Analytical Technologies in Biotechnology
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Module - 2
Radioisotopes Techniques
Lecture - 3
GM Counting and Scintillation Counting

In previous lecture, we have discussed about different types of radioactive decay. If you could recall, we have discussed about the decay by alpha particle emission, radioactive decay by negatron emission, radioactive decay by positron emission and decay by gamma rays emission. We have also discussed about their interaction with the matter, how all of these radiation or particles, sub-atomic particles interact with matter. And we have discussed about how they are expressed in terms of energy of radiation. Now in this lecture, we are going to discuss about detection and measurement of radioactivity.

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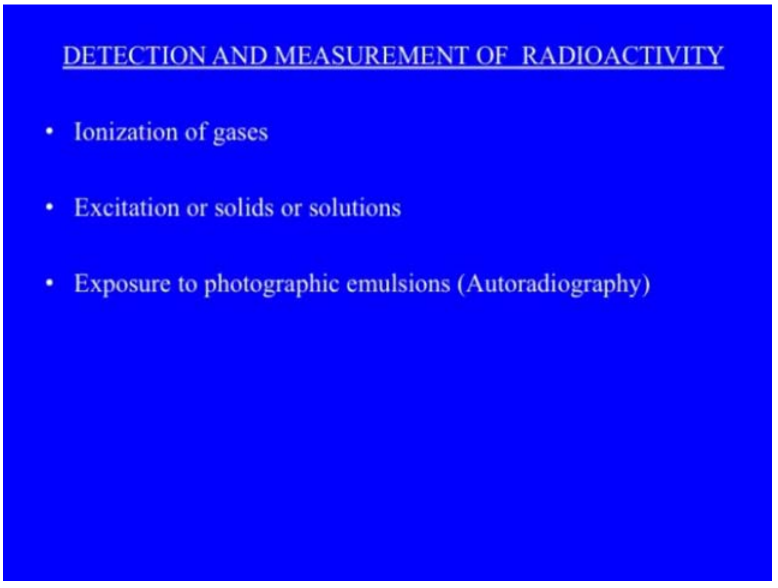

Now, the three commonly used method of detecting and quantifying radioactivity are based upon one ionization of gases, two excitation of solids or solutions, and three exposure to photographic emulsion or we call it autoradiography. Now, all of these methods, if we discuss ionization of gases, based upon ionization of gases the instruments which have been designed are GM counters. And they are specified for a ionization, they will be like measuring on the basis of ionization. The, in excitation this will be equipment which are based on the scintillation counting. And we are going to discuss, in coming lecture and then exposure to photographic emulsion, where the sample is put in the photographic emulsion and that is why it is called autoradiography.

Now, all of these detection methods for either detecting or quantifying radioactivity are, there are two kinds of counting one is absolute counting, where ideally all the disintegrations should be counted like for say, certain standard if you are counting. And then there is relative counting, where you are counting certain number of disintegrations, but they are proportional or they are, they will depend on the efficiency of counter. And they will be same, every time you count a for certain sample. Now, let us discuss all these three methods one by one in detail. We will start with ionization of gases.

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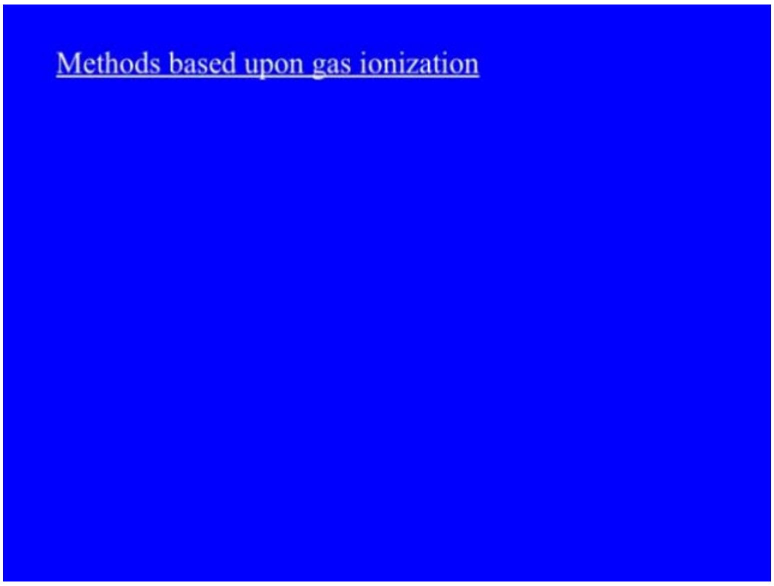

The methods based upon the gas ionization. We have to hear, what is going on or what is the basic principle is that, a particular gas enclosed in a chamber and that chamber contains electrodes. And if there is radioactive decay and these by, any of these emission then, these emissions could ionize the gas into positively charged atoms and electrons. And so if there is an applied potential then, a pulse will flow and that could be counted or that could be measured actually. So, what is here voltage or the applied voltage will play a very important role and we will be discussing about, the effect of voltage upon ionization. So, as I was discussing when a charged particle passes through a gas, it is electrostatic field will dislodge orbital electron from atoms and which are sufficiently close to its path.

And will cause ionization now, this particular ability to induce ionization will be decreasing in the order of alpha, which will be most ionizing then, beta which will be relatively less ionizing, than alpha and the gamma which will least ionizing. Remember, alpha particles are heavier helium nuclei actually and these have double positive charge plus mass of 4 an atomic number of 2. So, they interact most with the atom and they will be most ionizing ones, beta particles are lighter and quicker and so they will relatively ionize less than the alpha particles. Whereas, gamma radiation do not have any charge or mass and they will be the least ionizing.

Now in the, this particular method therefore, alpha and beta particles may be detected by gas ionization, but this method will be very poor or not suitable for detection of gamma radiation. So, here mostly alpha and beta particles could be utilized and in routine mostly beta particles are utilized like I said, earlier we have discussed that, alpha particles are not so much used in biological work. If ionization has to occur like I said, if particular charged particle is moving it can dislodge the electron and convert it into a positive charged atom. As this ionization occurs between a peer of electrodes, then which is enclosed in a suitable chamber then, a pulse flows.

And the magnitude of the pulse will be related to the applied potential and the number of radiation particles entering the chamber. So, this particular pulse flow will be totally dependent on the applied potential and how many radiation particles are entering that chamber, through a particular opening. Now, the efficiency of collection of ions depends on the voltage between the electrode. We will discuss that in a little while now, supposing at a very low voltage which initially, most on pairs which are created through ionization, will recombine rapidly before reaching the electrode.

So, what will happen so if they recombine before reaching the electrode, no pulse will flow and no current will be recorded. But as the voltage increases, a greater fraction of the ions are collected by electrodes before, they recombine and so a pulse could be recorded or could be measured. Now let us see, different regions or a curve which will show the effect of voltage upon ionization and we will see different regions in here.

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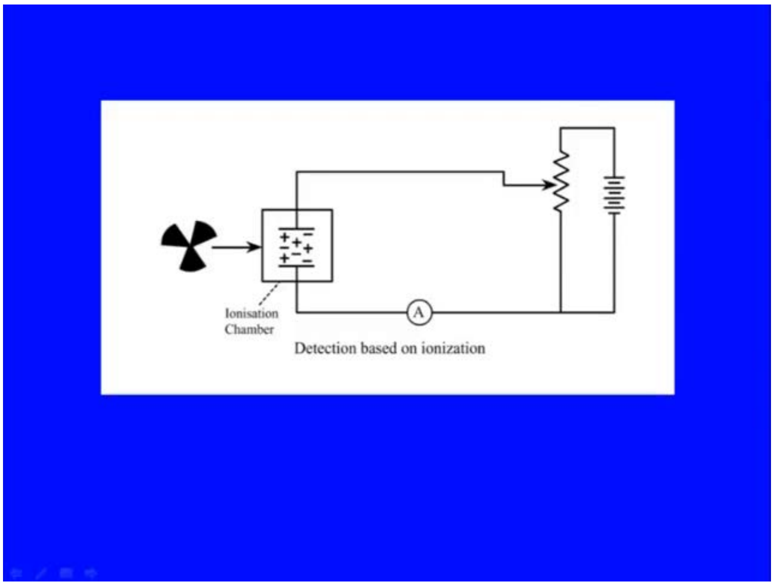

Now, before we go to the curve this is like very simple schematic here, which are, which is showing that there is a radioisotope here or a sample containing a radioisotope. And there is an enclosed chamber, the radiation enters from here, there are two electrodes and the radiation can create positive ions and electrons, that is positively charged particle and negatively charged electron. And if there is an applied potential then, they will both positive and charges will rush towards respective electrode and current will flow. So, that is a very simple schematic of a particular measuring device in the method based upon ionization.

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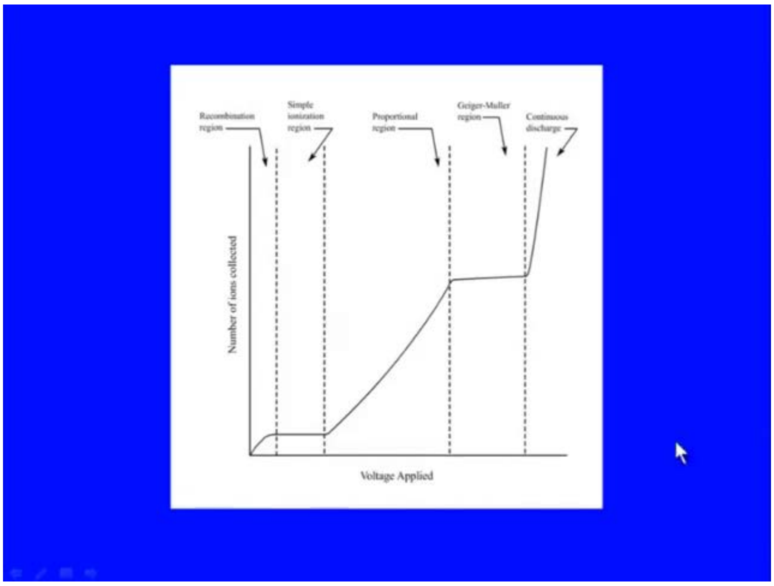

So, let us see what we were talking about is the effect of voltage upon ionization. Now here, if you can see this curve, this curve is first like shows a very starting point, where not much number, so y axis is number of ions collected and x axis is voltage applied. So, not many ions are being collected here and this region is called recombination region. Where most of them will recombine, the second region here is simple ionization region and the simple ionization region, if you could see it is kind of plateau here. Where number of ions collected, are almost are same or a constant as the voltage increases.

Now so not many ions or are being collected on here now, as the voltage increases then what you can see that number of ions collected are directly proportional to the voltage applied here. So, as the voltage is increasing number of ions are also increasing so here this is a proportional region actually, where there is a direct proportional relationship between the number of ions collected and voltage applied. Then, you get another region, another plateau which is called GM plateau or Geiger Muller plateau. Now, this is called GM region, where the voltage, as you increase the voltage there is no change in the number of ions collected.

So, number of ions collected in this region is independent of change in the voltage so here the, there is a constancy in number of ions collected. After this, if you increase voltage further then there is a region called continuous discharge, what it means is, even if you do not have any radiation or radioisotope then, also only the voltage can charter gas, which is present in the chamber. Now, these different regions are showed different effects, as the voltage increases. Let us discuss them in detail each of them here.

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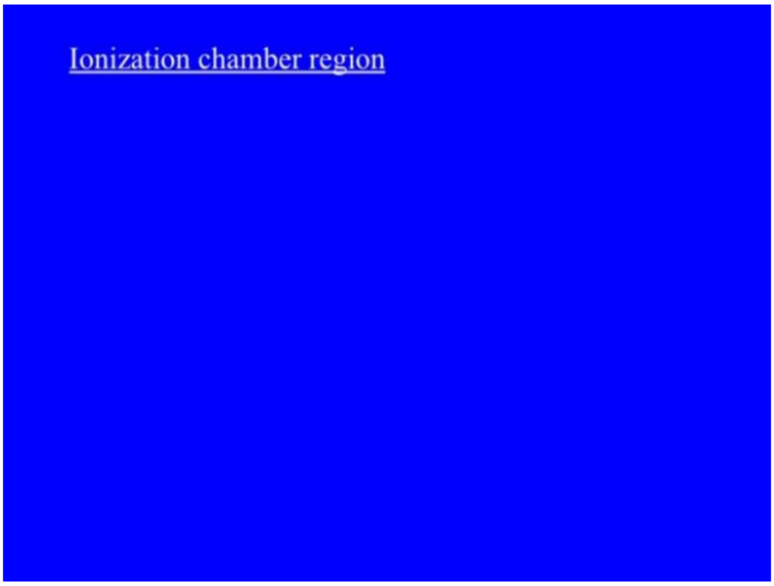

Now, let us start with ionization chamber region. You already discussed the recombination region, where the voltage is so low that moist of the ions here recombine and pulse flow is very, very low. Now, in ionization chamber region of the curve here, this particular region each radioactive particle produces only one ion pair for collation. So, what will happen, the currents which flow are very low and very sensitive measuring devices are necessary to measure the current pulse flow here. Now, this method is little used in quantitative work, but various types of electroscopes which operate on this principle are useful in demonstrating the properties of radioactivity.

So, it is not so much used in quantitative work, but it could be a good method or good like electroscopes could be utilized for demonstrating, the radioactivity or the properties of radioactivity. So, the recombination rate are almost 0 here and even with an increase in the applied voltage, you can, as you have seen in the curve the collected charge rate is kept constant. So, this is simple ionization chamber plateau, which is called so ionization chamber region is one where you really do not get lot of ions being collected at the electrodes. And there is a plateau region in this particular one, so it is not so much used.

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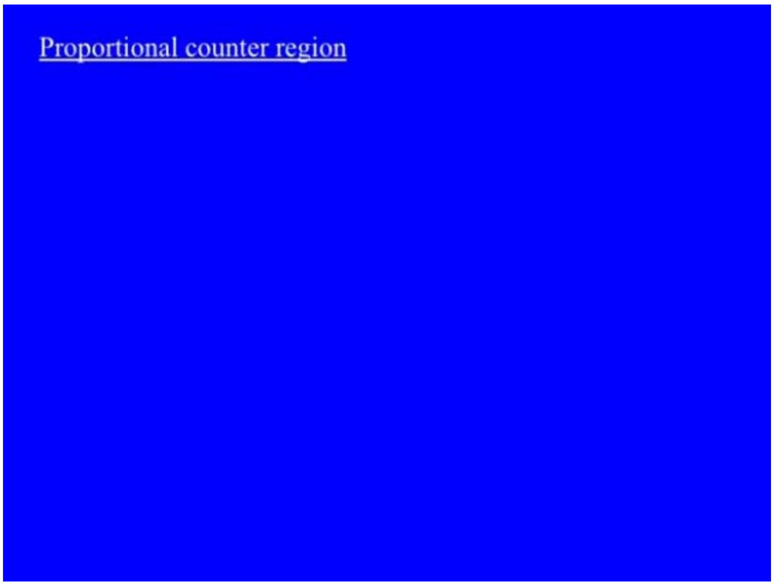

Now, as we increase the voltage further as you have seen, they were proportional counter region. Now as the applied voltage increases, the electron, the electric field strength, will be strong enough to not only remove the electron and positive ions of the primary ionization, but also to accelerate the primary ionization electrons and positive ions towards the respective electrodes. Now these accelerated electrons gained, are in a relatively higher kinetic energy and they will produce a secondary ionization of the gas, in the chamber. Now, which will result in the production of secondary ionization electrons, these secondary ionization electron will further ionize and this process goes on.

So, you can see that there is a cascade of ionization, there is primary ionization secondary and further ionization. Now, this is the principle of gas amplification and the multiplication process is known as a Townsend avalanche effect, on the name of the discoverer or it is called Townsend cascade. So, this leads to much larger flow of current and as you see, have seen as voltage increases, the current also increases proportionately or the number of ions collected also increases proportionately. So, there is you can say a very large gas amplification or ionization, occurs in this region. Now, the proportional counter region, the number of ion pairs collected like I said, directly proportional to the applied voltage until, a certain voltage is reached, when a plateau occurs, that we will discuss later on.

Now, before the plateau is reached, there is a region known as limited proportional region, which is not often used in detection and quantification. So, proportional counting has a particular advantage, that particles of different energies could be distinguished by the pulse height analyzer, as the size of the pulse received by the electrode, is proportional to the energy of original charged particle, entering the chamber.

So, this could be a technique to a method, to detect more than one isotope in the sample, because they have different energy spectrum, but problem is or the disadvantage is that, these counters require a very stable voltage supplied. Because as you have seen the small fluctuation in voltage, will result in significant change in the amplification or gas amplification.

Because, this is proportional counter region so if you have to measure two isotopes simultaneously, then one requirement would be that very stable voltage supply is needed for the measurement of two isotopes. So, proportional counters, are particularly useful for detection and quantification of alpha emitting isotopes. But as we say, as we have discussed these are relatively used ,very less in the biological work like, there are few isotopes emitting alpha particles, which are used in biological work. So, proportional counter region is very useful, but has certain limitations also.

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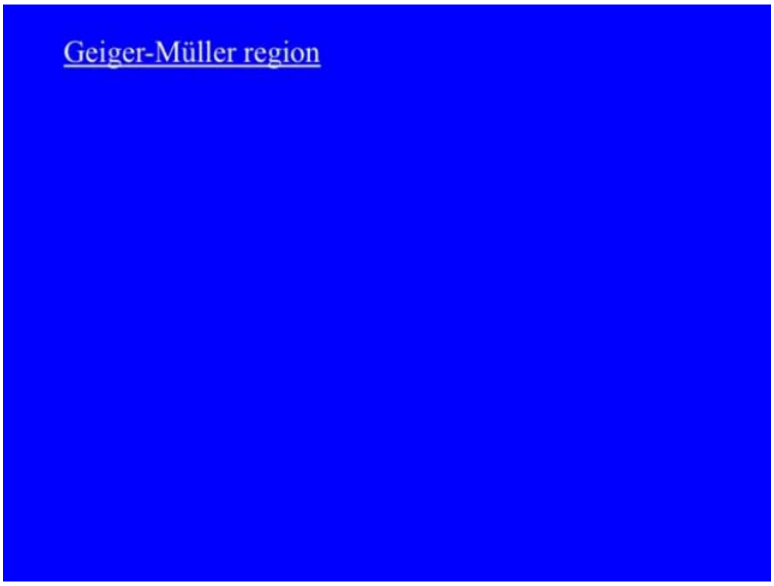

The next region as the voltage increases is GM region or Geiger Muller region. Now, in this region maximal gas amplification is achieved, as you have seen that this a GM plateau actually and voltage fluctuation will have little or no effect in a voltage range. And this is GM plateau, this is as we have seen in the curve so here what happens? All radiation particles including weak beta particles can induce complete ionization of the gas, in the chamber. And the size of the current is no longer dependent on, the number of primary ions produced here, so the number of times the pulse is produced, it is measured and not the size of the pulse, which is measured.

So therefore, it is not possible to discriminate between two isotopes used in GM counters. So, this is possible in proportional counting region, but not in GM counting region. And because you have, there is no change as such in the number of ions collected, as the voltage increases in this region. So, this is a count, this counters which is Geiger Muller counters work in the same manner as proportional counter, but only difference being that ion pairs form along the radiation track and produce an avalanche. But these will be ionization detectors, can be operated in either proportional or GM region, but g m counting is the main method employed.

And like I said, proportional counter regions require a very stable voltage supplied and many times scintillation counting has replaced that. And for normal routine purposes GM counters are used in many labs. Now, the last region which does not really require any discussion, is continuous discharge region, where voltage is so high that gas ionize, gases ionize by the applied voltage, even when low beta or other particles are present.

So, that is not really a useful region here so what we see in this particular effect of voltage upon ionization is, there are two regions which are, which could be used. One is proportional counter region, another is GM counter region and as I have said that, in routine GM region is most utilized and the counters based on this are called GM counters.

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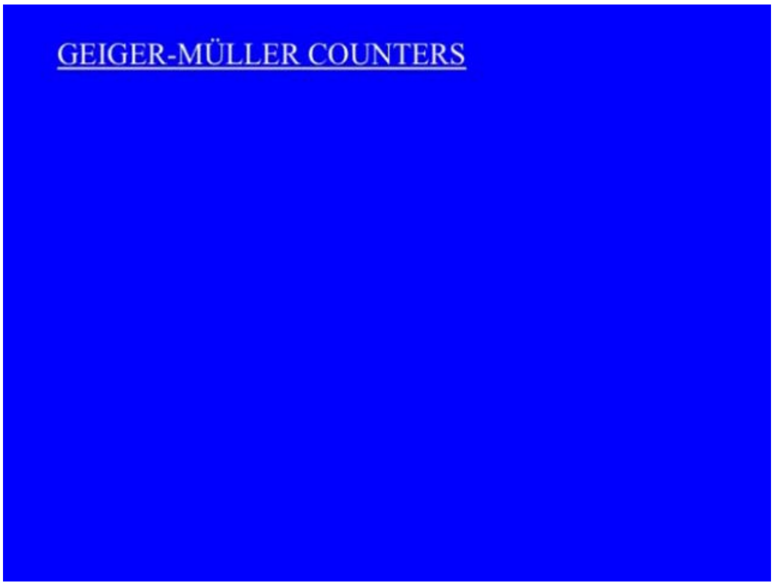

So, GM counters if we say, if we go little bit into history of these counters it was Hans Geiger, who developed a device in 1908, together with Ernest Rutherford. And this counter was only capable of detecting alpha particles then. But later on, 1928 Geiger Muller and this Hans Geiger and Walter Muller improved the counter so that, the other particles for ionizing radiations could also be detected.

Now, principle is very simple here that, in the Geiger Muller region all radiation particles, including beta particles, which are weak beta particles will induce complete ionization of the gas, in the chamber. The size of the current is no longer dependent on the number of primary ions, produced actually now, like I said voltage fluctuation have little or no effect And this results in a very reliable, sensitive, inexpensive and stable routine counting devices, known as GM counters. Now, all laboratories if you might have seen are the hand held counters, are present in all laboratories to monitor different things, which is like say as spill or certain gels or certain tubes, which contains these samples. So, simple detection of radioactivity could be done in here now, before we go on further, let us see on your screen.

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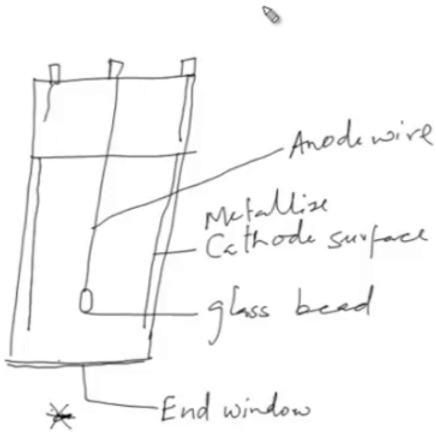

As we go on little bit about, how does GM counters looks like, we will see other figures also, but let us see on the screen and understand this. These are very simple counters like these are chambers, which contain an inert gas and so if you can see here, these are very simple chambers. Now so what we have is two electrodes now, here if you can see this is a simple chamber, this is the end window, so there could be different GM counters based on end window type or annular well type, where liquid samples are utilized or windowless counters. Now, this is like, if you say this is end window here and your sample will be placed somewhere here, which is your radioactive sample.

This is cathode, which is metalized cathode surface we can say. This surface is metalized so it could be called metalized cathode surface, this is central wire which is anode wire and there is a glass bead attached in here. Now, this inert gas in here, which is filled and as you go along, this particular one which is the radioactive sample, the radiation will enter through this end window. And will ionize the gas and the current or the pulse will be recorded.

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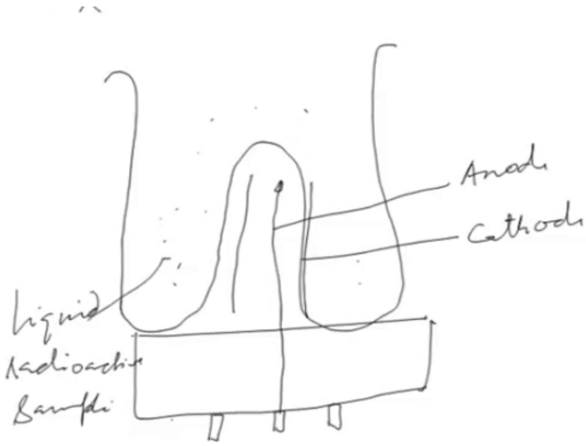

Now, this could be used for different kinds of samples, but there is one annular well type counter, which is utilized for the liquid samples, which could be utilized for liquid samples and it could look something this sort, which is, you have same similar sort of thing, but it is like you have a place for so there will be a cathode which is metalized cathode surface. Then, there will be anode here, which is anode wire in the center, the liquid sample will be filled in here.

So, this will be liquid radioactive sample and this is made up of glass actually, so many times these very big beta particles have to cross the glass chamber here, which might be a problem so in both of them weak beta particles cannot enter the chamber so many times windowless counters, where end window will not be placed, could be utilized. Before we go on, let us see another important part is that, in this GM counters there is a particular operating potential actually.

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Like if you could recall this curve here, this curve was a something looks like, this way where it was a proportional region and then GM counter, and then you would have a continuous discharge. Now, this region here which is the GM counter region or the GM plateau we can call it. Now, here you have a threshold potential, this will be somewhere in the center, it will be operating potential where mostly the GM counters will be operated. And as you go along, this will be the point where continuous discharge occurs, before that that will be the breakdown potential.

So, what one has to do is that, when you are operating, most GM counters will be operated somewhere in the operating potential region. And this, which is the threshold potential and breakdown potential are starting and ending point of the GM plateau. So, let us return to our discussion here so as we were discussing about the different kinds out counters. Let us discuss them in little detail.

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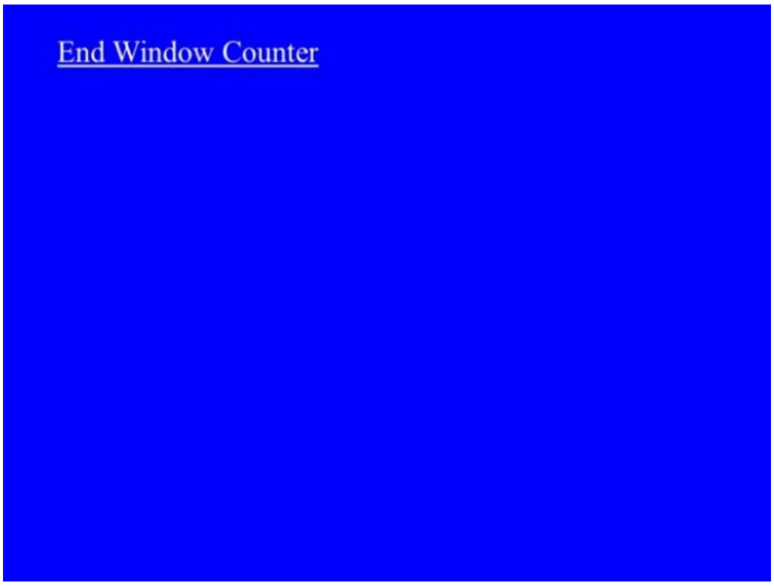

Now, first is end window counter now, as I have shown you this detector consist of a cylinder. Now this inner wall of this cylinder, is metalized and will serve as cathode there will be an axial wire anode, which is there and an end window. Now, this end window is typically made from glass or aluminum, but problem is this can only detect high energy meter radiations like 32p.

So, because 32p can penetrate the glass window and the weaker ones cannot enter so high energy beta particle, beta radiation can ionize the gas in that case. But to solve this problem, more delicate thin end window tubes made of mica or plastic nylon are used for the detection of the, of weak beta emitters like 14c. Now, if you have to take very weak beta emitters then, this end window things cannot be neutralized, so these emitters or alpha emitters are like 3h is the very weak emitters.

And the alpha emitter should be absorbed neutrally, by at the glass surface of my or the mica surface and they cannot be used. So therefore, they are incapable of detecting, these counters are incapable of detecting 3h, because the radiation cannot penetrate the end window. And are not very efficient detectors, of also alpha radiations so end window counters, they are not very efficient for very electrons for 3h and alpha radiations. But they are very good for say 32p or 14c radiations.

So, if you have very weak radiations, then you will need to have windowless counters. Now, this inability of end window counter to detect weak beta emitters, will present certainly a problem in bio-sciences. Because 3h is a very commonly used isotope so this problem is overcome by using a windowless counter, where a gas flow is used and this instruments are rather cumbersome.

And need to be carried around on an object, that will, that it looks like a trolley sort of. So, they are quite good for screening and other purposes, but they are not used routinely so these counters are not routine routinely used, because they are not very convenient actually. And this has been replaced like 3h counting has become very efficient and scintillation counters, as we discussed in liquid scintillation counting.

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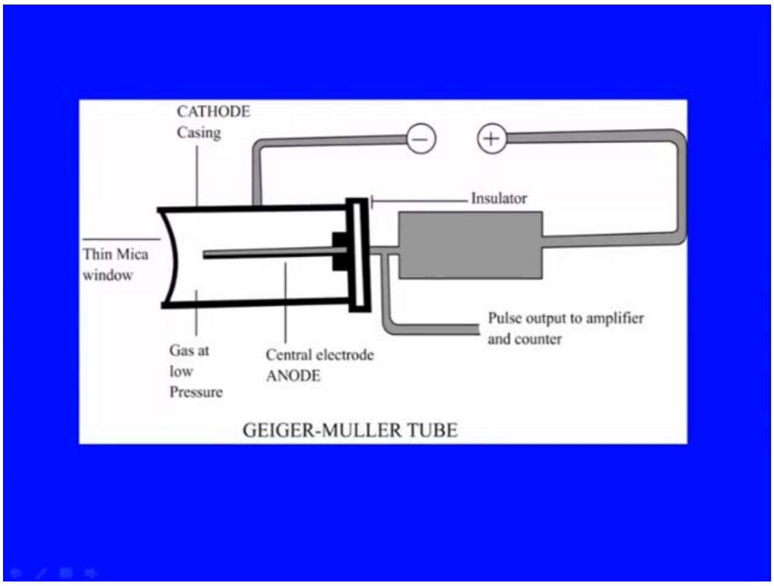

This is a schematic, as I have shown you earlier, but this is little improved figure here. Now, this figure you can see there is a thin mica window, there is a cylinder here ,the end of which contains a thin mica window, which could be used for say 14c, which is not very weak, but weak chemical, there is a cathode surface here, there is a anode here which is centrally placed and there will be inert gas in this particular chamber. Now, as radiation comes in, ionizes the gas and those particles which is positively charged atom and negatively charged electron, will move towards respective electrode. So, this is how the, it will be, the radioactivity will be major or recorded in here.

So, like I was saying that this q or the, or the GM counters, they are usually filled with an inert gas. And this inert gas, could be helium, could be neon or argon and to this a small amount of quenching agent is added. Now, this quenching agent could be like butane, could be propane, ethanol, chorine or bromine. So, why this quenching agent is added here, now quenching agent prevents continuous ionization, as it will have a lower ionization potential than the major gas, which is filling the cylinder. Now, the positive ions of helium what happens here is, that the positive ions of helium will collide, with say a quenching agent like butene.

And they will acquire an electron, from the butene to form neutral helium atom and positively charged butene ion will be created. The butene ions move to the cathode, they pick up an electron to become neutral again, how well many times due to physical and chemical properties of butene. The excess energy of recombination is not converted into electromagnetic radiation, which is done in the case of inert gas. But what happens, instead it breaks the chemical bond resulting in the destruction of the molecule.

So, this prevents the complete or continuous ionization, which would be done in case of inert gas, if quenching agent is not added, but problem is that after some certain number discharges, the quenching gas will be finished or it will not, no quenching gas will be left. So, then there that there could be situation where continuous ionization can occur and subsequent action need to be taken, for solving this problem. Now, as we know since maximal gas amplification is realized, in this region, the size of the output pulse from the detector will remain the same, over a considerable voltage range. As you have seen, there is a potential, there is operating potential and you will have same output pulse, in this GM plateau region.

Now, GM counters, if you see advantages of this, they are very simple counters to detect radioactivity, they are economical radiation counter with single electronic process. And it does not need amplification, of the large amplitude output signal it is, it is a very good routine, it is a very good device for routinely measuring the radioactivity. But certainly, there are disadvantages also for these particular counters. One is the number of times the pulse is produced here, you are measuring it is, the pulse and you are not measuring really the size of the pulse. Therefore, it cannot discriminate between different isotopes so using a GM counter you cannot really discriminate between, different types of counters.

So, this is one disadvantage of GM counting, then there is also problem of dead time. Like, since it takes a finite time, for the ion pairs to travel to their respective electrodes and other ionizing particles entering the queue. During this time, will fail to produce ionization hence are not detected. So, there is the so there by reducing the counting efficiently and this refers to as the dead time and around it is, the dead time of the queue is normally 100 to 200 microseconds. So, there are certain disadvantages, but there are advantages in terms of, a very simple economical device to measure radioactivity.

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In GM counters, like we were discussing about quenching also, there is another problem of quenching, which could be give a continuous output of multiple pulses. So, what has to be done is, you have to add certain quenching agents so that, that particular problem does not arise. So, to counter quenching one method is like set internally, mixing quenching gas with lower ionization energy to decrease the production of electrons at the cathode surface and to prevent counter. And prevent this particular problem, another is you can do it externally through an, electronic circuit to decrease the high voltage after the primary discharge.

This could be, there are methods to counter quenching and improve the performance of GM counters. So, this completes section on the methods based upon gas ionization. So, what we have seen in methods based upon gas ionization that, first is the voltage will have, will have an effect on the ionization of the gasses. And as you have seen, as the voltage increases the ionization increases like in proportional counter region, there is number of ions collected or the pulse flow is directly proportional to the voltage increase.

But there is another region called GM region, where voltage is high and there is no effect of, increasing voltage in that particular region.

In the sense that, number of ions selected is a constant so that is the region which is mostly utilized in GM, in the methods based upon gas ionization. It is a very cheap, economical and a routine device, which is sued in different labs to count or to measure radioactivity. It may not be used so much quantitatively, but for just knowing the radioactivity for, like monitoring if there is spill or any other problem is occurring. And for routine check, that in which tube you have a radioactivity or which sample of contains radioactivity this could be used. So, this complete the section on methods based upon gas ionization.

Now, let us move on to the next method, that is scintillation counting, a method based upon the excitation. Now, if you could recall a methods based upon, excitation is now a very widely used as, this is one method which could measure very weak particles or radiations. Now, before we go into detail now here, one principle of these methods based upon excitation, that is luminescence process plays very important role in radiation detection. And the interaction of different radiations with a scintillator or a fluor a material, these are the materials which activate scintillation, the property of luminescence, when excited by an aging radiation.

So, what happens when you are fluor or a scintillator it leads to the excitation of the compound and then emission of photons of light on de-excitation. Now, the process is known as scintillation and the scintillations are converted to photoelectrons that are magnified through the photo multiplier tube, to electrical signals. And this forms, the basis of scintillation counting .

So, scintillation counters are quite different from the GM counters, where a gas ionization is the basis. Here excitation is the basis now, the electric pulse in photomultiplier, is directly proportional to the energy of the original radioactive event. And therefore, two or more isotopes can be measured in the sample provided, they have sufficiently different emission energy spectra.

What does it mean is that, if say you have certain pairs of isotopes which have different energy spectrum like for example, you can take weak beta emitter and a strong beta emitter. Then, they will have sufficiently different emission energy spectra and then they could be distinguished or they could be detected, that there are more than one isotope in the sample.

And this is possible because the pulse is directly proportional to the energy of the original radioactive event, which is not possible in GM counters. And which was possible in proportional counter region, but it has its own limitations. So, scintillation counting provides information for two kinds, one is quantitative, another is qualitative. In quantitative information, number of scintillation is proportional to the rate of the decay of the sample, that is amount of radioactivity could be calculated. In qualitative, the intensity of light given out and therefore, signal from photomultiplier is proportional to the energy of radiation. So, both qualitatively and quantitatively, scintillation counters could be utilized for.

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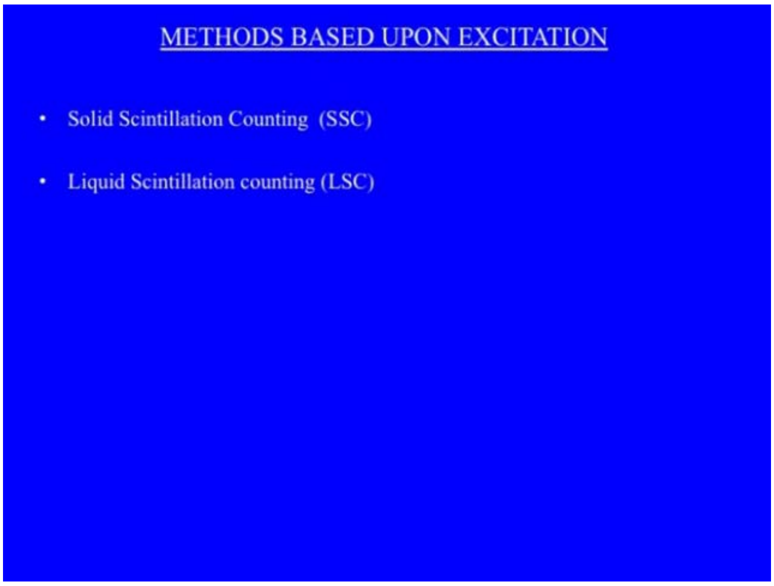

Now, there are two types of scintillation counting methods, one is solid scintillation counting and another is liquid scintillation counting. Now, before we move on I would just give a brief introduction of these two scintillation methods on your screen. So, solid scintillation counting and liquid scintillation counting, if we, if we see how they are measured in, a very simple schematic representation of these devices, will be that.

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What you have is, either liquid or solid scintillation counters. Now, here you have a voltage supply, there is high voltage supply, there is a scaler here. Now, in solid scintillation counting a sample is placed in a particular lead shielding. Now, in the solid scintillation counting, solid crystals of fluor are utilized and they are placed in here, which is the particular fluor or crystals will be placed in, very close to the sample. And sample contains, sample is a radioactive sample here and this will be photomultiplier.

So, what happens is, that here a sample is placed, radioactive sample this is mostly gamma radiations or radioisotopes emitting gamma rays or a very strong, very high energy beta emitter. It could be also alpha also, but like I said they are not so much used, but these radioactive decay will be entering, will be interacting with the fluor, where the fluor will be excited and on de-excitation, it will emit a light. And that will be taken up by, the photomultiplier and finally, will get a signal. So, this is how solid scintillation counting is done and we will be dealing, we will be discussing it in detail. Now, this is solid scintillation counting.

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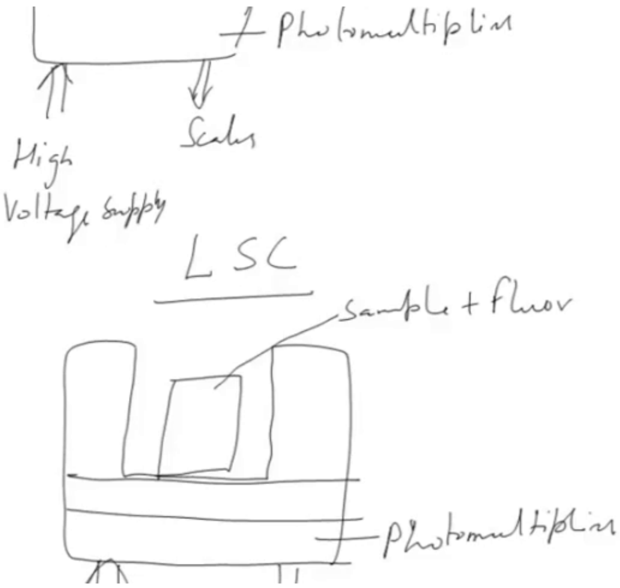

Now, in liquid scintillation counting, that is or we can say LSC here, in liquid scintillation counting similar device will be there or similar arrangement is there. But there is a difference here is, rather than having a separate crystal or fluor. The fluor is mixed with the sample, this sample will contain, sample that is radioactive sample plus, fluor or we call it scintillation cocktail is there. And the sample is put in scintillation cocktail, scintillation cocktail contains solvent, fluor and other things. There is no crystal in here, but there will be a photomultiplier tube here. And this photomultiplier tube will pick up the light, which is, which is like a finally emitted by the fluor actually.

And we will see there are primary fluors and secondary fluors and how this energy transfer takes place, in liquid scintillation counting. So, again there will be a high voltage supply and there will be a scaler in here. So, this is a very simple schematic of the scintillation counting methods, which is solid scintillation counting and liquid scintillation counting. Let us return to our discussion here, so let us discuss first solid scintillation counting. Now, in solid scintillation counting the sample is placed adjacent to a crystal of florescent material, like I have shown you just now. So, our sample or radioactive sample is placed very close to the florescent, crystal of florescent material.

Now, the crystals that are normally used for gamma isotope is, sodium iodide, for alpha emitters it is zinc sulphide crystals. And for beta emitters, there could be organic scintillations such as anthrocene and others could be utilized. Now, the crystals themselves are placed near to photomultiplier so which in turn is connected to a high voltage supply end scaler. Now, solid scintillation counting is particularly useful for gamma emitting isotopes, because these rays are electromagnetic radiations and collide only, rarely with neighboring atom to cause ionization or excitation. But since it is a solid crystals, the gamma radiations are more suitable.

Now, solid scintillation counting is generally unsuitable for weak beta emitting isotopes, like I said 3h or 14c it is not very suitable, because even the highest energy negatron emitted by these isotopes, would have hardly sufficient energy to penetrate the walls of the counting wires. And in which, the samples are placed for counting and again they will not be able to excite also, very effectively the fluor, solid fluor actually.

Now, many of the isotopes used in (( )) are gamma emitting isotopes. So, solid scintillation counting is frequently used in biological world. So, here solid scintillation counting is very suitable for gamma emitting radioisotope, but it is not suitable for weak beta emitter as they will not, they will not be able to come out of the sample tube and excite the fluor.

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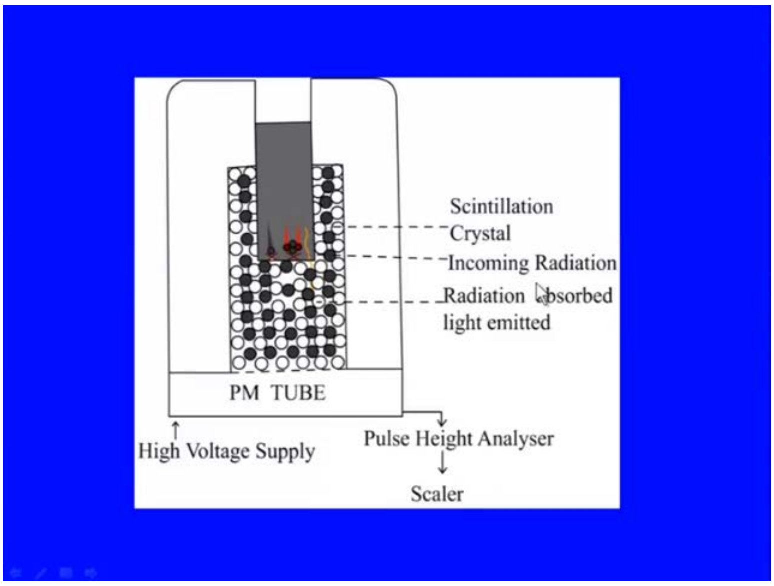

This is a very simple schematic, of solid scintillation counting here and if you can see here, this is the radioactive sample, which is placed in here. And you can see, surrounding it very close to this, is the fluor or scintillating crystals, which will be excited by say if for example, gamma radiation, gamma rays are coming out. Then, the incoming radiation will excite them, on de-excitation they will be a emitting the light. And this light will be measured by or it will be amplified by PM tube photomultiplier and finally, converted to electric signal to be measured.

So, in solid scintillation counting you have to have, these crystals approach very close to the radioisotope. It is a very useful technique, like we said in lot of different biological or biotechnological applications. So, after this we are going to, in the next lecture we are going to discuss about liquid scintillation counting, which is the most widely used technique, as far as radioactivity measurement are concerned, because it could measure a very weak beta emitter highly efficiently, as we will discuss in the next lecture. And it is like a one of the most neutralized technique and most efficient one also, relatively it will be an expensive technique. But the cost of this technique or cost of measuring each sample could be overlooked because of its usefulness. So, we will be stopping here today. In the next lecture, we will start with liquid scintillation counting.

Thank you.