Introduction to Biomedical Imaging Systems
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Lecture - 11
Types of Ionizing Radiations

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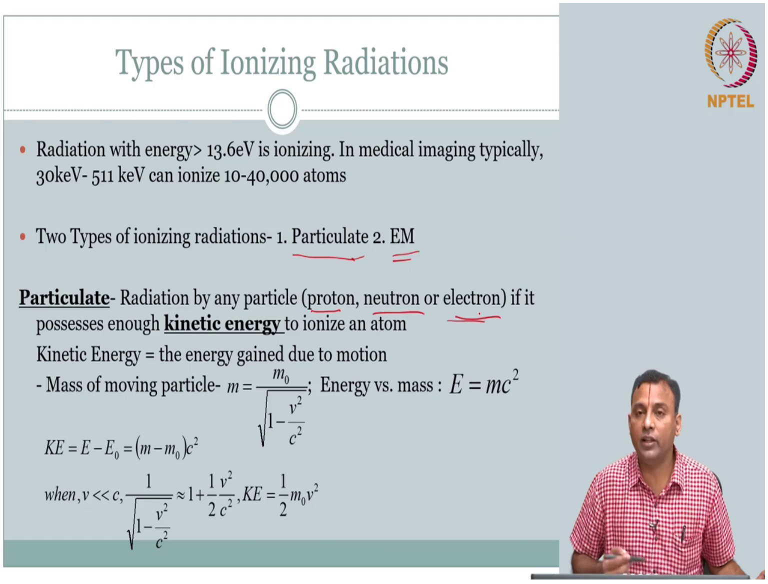

Well, particulate radiation is something is one of the Type of Ionizing Radiations, right. So, we talked about this and what we will do is the order in which we will proceed is we will try to understand how does particulate right, radiation interact with the material. And then go to electromagnetic and how it interacts electromagnetic radiation and how it interacts with the material ok, in that order we will go.

So, when we talked about particulate, recall, of course these are just proton, neutron, electron are listed here; but you could also have other you know particulate, for example, alpha particle or beta particle. So, you will come across those, perhaps when we deal with radio activity right, radio traces, nuclear medicine that we kind of introduce, right.

So, we will talk about those when we get there. But for the purposes of this module, where we are interested in understanding predominantly the X ray right, X ray aspects because we want to do x ray in projection radiography and X ray CT. So, we our interest so far on the X ray part in this module. So, we will restrict ourself therefore, to the particles that are here, more specifically on the electron, ok.

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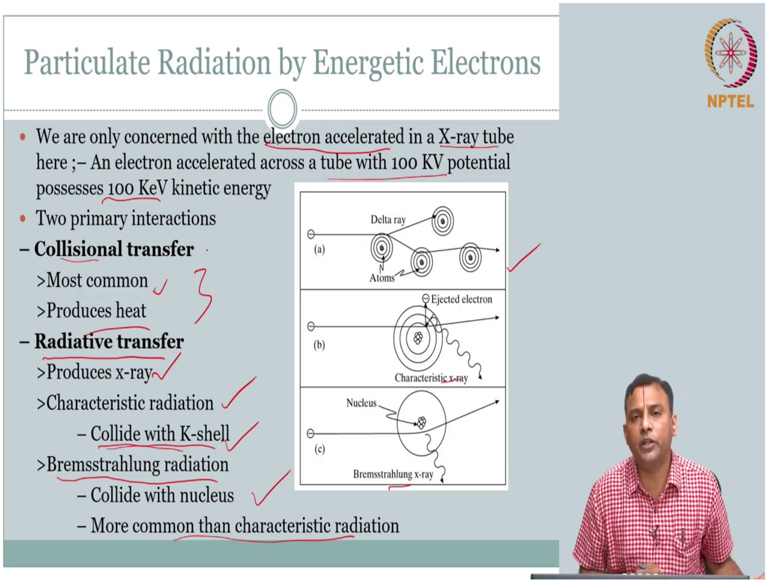

So, to reiterate, we are only concerned with electron; actually we saw this right, in one of the examples yesterday when we wanted to calculate the number of atoms that will be ionized. We already said in an X ray tube for example, you know we have tungsten at the anode remember. So, we are only concerned with electron accelerated in X ray tube here; see that is the particulate radiation that we will use. And how is it used? It is used for generating X rays, right.

So, this is in a X ray tube, X ray tube generates X ray. So, we are using a particulate radiation, particulate ionizing radiation to generate X ray. So, we will see how what happens, why X ray comes out. So, in this context, an electron is accelerated across a tube and that is why it has energy.

So, electron is a particle and it has energy which is sufficient to cause ionization. So, it is a particulate ionization radiation. So, now let us move on, ok. If I have a particulate with enough energy; how does it interact with the medium, right? How does it interact with the material?

So, there are two primary interactions of interest, ok. First one is very common right, which is called as collisional transfer, the name is kind of suggestive. What is collisional? So, if I have you know just a just to appreciate the concept, I am going to use; this is not realistic, we are not electrons right, we do not have that much energy. But pretend I am I have energy, I am you know magnified version of an electron and I am going to with all the energy run through and there are lot of people right, lot of other electrons they are there. What will happen?

First thing is I will collide with them, right. I have more energy than them, because I am running right, I have more kinetic energy. So, they are all standing there, I am going to collide with them. What will happen? Most likely, you know most likely I will probably push them by the impact they will probably moved around, I will lose energy by this collision, right.

And then eventually I will lose energy and all of them, they are now excited right; I push them, I transfer some energy, so they have to come back to their rest state. So, in the process what will happen? They will dissipate energy, come back to ground states; so there will lot of friction, there will be heat generation.

So, all the energy that I carried with me, when I collide, I kind of distribute it and when they come back to rest, essentially there are lot of heat dissipation. So, this is the most common interaction that happens. So, if I have a charged electron, you know essentially it creates heat; because it hits the cloud and looses energy.

Is this interesting to us? Is this important to us? What do you think, right? I mean, so we say that if you have a charged electron right, you give sufficient energy; it will go interact in this manner and this is the most common interaction. Is this in your mind do you think it is a useful interaction or not so useful interaction?

Well, useless or useful depends on the context. What is our context? We want to generate X rays. What is generated? It is produces heat; that means your X ray tube right is going to get heated up, that is all, right. So, it is not really useful for our purpose. What is our purpose? I want X ray energy to come out right. I do not want heat energy to come out.

So, it is common, but it is going to take place, there is going to be heating. So, when you design a tube; you will have to make sure that, you have mechanism, so that there is no overheating and stuff. So, we will come to that when we do the instrumentation, ok. So, what could be the other?

So, clearly this is not, this is most common; but it is not really that useful for us. What is going to be useful for us? For us we need to produce X rays or energy that comes out with X ray range, right. So, that is going to happen due to radiative transfer, this is the one that produces X ray.

Of course even there that radiative transfer, there are two kind of mechanisms or two phenomenon through which X rays are generated right. One is going to be the characteristic radiation right, where we kind of talked about this even in the intro, right. So, essentially when you knock out the electron in the K shell; remember the organization structure of an atom that is where we probably mentioned this.

And we talked about ionization in the previous lectures. So, there is where we said you know you knock an electron and it becomes ion. So, this is a radiation, ionizing radiation, so it all makes sense, right.

So, characteristic radiation is a phenomenon where when you have a energetic electron, that goes and collides right; you have radiate into a material, you have a electron cloud, you have radiative transfer and the collision with K shell produces characteristic radiation, we will go into that then in the subsequent slide.

The other most useful interaction is bremsstrahlung radiation, right. Bremsstrahlung radiation; what happens here? We are talking about K shell that is electrons. So, when a charge electrons right; when high energy electron goes, interacts with the electron cloud, you have something here. Then there is a nucleus, right.

So, this one essentially has to do with when the charged you know energetic electron particulate, that goes and interacts with the nucleus; that time energy is released and that turns out to be in the X radiation, X ray energy level and this is more common than characteristic radiation.

So, from my X ray tube for example, it is actually the bremsstrahlung radiation that gives us the energy mostly, ok. So, we will go look into each of this in the subsequent 20, 30 minutes, ok. So, here is a sketch, we will basically start with the first one right, which is a collisional transfer and then move on to characteristic and bremsstrahlung.

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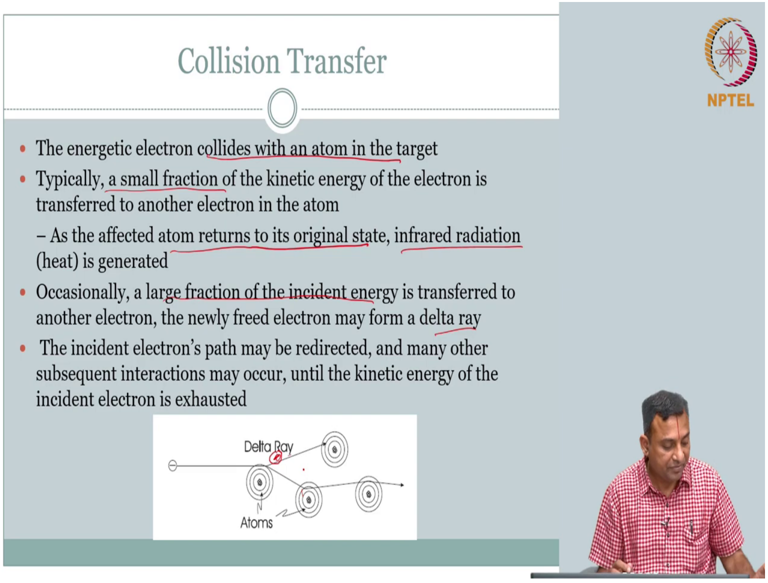

So, collisional transfer; what happens in collisional transfer right, let me just re show the corresponding sketch, very intuitive, right. I gave you an analogy of me running in you know, similar you pretend that say electron, the electron has say energy now, it is going and this is an atoms cloud, right. You have a atom, you have electron cloud around it; you have a nucleus and electron that compose the atom.

So, what could happen? First thing is like, I said you go in, you start to interact right, loose some energy and with reduced energy you go further, interact here; with reduced energy you go further, you interact here. So, in the each process, you lose energy and whenever this come backs right; when the rearrangement takes place here, it essentially gives you a heat energy. So, it is a small energy that comes in the infrared radiation range and so that happens, so that is clear.

So, it is only collisional, it does not really knock another electron out or anything like that; it just looses energy, but it still has enough energy to go to interact with the next atom, electron cloud of the next atom, looses energy there and subsequently until it has energy, it will do interact and then die out.

So, what about this guy? This is a interesting secondary effect. So, you have this electron goes; if it turns out that it can knock another electron right, if it can knock that electron and give it sufficient energy. It is like, so I was running several of you right in our analogy. So, when I go yeah; if I try to push through the crowd, people will realign, I will lose energy, there will be lot of friction heat.

But then it could also happen that, maybe I latch on to someone and I transfer lot more energy which is sufficient for that person to actually start to go further down and push other people right, that is exactly what is happening here. So, charged electron goes, knocks out, it transfers lot of energy to that right to that particular electron, notice it is on the outer, right.

So, the energy as you go away from the centre, the binding energy is also going to be lesser, ok. So, it is going to knock out this guy and that is going to have sufficient energy. So, now, that is an electron with enough energy to go. So, essentially that is another particulate right, that can go and do the interaction; it is exactly analogous to, you have the particulate radiation coming and interacting with this atom.

Delta ray is nothing but, if this electron is knocked out. So, this is the secondary. So, this is exactly same as what would have. So, the same interaction of, this will now can undergo colloidal or another delta right, depending on the energy is involved, another delta and then so on and so forth. But, essentially the idea is even here that is going to be mostly colloidal; so nothing much happens, only heat is generated here.

So, the energetic electron collides with an atom in the target. So, only a small fraction of the energy is transferred, ok. So, if that is the case, it is transferred to another electron. So, it is going to locally readjust itself and then come back to ground state, giving that extra energy out, right.

So, as the affected atom returns to its original state, small energy comes, I mean when I say small what do I mean? I mean it gives out energy; but that energy is in the infrared radiation, so heat is generated, ok.

So, if you actually recall I would, it will not be a bad idea to look through our first electromagnet radiation spectrum that was shown right; the where there was a lambda scale, there was a frequency scale, there was a energy scale. We will actually end up referring to that a lot in this lecture and the next lecture and there is; so it might be handy, if you want to just pull that out and have it ready.

So, you will notice that, infrared spectrum the energy is less compare to your X ray, soft X ray, hard X ray, gamma rays right; we had and then on the lower side you had microwave, RF and so on and so forth. So, there is a energy that is coming out, that happens to be in the infrared range, so heat is generated.

Occasionally, like I said you could have enough energy right; large fraction of the incident energy is transferred to another electron and that is freed and now you can pretend that this delta ray is going to behave like all the process we talked about, it is going to do colloidal and radiative further down, clear, ok.

So, we, so, the incident electrons path may be redirected and subsequent interaction. So, it is kind of uncontrol, right. So, you go in and then lot of atoms are there and this is going to happen. So, this is going to continue, ok.

So, what we are interested here is, understand that we are talking about energized particulate, that is interacting with a atom. So, it can produce in this way essentially heat. So, this is of not that from a signal point of view, this is not going to contribute to our signal, ok fine.

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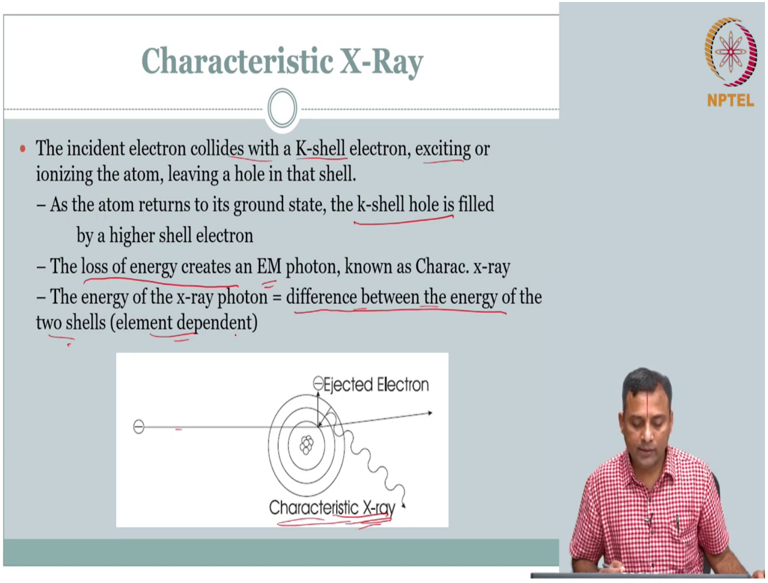

So, let us move onto the more interesting stuff; because we want to produce X rays, first is the characteristic X ray. What do we mean by characteristic X ray? Remember the electron goes knocks out a K shell right, let us see here. So, the electron, this has energy, it goes; but it does enough energy.

What is that enough energy here? Recall our binding energy concept, right. So, this has to have energy that is greater than the binding energy of the K shell electron of this atom. If it has energy greater than the binding energy; then it will release this electron, see that is why we talked about ionization, right. So, this is going to eject this electron out.

So, subsequently what will happen? If this is ejected, rearrangement is going to take place; recall how we talked about excitation, ionization, right. So, rearrangement is going to take place. So, the shell the electrons from outer shell will start to fill in the wide and rearrange itself, in the process the extra energy comes out. How does the extra energy come out? It comes out in the form of electromagnetic radiation.

We will define electromagnetic radiation subsequently after we finish particulate interaction; but you would have heard about electromagnetic radiation already, whatever comes to your mind right about electromagnetic radiation, remember the spectra that we showed, that is sufficient at this point, ok. So, energy comes out as a electromagnetic radiation in the, the energy is in the X ray range, so that is X radiation.

We still have to understand why it is characteristic. What do you think why is it characteristic? Well, I have energy that I know I am putting in let us say, right. If I know what is the energy coming out; can I then say anything about the atom or the material, right? In other words, if this energy that you are getting is unique to a particular transition, that is taking place for a particular atom.

So, from this energy, you tell me you are observing 576 kilo electron volt, then I will tell you that, that atom is tungsten, right. If you can do that, then that is characteristic. So, the X ray that is coming out at the energy levels, because X ray energy is wide range. So, from the energy of the X ray, if you can tell what probably is the atom that is involved in ionization that has given out this X ray; then that is characteristic X ray, ok. So, we will spend one more slide on that.

So, the incident electron collides with K shell electron; we talked about this, exciting or ionizing the atom, leaving a hole in that shell. So, the K electron, shell is having a hole; then rearrangement takes place. As the atom returns to its ground state, the k shell hole is filled; when it is filling high energy to ground state low energy that means it has to shed out the extra energy. So, that loss of energy creates a electromagnetic photon ok, known as the characteristic X ray.

So, now, this is the deal right, the energy of the photon; what is the energy of the photon that is going to come? Because, it is transitioning right, high energy to low energy. So, there is a realignment that is taking place. So, it has to be the difference between the energy of the two shells right, because it is transitioning.

So, the energy that is coming out, I know the binding energy of k electron of the atom, I know the binding energy of l atom, I know the binding energy of m electron, m shell, right. For a given atom, if I know the binding energies at respective shells; then perhaps if I know the energy that is coming out and that happens to be a difference between energy of two shells.

So, in other words, it is actually element dependent; then I can identify that element right from the energy. So, it is characteristic of that atom, it is characteristic of this two shells that are involved in re-arrangement, that is why it is characteristic x ray, clear. But one another point that you may want to recognize here is; that means, I am going to get energies right, discrete energies discrete energy level.

So, energy comes out at a particular energy level that is a key, ok. So, because of that I may be able to tell what two shells are involved and therefore, what atom it is. So, it is discrete in nature, ok.

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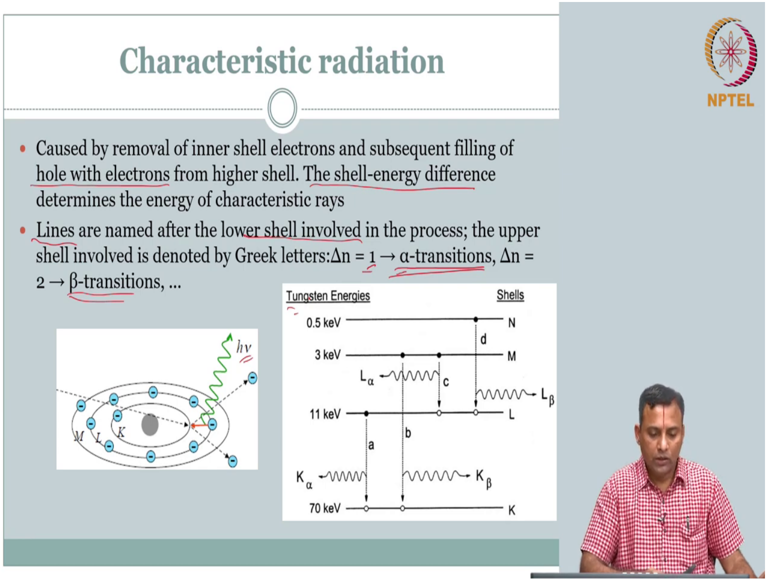

So, what is the other one? So, before we go just to extra material for you to appreciate the conventions, right. So, caused by removal of inner shell of the electrons and subsequent filling of the holes ok, this is what we just saw. So, there are some conventions; because you said characteristics X ray right and you know which shell is transitioning. So, there are conventions for naming this.

So, the shell energy difference determines the energy of the characteristics. So, how do we communicate this? How do we be more specific about it here? So, you have different shells K, L, M right; you have a hole and there is a transition that is taking place to fill the hole and in the process, electromagnetic energy comes out in the X radiation, ok.

Again we will see this again, electromagnetic radiation when the energy comes out as photons, the energy is h nu, we will define that, ok. So, the point is this comes out.

So, now, the question is, if this is characteristic; there could be jump from L to K or M to K or M to L, there are so many jumps, because it is going to reorganize itself, re arrange itself. So, is there a better way and each energy could be characteristic; it should be it could be different, depending on the respective of binding energies involved. So, is there a better way to you know communicate this, right?

So, what they do is, the lines are named, what is lines? Just as we said what are these energy levels are discreet, right. So, if you do the spectrum of energy right, you will have lines; only at certain discreet locations, you will have the characteristic X radiation depending on what is a characteristic, right.

So, these are what is considered lines. So, it is in the spectrum, remember spectral lines; lines are named after lower shell involved in the process. What is the lower shell? K is the lowest L, M, N; so, lower shell that is involved in the process right, that shell will be used, the upper shell involved is denoted by Greek letters.

What does that mean? For example, if there is a shell transition is delta n is 1, 1 shell transition. You can have that 1 shell transition anywhere right; I can have M to L or L to K, both of this is 1 shell transition. So, it turns out that, if it is 1 shell, we call it alpha transitions; if it is 2 shells, we call it beta transitions, but then we use the lower letter, lower shell involved in the process.

So, if I want to communicate that some transition happen from L to K, delta n is 1. So, that is a alpha transition. So, whatever is receiving lower shell is K. So, if I want to communicate that, I will say K alpha, right. So, let us see. So, some energy levels, so, that is why we said it is for tungsten all these are known right, each shell what could be. So, this is your K, this is your L; if you are transitioning from L to K, you are having one jump, delta n equal to 1, which is alpha transition. So, it is alpha transition.

And you are using the lower shell involved, so K; so, K alpha; if you say K alpha, then you know you are transitioning from here to here. If you are doing K beta; that means beta is 2. So, K beta, so that means lower is K beta is 2; that means this would have come from two levels upper right M, M to K transition.

Likewise here if you notice, L is the lower energy, lower shell; alpha means 1 transition, L alpha represents M to L transition, L beta represents N to L and so on and so. Now, you understand, that means all this the energy levels are unique. So, if it is jumping and the energy that comes out is also in the X ray range, that is a unique energy.

So, you can tell whether that X ray characteristic X ray is a L alpha or a K alpha, right. You can or a K beta, you know based on the energy and the energy that is observed you can tell and that is unique to the atom; because each shell, each bonding binding energy of different atoms are different, slightly different, right.

So, that is why it is characteristic, ok good. So, this part is done. So, let us move on to ok; this is actually giving you some signal, but still this is not really that helpful. Why? This is going to just give me one X ray energy at that particular line right, that particular frequency.

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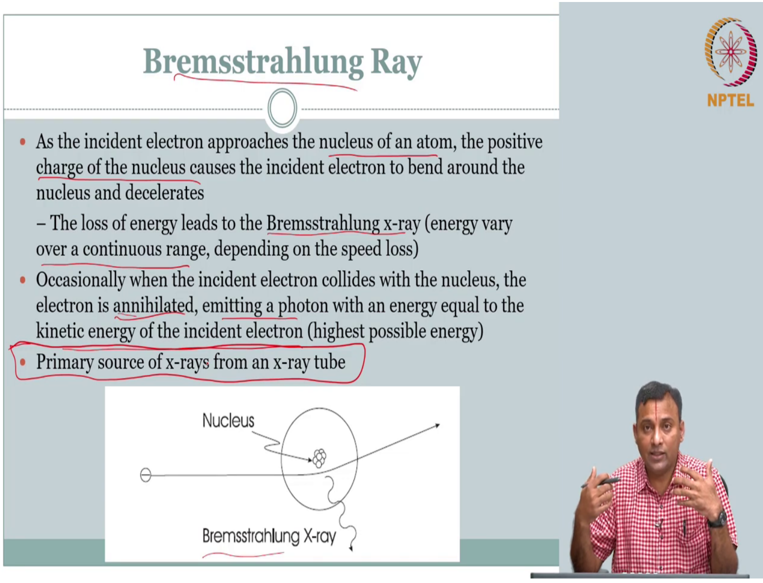

So, what is the most important interaction from a signal perspective? It is bremsstrahlung. Remember what was bremsstrahlung? I told you that it is going to interact with the nucleus, let us again do some analogy. I mean I know these probably are very poor analogies; so be it, I mean at least it gave me some feeling for what it is, right.

So, pretend. Pretend you are the electron with energy. So, it is like you are driving your car in the highway, you have lot of momentum; so you are going at a velocity, you are accelerating, you have reached and you are really moving faster right in the freeway.

So, you have enough energy, but then you notice there is this big advertisement right, something that attracts you; that is flashing, they are standing here and you are able to see that and they are flashing here, say let us say an attraction is there right, you know food promo or some other things. So, you see all colorful things and they are trying to you know call catch the attention of everybody who is driving through that freeway.

What is going to happen, you will probably apply brake; because it is attracting you, you will apply brake, slow down, probably go towards it to get a closer look at it, right. If you are not completely interested; if you are not completely attracted towards it, all likelihood you will go further. So, what is happening?

There is a centre of attraction, it is trying to pull you there. So, you are going fast, it is trying to pull you there; so you are applying brake, you are slowing down and then you lose energy. So, essentially you lose speed. So, you lose energy, because you are braking. And then you find that it is not attractive enough, that you have not still lost all the energy and so, you detour right, that is exactly what is happening here.

So, the electron is going, the positive charge in the nucleus tries to attract this electron and so it is trying to pull it towards it. In the process this electron is applying a brake or it is like braking to slow down and it changes path and if it does not completely attracted, it changes direction and goes.

So, in the process what is going to happen? It is applying brake starting here; because of this influence is continuously applying brake to slow down. So, what is going to happen? It is going to reduce in energy. So, what is happening that energy? That energy is going to be sent out. So, that energy that it is sending out, because of this braking is; if comes out in the X range, X ray range, X ray energy range, that is your bremsstrahlung X ray.

Why is this bremsstrahlung? That is just a German word; that means braking, so this is braking radiation in English if you want to look at it. So, you relate the analogy, why it is braking; that is why it is seems like; it is slowing down, because of this attraction to the nucleus, the nucleus is slowing down, it is braking the, not braking into pieces, braking means applying the brakes right braking and slowing down.

So, that energy that comes out because of the braking, because of the slowing down, because of the influence of the nucleus, that energy comes out as in the X ray range. So, this is a most important thing, this is a continuous, right. You are applying brake; so that means you are releasing energy right, unlike your characteristic which was shell dependent and therefore, there was discreet this is a continuous range of X ray energy that is going to come out, ok.

So, let us just put it. So, as an incident electron, approaches the nucleus of an atom, the positive charge of the nucleus right that is the attraction here. Tries to bend around the nucleus and decelerates, decelerates means slows it down. So, the picture that you see here kind of represents the meaning right captures the meaning nicely.

So, the loss of energy leads to bremsstrahlung. Like I mentioned, important aspect is it is a continuous range; of course depends on how much speed is lost right, how it has lost, but the point is it is over a continuous range. So, you come with some energy, you start to apply brake, you start to lose energy, and the energy that you lose comes out in the X ray radiation range and eventually it goes out, it stops, right.

So, in a rare case; in a rare case what can happen; like in our example you go the attraction, so attractive that you actually stop the car and go in. So, your car is no more, you are no more on the freeway right; you are not going to go to another place, you are just attracted here completely, you are for lack of better words just to say you are annihilated, destroyed, right.

So, the idea is in which case what has happened, you have lot of energy you came in; you got completely attracted, you lost all the energy, you are stopping there, you lost all the energy. So, all the energy that you carried forward has to be released, emitting a photon.

So, occasionally, when the incident photon collides with the nucleus; the electron is annihilated. In the process what happens? Emitting a photon with an energy equal to the kinetic energy of the incident electron, so this could be the highest possible energy that can come out, clear.

So, probability wise this is less, occasionally only it can hit. So, mostly it is going to be a continuous way, continuous scale of energies and the energies should be less than what it came; only occasionally when this is completely annihilated, the X ray that comes out will be of the energy that this particulate carried ok, the highest possible energy.

So, the most important message is bremsstrahlung radiation, this interaction is the major source of X ray generation in your X ray tube, clear. So, we are interested in understanding how X rays interact with X ray energy, interact with body that is what you are going to study. But before that to generate X rays, we use the idea of a particulate with the energy, how it interacts with the material and generates X ray, clear.

Of course in the process, we could not help; but we also touched upon, the energies that are coming out is electromagnetic radiation with X ray energy, ok. So, we did not still really talk about electromagnetics, which we will do now; but the idea of particulate interaction I hope you got it, it is important that interaction or the particulate radiation is important in the context of generating X rays, ok.

So, is that our signal, I mean from a medical imaging perspective, medical imaging systems perspective; is that our signal? Well, that is a that is the signal of the input level right, you have to create a source signal. So, you have created the source signal. So, radiation, particulate radiation is useful there; then we need to understand this electromagnetic radiation with in X ray energy range, right.

How does that interact with material? That is the natural, because that is what is important from a imaging perspective. I generate this X rays, send it through the body. So, I need to understand how that interacts with atoms in the body, right naturally.

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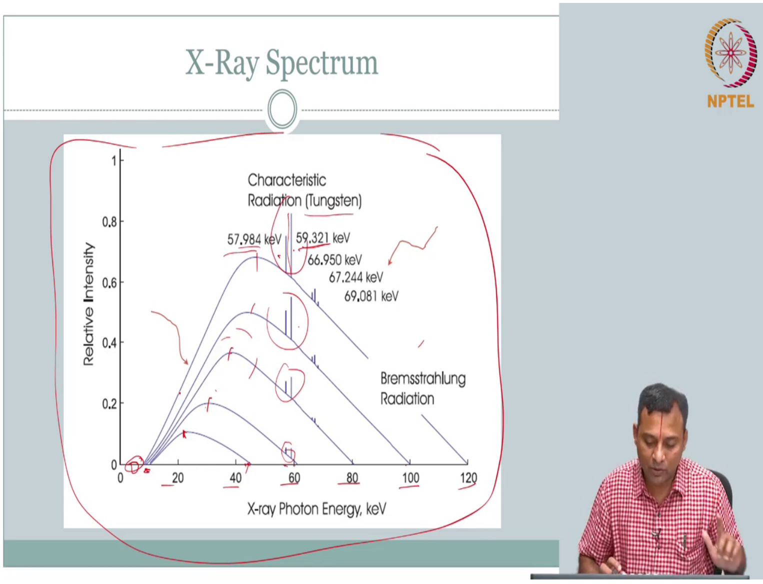

So, that is what we will do. Before we do that, this is a very important plot that you see here; I think it deserves some attention and real appreciation. What you see here, because we will end up using this; because like I said, this is going to be sent into the body. So, this is your signal source right, this is the signal that you are sent into the body; this signal with this characteristic is what is going to is sent into the body, this is output from the X ray tube, ok.

So, this is what is going to go into the body. So, it better spend some time to understand what goes into the body, so that when it comes out; based on what comes out, we have input, we have an output, can we say something about the medium, say that is the goal, can we say something about the medium inside, right clear.

So, what do you see here? Two things standout; I mean literally one is standing out right, the lines that you see. What are these lines? These are the characteristic radiation, of course, example here is tungsten. So, these are the characteristic radiation. What is characteristic radiation? We just saw. This is your X ray photon energy. So, this is the photon energy that comes out in X ray range. What is the range? There is a huge range that is plotted here.

I think you understand what these are different plots that you see; each of them are ending at highest energy here right, because this is relative. So, highest energy here is 0; actually there is. So, here how do you do that? How do you generate the highest energy? How do you change the energy? This is just nothing but the voltage right, electron is accelerated across a voltage potential.

So, I do first experiment, I have voltage drop of 20 right, here I do not see anything. So, here 40, 40 whatever slightly greater than 40, slightly greater than 61, 80, 100, 120. So, I run the X ray tube with different voltage drop; each time I do the voltage drop right, for that it goes hits the tungsten and X ray energy is coming out and that X ray energy, the distribution of that energy is what is plotted.

So, when I hit when I operated with this whatever about 45 kilo Volt potential; when I operated with 45 kilo Volt potential, then I get the kinetic energy is 45 kilo electron Volt, that goes bombards with the tungsten anode. Look at the energies that are coming out; the energies that are coming out continuous, it peaks somewhere and then it drops down.

In fact, if you look at it, all of the. So, if I next increase the voltage, I get this plot. If I increase the voltage, I get this plot. So, all of them have this kind of a hill shape. So, it is increasing right, the energy the X ray energy that comes out that is increasing and then it drops down ok; number of X ray photons in each of the intensities, that is what this plot is. So, you have so many, so several interesting aspect can be observed.

One is, in this plot for example, I do not see any lines right; I start to see the lines only when I breech some value here, I start to see two lines here. Of course, the amount of that is taller right, but then it appears at the same level. So, when I apply 80 also I get that, when I apply a 100 also I get that, 120 also I get that.

So, what is that? That is your characteristic radiation at discrete level. So, depending on the energy, that you supply in relation to the K shell binding energy, right. So, if when you applied the 40, whatever 45; it was not sufficient to create characteristic radiation that is why I do not see any characteristic radiation. So, only when I started heating it slightly greater than the K shell binding energy of the tungsten, I start to see characteristics radiations, right.

So, these are characteristic; because from the values, you can actually comment right, because this will be for tungsten, these are the transitions. So, all this can be commented ok, just by looking at this spectral line. So, that is one message. So, that is literally standing out.

The other thing is, yeah we did know that it was continuous, bremsstrahlung radiations is continuous. So, you have two interactions; characteristic X rays and bremsstrahlung X ray, right. So, one is continuous, the other is discrete. So, this is the interaction that comes out.

So, what is not that explainable is, ok? When I send high energy right to interact, I get more X ray energy. So, more photons with X ray higher energy right, that is fine. So, that is why it is. But why is it a hill? It starts only from here, this is kilo electron volt right energy. So, you could have some 100 of electron volts right; why is it not there, why is it not generating that? Well, it turns out that it does generate that, but then you are looking at a material which is tungsten, right.

So, when you have low intensity, low energy X rays right, the soft X ray range for example, or even here if you see, it is sloping out; it is not like it is generating and then it comes down. What happens to this? It is not generating these intensities; why right? There is no value, no matter how large you apply. Why?

Because these energies that are generated right; the X ray energy that is generated because of these interactions are small enough that, it essentially interacts with the tungsten again right before coming out of the material and it gets observed in the tungsten. So, it just heats up, remember colloidal. So, essentially the lower energy that is generated, low energy X rays that are generated are generated and also absorbed by the material and therefore, it does not come out.

So, it has to have some energy, before it can start to come out have characteristic and; so, when that energy is greater than characteristic energy, you get characteristic radiation; K shell electron binding energy, you get characteristic radiation, otherwise you get this shape. So, you can see that if I want to increase the X ray intensity right, I can. So, this peak, this peak, this peak, this peak, this peak it seems like it is linear. So, I can increase the voltage and therefore, I can increase the X ray intensity that is coming out, ok.

Of course, why is this sloping down and coming to 0? When does it come to 0? That means, I have applied 120 kilo electron volt, if I want everything to be 120 kilo electron volt to come out; that means your bremsstrahlung, remember the occasionally it gets annihilated, only then you get all the energy that goes in comes out, but statistically that is very less, right.

And therefore, when I do 120 kilo electron volt, I want and I do not see the highest energy anywhere, because relatively that is very weak. So, predominantly what happens is, you get, when you apply 80 kilo electron Volt; you get most intensities, you get is much lower than the highest, there are some and literally negligible or 0 is your complete annihilation, ok.

So, this is a very important aspect, because when I do the X ray tube and I say we are sending X ray energy into the body; you know you are not just sending one or the other, you are sending a spectrum inside, remember that, we will come back to that, ok.

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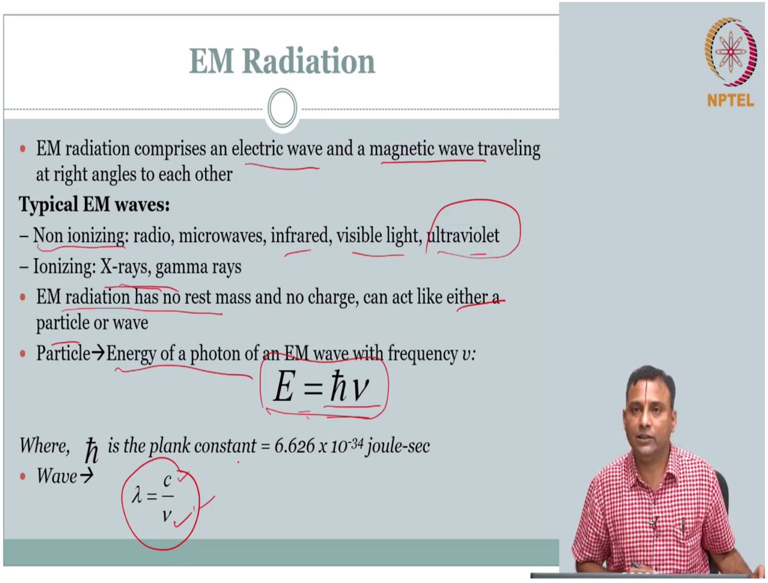

So, now, we should probably make it little more formal; because we started using the term with assumption that you would have definitely heard about this before. So, here it is kind of just making it formal. So, I what is the electromagnetic radiation? So, you have electrical and magnetical wave, right. So, both electric and magnetic waves are perpendicular to each other and they travel perpendicular.

So, you know the typical electromagnetic wave introduction chapters in your textbooks you will see; they will use a I mean at least that is what I remember from my course, right. So, you have a wall and a floor. So, there will be sinusoids right, depicting one wave, electrical wave for example on the floor, on the wall and magnetic wave on the floor and the direction perpendicular to this plane will be the direction of propagation of the electromagnetic wave, ok.

So, electromagnetic comprises of electric wave and magnetic wave travelling at right angles to each other. So, we will quickly run through typical electromagnetic waves that we actually have started talking. In fact, the first spectrum that I showed will be useful; it just have that picture and you will recall. So, we have non-ionizing the low energy sides; when you talk about ionizing, remember we are talking about ionizing human body, ok.

So, in that context, non ionizing are radio waves, microwaves, infrared visible, and ultraviolet. Ultraviolet you know when you push to the limits, still we will have to be careful; but still you know it depends on, it is considered non ionizing until here, ok. What are ionizing? Then starts ionizing, that is you have energy levels that are greater than 13.6 electron volt binding energy for hydrogen right, so that it can cause ionization of the hydrogen atom.

So, ionizing we started with the X rays, of course we are interested in X rays and gamma rays; gamma rays not probably in this module, but when we go to nuclear medicine. So, distinguish between what he saw already right, the particulate radiation and the electromagnetics.

The electromagnetic radiation has no rest mass and no charge. So, we talked about electron and negative charge and we talked about m 0 and m talking about relative velocity and therefore, relativistic mass that is not applicable here; although electromagnetic wave can display both behaviors, that is it can either act as particle or wave, ok.

So, typically when we talk about particle, you can think about right what particle; I mean it is basically discreet packets, packets of energy or photons, right; energy of a photon of an electro. So, when we talk about particle nature, we are talking about discrete packets of energy, which we call it photons and we talk about energy of photon, you get the, we saw it in one of the sketch before, the energy comes out as h mu. What is this h, what is this mu?

Mu is the frequency, h is your Planck's constant, ok. So, h is your Planck's constant. So, if to characterize the particle nature, when we talk about the energies; h mu tells everything ok, which is what we will discuss further, because X ray photons come out with an energy. So, that is what we meant. So, when we talk about waves typically; how do you characterize a wave? You have to wave means you have to have some wave velocity, some wave length, some frequency, right. So, that is your binding equation.

So, if it is a wave, if you have to describe a wave; you need to know this relation between wavelength, velocity and frequency. So, whichever way you remember that is fine. This is the way to characterize the wave nature or to describe the wave nature; this will be the parameters that will be used, clear. So, let us stop here. What I would like to do is, continue further with interactions of this electromagnetic wave with the material.

Thanks.