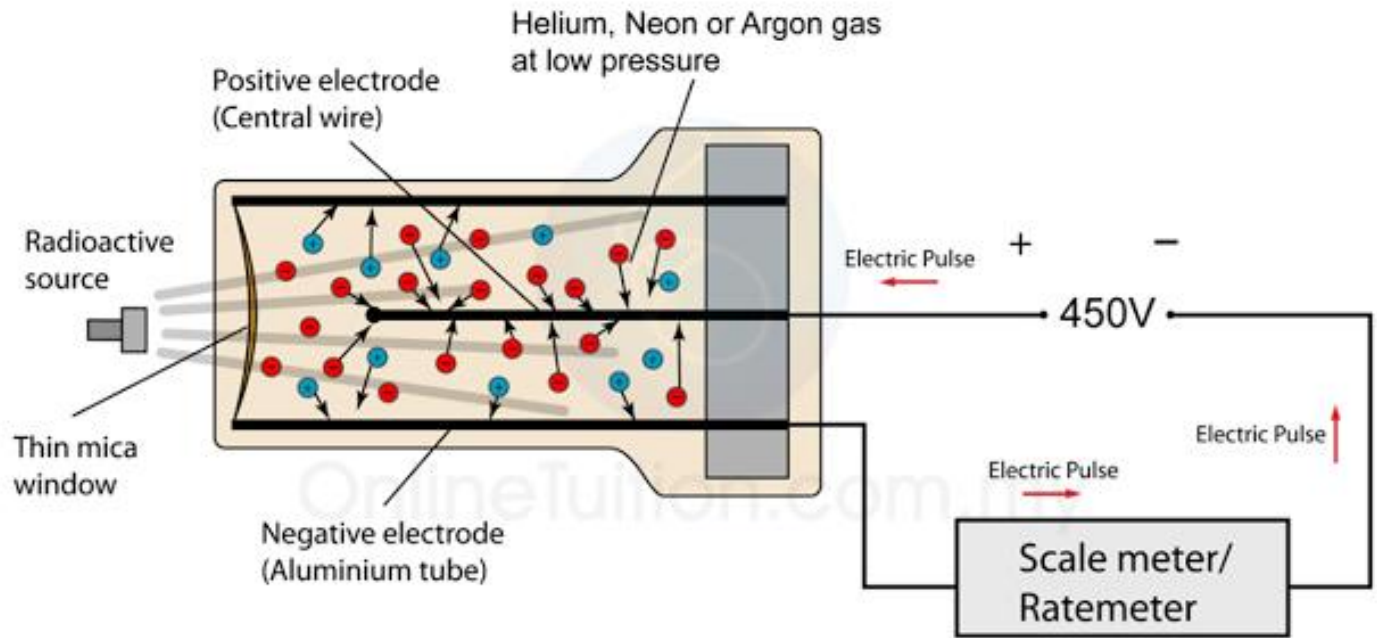
❑The tube contains argon gas at low pressure.

❑The end of the tube is sealed by a mica 'window' thin enough to allow alpha particles to pass into the tube as well as beta and gamma radiation.

❑When a charged particle or gamma-radiation enters the tube, the argon gas becomes ionized. This triggers a whole avalanche of ions between the electrodes.

❑For a brief moment, the gas conducts and a pulse of current flows in the circuit.

❑The circuit includes either a scaler or a ratemeter. A scaler counts the pulses and shows the total on a display.

❑A ratemeter indicates the number of pulses or counts per second. The complete apparatus is often called a Geiger counter.

AVALANCHE

An electron, positive ion, or gamma radiation that penetrates the tube through a *mica* window, will ionize a number of the atoms in the gas, and because of the high positive voltage of the central wire, the electrons will be attracted to it while the positive ions will be attracted to the wall. The high voltage accelerates the positive and negative charges, and hence they gain more energy and collide with more atoms to release more electrons and positive ions; the process escalates into an "*avalanche" which produces an easily detectable pulse of current.*
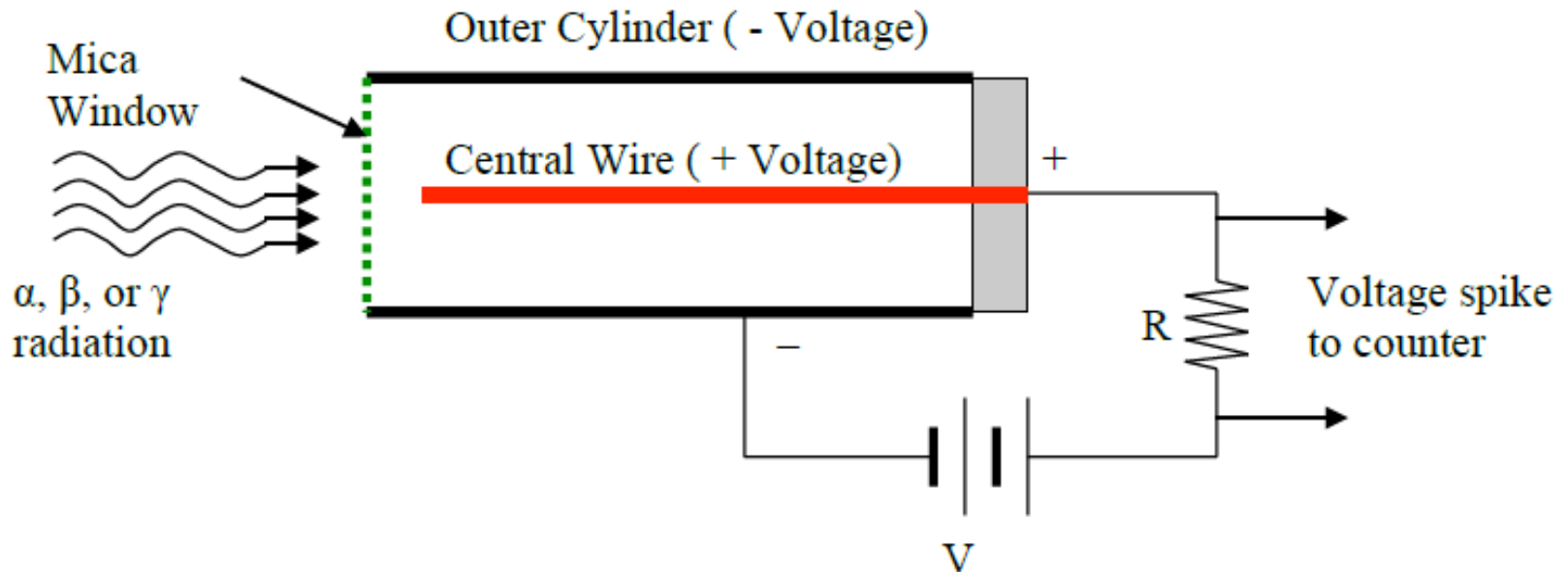
AVALANCHE (cont.)

With the presence a suitable filling gas, the current quickly drops to zero so that a single voltage spike occurs across a resistor; an electronic counter then registers this voltage spike.

A typical composition of the gas filling a Geiger counter tube was usually a mixture of argon and ethanol; more recently, tubes filled with ethyl formate in place of the alcohol are reported to have a longer life and smaller temperature coefficients than counters filled with ethanol.

SELF-SUPPRESSING MECHANISM

A very important property of the Geiger counter is its self-suppressing mechanism. The counter is triggered by the pulse from the tube and feeds back a square pulse of 300-500 µsec duration to the central wire. This pulse has an opposite polarity and high enough amplitude to extinguish the discharge. This allows for the counter to reset as fast as possible in order to register the next voltage spike induced by the penetrating radiation.

The Geiger detector is usually called a "counter" because every particle passing through it produces an identical pulse, allowing particles to be counted; however, the detector cannot tell anything about the type of radiation or its energy/frequency - it can only tell that the radiation particles have sufficient energy to penetrate the counter.

To improve its sensitivity to alpha and beta particles, the ST150 detector has a very thin mica window with a superficial density of only 1.5 – 2 mg/cm2. *This window is therefore extremely fragile and if broken cannot be repaired. Never allow any object to touch the window!*

THE GEIGER TUBE VOLTAGE CHARACTERISTIC CURVE

The most important information about a particular counter tube is its voltage characteristic curve. The counting rate due to a constant intensity radioactive source is graphed as a function of the voltage across the counter; A curve of the form shown in Figure is obtained.
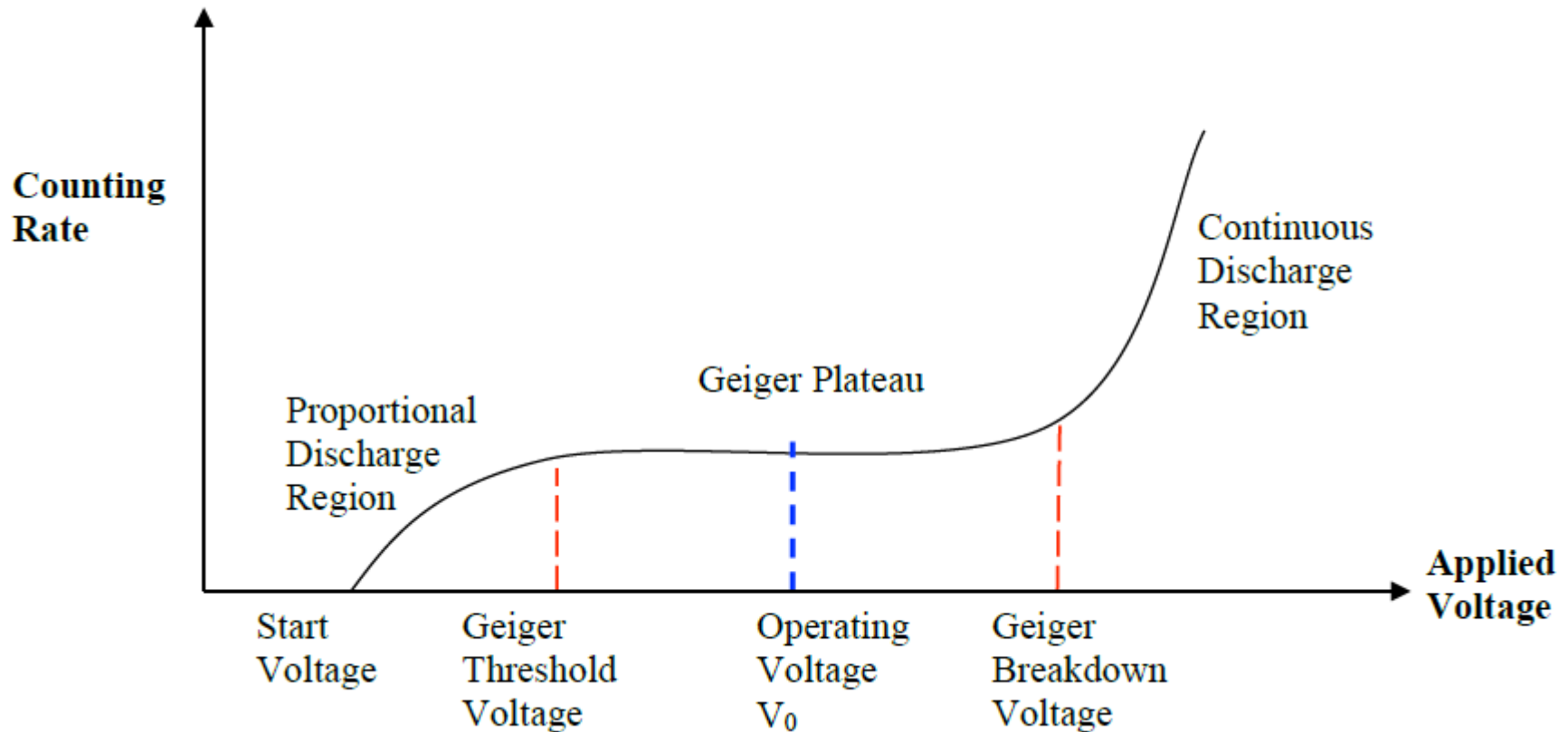
THE GEIGER TUBE VOLTAGE CHARACTERISTIC CURVE

The counter starts counting at a point corresponding approximately to the Geiger threshold voltage; from there follows a "plateau" with little change in the counting rate as the voltage increases. Finally a point is reached where the self-suppressing mechanism no longer works, and the counting rate rapidly increases until the counter breaks down into a continuous discharge. *In order to ensure stable operation, the counter is operated at a voltage corresponding approximately to the mid-point of the plateau.*

Hence, a flat plateau is regarded as a desirable characteristic in a counter; a long plateau is also desirable, but is not as important. In practice most counters have a slightly sloping plateau, partly because of geometrical limitations of the counter design, and partly because of spurious counts due to an unsatisfactory gas filling or to undesirable properties of the cathode surface.

The correct operating voltage for any particular Geiger-Mueller tube is determined experimentally using a small radioactive source such as Cs-137 or Co-60. A properly functioning tube will exhibit a "plateau" effect, where the counting rate remains nearly constant over a long range of applied voltage; the operating voltage is then calculated roughly as the voltage value corresponding to the middle of the plateau region.

DEAD TIME, RECOVERY TIME AND RESOLVING TIME

Geiger-Mueller tubes exhibit *Dead Time effects due to the recombination time of the internal* gas ions after the occurrence of an ionizing event. The actual dead time depends on several factors including the active volume and shape of the detector and can range from a few microseconds for miniature tubes, to over 1000 microseconds for large volume devices. The counter discharge occurs very close to the wire, and the negative particles, usually electrons, are collected very rapidly.

The positive ions move relatively slowly, so that as the discharge proceeds a positively charged sheath forms around the wire. This has the effect of reducing the field around the wire to a value below that corresponding to the threshold voltage, and the discharge ceases. The positive ion sheath then moves outwards until the critical radius *r is reached, when the field at the wire is restored to the threshold value. This marks the end of* the true "dead time". If another ionizing event triggers the counter at this stage, a pulse smaller than normal is obtained, as the full voltage across the counter is not operative. However, if the positive ions reach the cathode before the next particle arrives, the pulse will be of full size.

DEAD TIME, RECOVERY TIME AND RESOLVING TIME
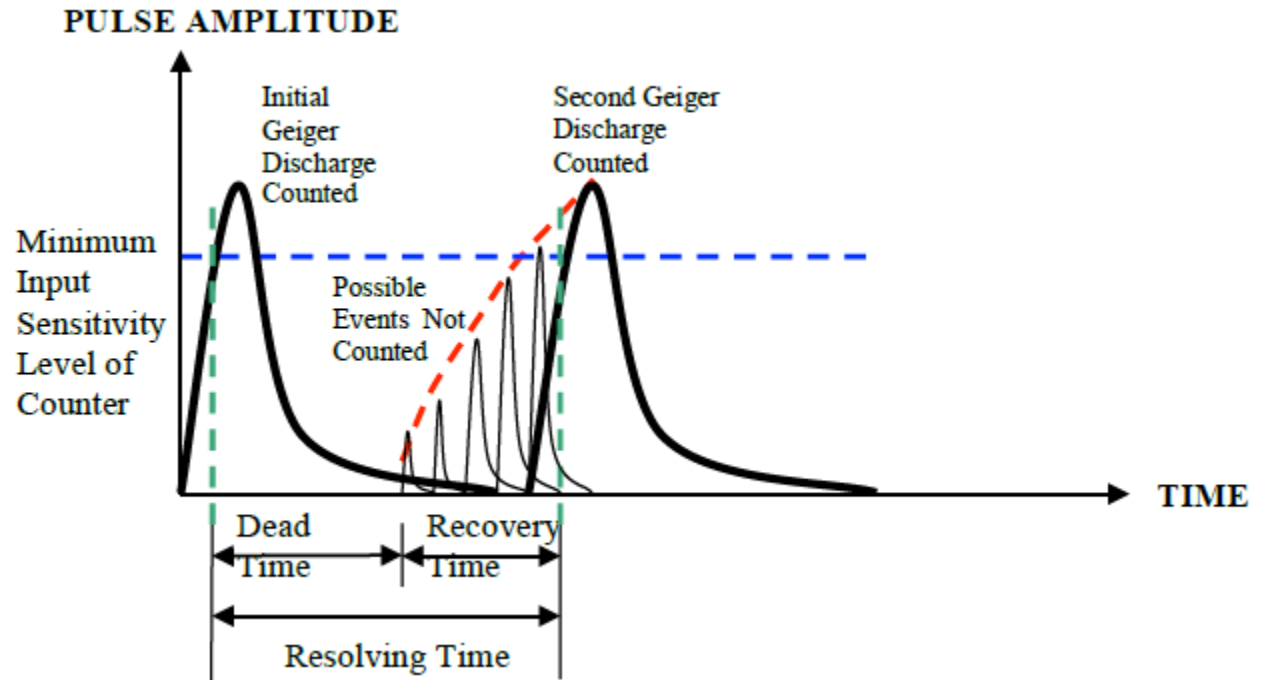
This effect can be demonstrated with a triggered oscilloscope; as shown in Figure 3, the period during which only partially developed pulses are formed is termed the *Recovery Time. The* effective *Resolving Time or insensitive time following a recorded pulse, is determined by both* the dead time and the recovery time, and will depend not only on a number of parameters associated with the counter dimensions and gas filling, but in principle, also on the operating voltage of the counter, on the sensitivity of the electronic recording equipment and on the counting rate. *It is necessary to apply appropriate corrections to the observed counting rates to compensate for this resolving time.*

TRUE VERSUS MEASURED COUNT RATE

When making absolute measurements it is important to compensate for dead time losses at higher counting rates. If the *resolving time t of the detector is known, the true counting rate N may be calculated from the measured counting rate n using the following expression:*

$$N = \frac{n}{(1-nt)}$$

If the detector resolving time is unknown, it may be determined experimentally using two radioactive sources simultaneously. Maintaining constant counting geometry is important throughout the experiment; hence a special container carrying both sources would be ideal for performing the measurement – however, good results may be obtained by careful positioning the two standard sources side by side. With the operating voltage set for the GM tube, denoting the measured count rate for the two sources (n_1+n_2) *side by side as n_s, the measured count* rate for source *a alone as n_1 and the measured count rate for the source b alone as n_2, the* resolving time is given by:

$$t = \frac{n_1 + n_2 - n_s}{2n_1 n_2}$$

Therefore, only the resolving time of the GM tube affects the true count rate.

The Resolving Time of a G.M. Counter

For a tube having a resolving time *t*, it means that for each single count registered. The tube is inoperative for *t* sec. Thus if we have *n* record sounds registered per sec., the lost time in one sec is *nt* and the effective operating time is (1-*nt*). Following from this, if we assume that the corrected count rate is *N* counts per sec. Then

$$N = \frac{n}{(1 - nt)} \qquad (1)$$

The resolving time can be found readily using the "two-source" method. This is carried out experimentally by counting the two sources one at a time and then both together. If n_1, n_2, n_s are the counts registered per minute for the first source, the second source and the combination of the two sources respectively, we can write:

$$N_1 = \frac{n_1}{(1 - n_1 t)} \qquad (2)$$

$$N_2 = \frac{n_2}{(1 - n_2 t)} \qquad (3)$$

$$N_s = \frac{n_s}{(1 - n_s t)} \qquad (4)$$

Since $\quad N_s = N_1 + N_2$

$$N_s = \frac{n_1}{\left(1 - n_1 t\right)} + \frac{n_2}{\left(1 - n_2 t\right)} \qquad (5)$$

From (4) we have
$$n_s = \frac{N_s}{\left(1 + N_s t\right)} \qquad (6)$$

Substituting (5) into (6), we obtain after manipulating:

$$n_s = \frac{n_1 + n_2 - 2 n_1 n_2 t}{\left(1 - n_1 n_2 t^2\right)} \qquad (7)$$

Normally $n_1 n_2 t2 << 1$, we can approximate eq (7) to

$$n_s = n_1 + n_2 - 2 n_1 n_2 t \qquad (8)$$

which yields
$$t = \frac{n_1 + n_2 - n_s}{2 n_1 n_2} \qquad (9)$$

LIMITATIONS

There are two main limitations of the Geiger counter. Because the output pulse from a Geiger-Müller tube is always the same magnitude regardless of the energy of the incident radiation, the tube cannot differentiate between radiation types. A further limitation is the inability to measure high radiation rates due to the "dead time" of the tube. This is an insensitive period after each ionization of the gas during which any further incident radiation will not result in a count, and the indicated rate is therefore lower than actual. Typically the dead time will reduce indicated count rates above about 10^4 to 10^5 counts per second depending on the characteristic of the tube being used. Whilst some counters have circuitry which can compensate for this, for accurate measurements ion chamber instruments are preferred for high radiation rates.