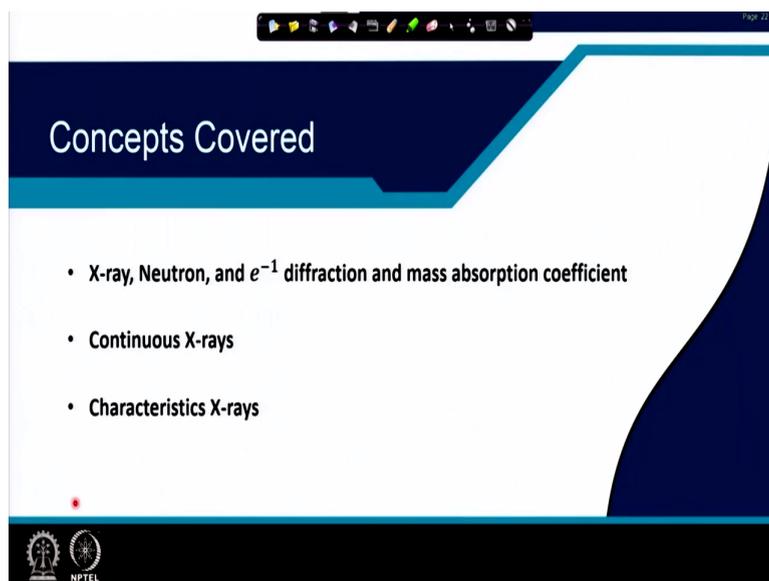


**Texture in Materials**  
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**Module - 05**  
**Principles of texture measurements by X-ray diffraction**  
**Lecture - 23**  
**Penetration Depth of X-Ray, Neutron,  $e^{-1}$  & Basics of X-Ray Generation**

good afternoon everyone and today we will continue with the module number 5 that is Principle of texture measurements by X ray diffraction. this is lecture number 23, in which we will try to understand the Penetration Depth of X Rays, Neutrons, and electrons in a more fundamental level and then we will go to Basics of X Ray Generation.

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The concepts that will be covered is X ray, neutron and electron diffraction and its mass absorption coefficient leading to its penetration depth and how continuous X rays are produced and how the characteristic X rays are produced.

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**X-ray diffraction method**  
X-Ray are scattered by the shell electrons of atoms through interaction between the charged electrons and the electromagnetic field of the x-rays

- Spatial resolution  $100\mu\text{m}$  & Angular accuracy  $2^\circ \rightarrow$  Measures average texture at surface ( $\mu\text{m}$  penetration).

**Synchrotron X-ray method**

- Parallel x-ray i.e., with minimum angular divergence  $\rightarrow$  Small beam size
- Very high intensity  $\rightarrow$  lower (short) wavelength
- $\rightarrow$  Large penetration depth in mm  $\rightarrow$  Macrotexture
- $\rightarrow$  High spatial resolution ( $0.1 - 100\mu\text{m}$ ) & Angular accuracy  $0.1^\circ \rightarrow$  Microtexture or local texture

$\frac{\mu}{\rho}$  ( $\text{cm}^2\text{g}^{-1}$ ) is mass absorption coefficient,  $\rho$  is specific weight of the interacting metallic material

$$\frac{\mu}{\rho} = k\lambda^3 Z^3$$

$\frac{\mu}{\rho}$  of x-rays are very high  $\sim 30 - 400 \text{ cm}^2\text{g}^{-1}$

$$I = I_0 \exp(-\mu t)$$

Penetration depth of x-rays are limited to  $10 - 100\mu\text{m}$

$\frac{\mu}{\rho}$  for Mo, Cu, and Co -  $K_\alpha$  x-rays is given in Table 3.4 O. Englar, V. Randle -Intr. to texture Analysis, page 65.

X ray diffraction method, X rays are electromagnetic radiations, which are scattered by shell electrons of the atoms which are present in a periodic arrangement inside a poly crystalline metal or alloy. Here the interaction is between the X ray, which is electromagnetic radiation and the charged electron, leading to scattering and thereby diffraction. Now, this interaction produces diffracted X rays.

However, the incident beam of this X rays are divergent and its wavelength is also smaller, smaller than the periodic lattice arrangement; but it is quite high and therefore, it has a spatial resolution of 100 micrometer and an angular accuracy of 2 degrees. As we said that the it measures average texture from the surface up to few micrometer depth penetration and gives micro texture. synchrotron X ray method are specialized radiations, which are obtained in a beam line where there is a synchrotron accelerator.

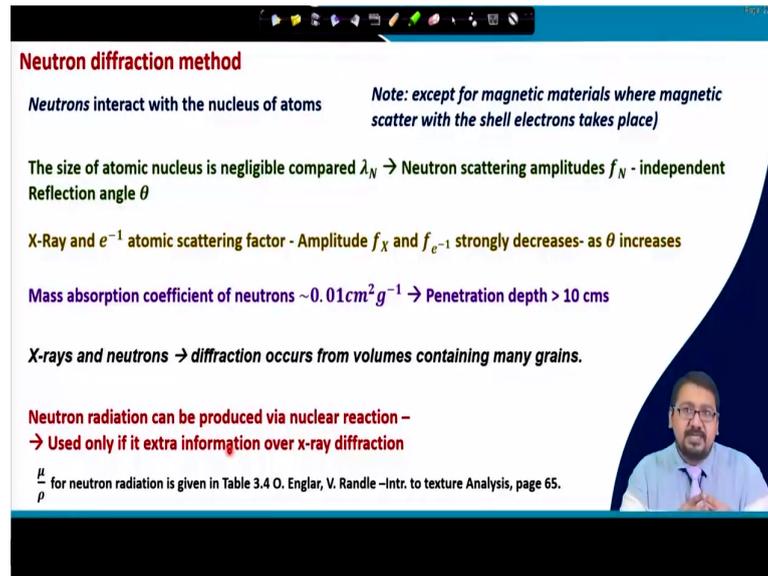
It can produce short wavelength, lower than the natural X rays, the wavelength is that it can produce are shorter than the wavelength of natural X rays. And thereby they can be made parallel, they have minimum angular divergence and therefore, can be made into small beam, thin beam size. It has very high intensity because of its lower wavelength that the energy of the radiation is inversely proportional to the wavelength and therefore, lower the wavelength, the energy of the wave is much higher. It has higher penetration depth. Therefore, it can obtain macro texture; because of very thin beam size, it can have very high spatial resolution. Because of high resolution, 0.1 to 100 micrometer, one can adjust higher angular accuracy of

0.1 degrees, it can give micro texture as well. if we look into these X ray diffraction methods, the absorption of these X rays, means the normal X rays and the synchrotron X rays.

Let us talk about the normal X rays, depending depends upon the value  $\mu$ , which is given here. This  $\mu$  is the linear absorption coefficient; usually  $\mu$  is not used, but  $\mu$  by  $\rho$  is used, where  $\rho$  is the density that is the specific weight of that material in which the X ray radiation is interacting, right.  $\mu$  by  $\rho$  which is in unit centimeter square per gram, is known as the mass absorption coefficient, mass absorption coefficient. And this is the most important variable that is considered for understanding absorption of various radiation. Now, this mass absorption coefficient depends upon a constant  $k$   $\lambda$  to the power cube and  $Z$ , which is the atomic number of the interacting material to the power cube, right.

Now,  $\lambda$  is wavelength of the incident radiation, in this case it is X rays; in case of neutron or electron it will be it will be of neutrons and of electrons,  $k$  is a constant, which is dependent on the type of radiation and is dependent on the interaction of that radiation. Say for example, X rays it interacted interacts with the matter in a different manner than that of the neutron and that of the electron.  $k$  constant will be dependent on that kind of electromagnetic radiation. if we look into the X rays as it interacts with shell electrons and nucleus too; it has a very high mass absorption coefficient for different materials, which is being collected, right. It is very high, that is about 30 centimeter square per gram to 400 centimeter square per gram. in an average you can say that it is in a range of about 100 centimeter square per gram as given in most of the reference books and the textbooks. If we look into Valerie Randle and Olaf Engler book, where Introduction to texture Analysis; the table for mass absorption coefficient for molybdenum, copper or cobalt,  $k$  alpha radiation, when it is interacting with different matter is given, it is table number 3.4. You can go and check it. As if the intensity  $I_0$  is incidenting on a certain matter and then it is diffracted in; so let us say that it is in the reflection geometry or in the transmitted geometry. The incident the diffracted beam that is coming out that is given by equal to  $I_0$  exponential minus  $\mu t$ , where  $t$  is the thickness of the material through which the absorption has taken place. The penetration depth of normal X rays is in a range of 10 micrometer to 100 micrometer based upon this  $\mu$  by  $\rho$  that is the mass absorption coefficient.

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**Neutron diffraction method**

Neutrons interact with the nucleus of atoms *Note: except for magnetic materials where magnetic scatter with the shell electrons takes place)*

The size of atomic nucleus is negligible compared  $\lambda_N \rightarrow$  Neutron scattering amplitudes  $f_N$  - independent Reflection angle  $\theta$

X-Ray and  $e^{-1}$  atomic scattering factor - Amplitude  $f_X$  and  $f_{e^{-1}}$  strongly decreases- as  $\theta$  increases

Mass absorption coefficient of neutrons  $\sim 0.01 \text{ cm}^2 \text{ g}^{-1} \rightarrow$  Penetration depth  $> 10 \text{ cms}$

X-rays and neutrons  $\rightarrow$  diffraction occurs from volumes containing many grains.

Neutron radiation can be produced via nuclear reaction –  
 $\rightarrow$  Used only if it extra information over x-ray diffraction

$\frac{\mu}{\rho}$  for neutron radiation is given in Table 3.4 O. Englar, V. Randle –Intr. to texture Analysis, page 65.

If we look into the neutron diffraction method, the neutron interacts only with the nucleus and that except when the material through which the interaction is taking place is magnetic, the neutral interaction in that case only become a magnetic scatter, which we are not considering in this lecture.

In those cases magnetic scatter occurs by the shell electrons; but in normal non magnetic materials poly crystalline materials, neutrons interacts with nucleuses of the atoms. And as the size of the nucleus inside each of this atom which is periodically arranged in a poly crystalline material the, is very small as compared to the wavelength of the neutron. The atomic scattering factor of the neutron radiation is independent of the reflection, that is the diffraction angle theta, right. not only the diffraction angle theta, but all scattering angle theta, right. Even though the diffraction intensity will come larger, because of the periodic structure following Bragg's law and structure factor calculation; but when you talk about the atomic scattering factor, it is independent of any theta scattering angle.

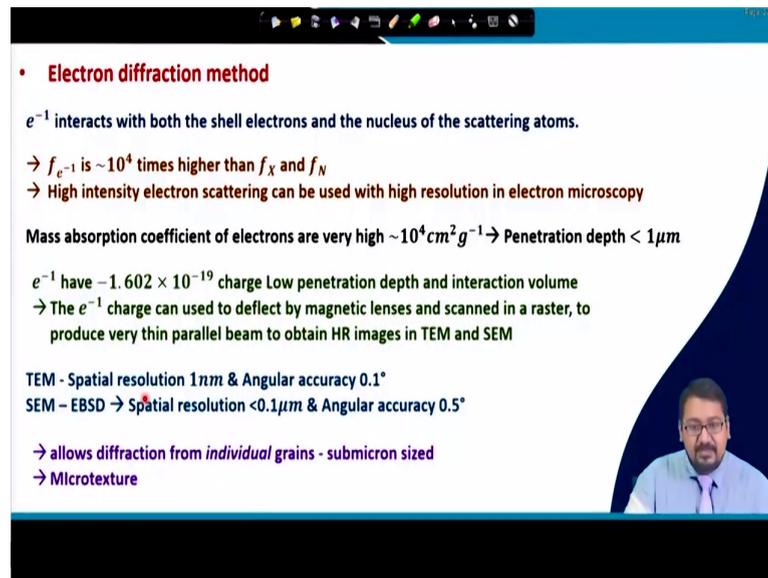
When we compare and talk about X rays and electrons atomic scattering factor  $f_X$  and  $f_{e^{-1}}$  electron; they strongly decreases with theta, because it interacts with shell electrons and also with the nucleus in both the cases. Its interaction and atomic scattering factor decreases as theta increases. In case of neutron diffraction, because there is a lot of empty space for the neutron to travel and the atomic scattering factor also do not reduce with respect to theta; its mass absorption coefficient that is  $\mu$  by  $\rho$  is extremely low as compared to that of the X

rays and this is about 0.01 centimeters cube per gram. If it has such a low mass absorption coefficient; then it can go to a much higher penetration depth and that is it goes more than 10 centimeters. However, that neutrons and X rays, they the diffraction occurs from a large volume of grain, right. It has a large beam thickness, means beam diameter and it diffracts simultaneously from many grains right and it cannot give a very small information from a very small area or a small diameter of beam cannot be produced.

in, if we look closely, neutrons even though give information of penetration depth greater than 10 centimeter; but neutrons can only be produced in a nuclear reactor and it should be only used, if the information cannot be obtained from a normal X ray diffraction or something, ok. I forgot to mention here that the mass absorption coefficient  $\mu$  by  $\rho$  of the neutron radiation is also given in the same table, table 3.4 in Olaf Engler and Valerie Randle's book of Introduction to texture Analysis page of 65.

You can check that and you can you will be able to see that, for various materials for which the neutrons will be interacting will have a different mass absorption coefficient; but that mass absorption coefficient is considerably lower than the mass absorption coefficient for the X rays. What I was saying that, neutron radiations are usually produced in nuclear reactor and I have seen one which is present in Germany, in Helmholtz Zentrum Geesthacht, in small town of Geesthacht and there the beam line for the neutron radiation is closed, because of the environmental protection. I also support that. Only when it is needed is usually used, but most of the beam lines which are there in most of the in the countries are closed, particularly in Germany.

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• **Electron diffraction method**

$e^{-1}$  interacts with both the shell electrons and the nucleus of the scattering atoms.

→  $f_{e^{-1}}$  is  $\sim 10^4$  times higher than  $f_X$  and  $f_N$   
→ High intensity electron scattering can be used with high resolution in electron microscopy

Mass absorption coefficient of electrons are very high  $\sim 10^4 \text{ cm}^2 \text{ g}^{-1}$  → Penetration depth  $< 1 \mu\text{m}$

$e^{-1}$  have  $-1.602 \times 10^{-19}$  charge Low penetration depth and interaction volume  
→ The  $e^{-1}$  charge can used to deflect by magnetic lenses and scanned in a raster, to produce very thin parallel beam to obtain HR images in TEM and SEM

TEM - Spatial resolution  $1 \text{ nm}$  & Angular accuracy  $0.1^\circ$   
SEM - EBSD → Spatial resolution  $< 0.1 \mu\text{m}$  & Angular accuracy  $0.5^\circ$

→ allows diffraction from individual grains - submicron sized  
→ Microtexture

Electron diffraction method are used to obtain local texture that we have come to a conclusion up to now I think. However, if we look deeper, electrons interacts with both the shell electrons and the nucleus it has a charge and therefore, its scatters the atoms, right. It is it has a very low lambda, so the theta that is the Bragg's angles will be very low. If we talk about the atomic scattering factor of the electron beam, the atomic scattering factor of the electron beam are in 10 to the power 4 times higher than that of the atomic scattering factor of the X ray beams and the neutron beams. high intensity electron scattering is there; therefore, it can be used for high resolution in an electron microscopy, right. Because of this high intensity and very low wavelength, the mass absorption coefficient of the electrons are also very high, much higher than that of X rays and of course, then for neutrons. It is about 10 to the power 4 centimeter square plus per gram. then what happens; that the penetration depth will be much lower, much lower than even 1 micron. Depending upon the type of the material that it is interacting, the atomic number of the material. If you have a lower atomic number material like magnesium, then it will in aluminum, then it will have lower penetration depth and it will have lesser mass absorption coefficient. If you have a material like zinc or other material, which have a higher atomic number; so it will have a much lower penetration depth than even than the 1 micron. So, electrons have charge, this charge is about 1.6 into 10 to the power minus 19. it has low penetration depth and it has low interaction volumes.

Electron charge can be used, what we can do, but in case of electron is that, by utilizing a set of magnetic lens, which are known as condenser lens; the electron beam can be converged or

made parallel into very thin beam, such a thin beam. That beam can be utilized to produce very thin parallel beams to obtain information from the smallest pixel possible, right.

One can obtain high-resolution image in a SEM or a TEM rather, right. TEM is mostly used for higher resolution images than the SEM basically; because SEM is in reflection geometry and then its resolution decreases, because many geometric factor. Whereas, the TEM we have the direct beam, where the resolution can be kept to a much higher level. That in case of TEM, the spatial resolution of the electrons can be obtained up to say 1 nanometer, which is extremely high and the angular deviation is less than 0.1 degrees. Whereas, in case of SEM and EBSD particularly, where we are getting quantitative microscopy; the spatial resolution is less than 0.1 micrometer and accuracy level of 0.5 degrees. Now, that with the advent of technologies and newer developments, this spatial resolution of the SEM is constantly decreasing. Now we have seen that we are able to obtain even grains of the size of 150 to 150 nanometers in polycrystalline nanostructured grains, in case of using an SEM EBSD.

This higher spatial resolution allows diffraction from not only individual grains only; but even from a very smaller parts of the individual grains of sub-micron structured individual grains and therefore, we can obtain micro texture.

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**Continuous X-rays** • X-Rays – discovered by Röntgen -1895

- X-Ray tube possesses two metal electrodes- Anode and Cathode in vacuum – High voltage– 10KV
- Electrons are rapidly drawn to the target – anode at high velocity
- X-Rays are produced due to rapid deceleration of  $e^{-1}$  hitting anode target x-ray tube and radiates in all directions
- $K.E. = eV = \frac{1}{2}mv^2$ ,  $e = 1.6 \times 10^{-19} \text{Coulomb}$ ,  $m = 9.11 \times 10^{-31} \text{Kg}$ , If tube voltage is 30KV

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.602 \times 10^{-19} \times 30000V}{9.11 \times 10^{-31}}} = 1.03 \times 10^8 \text{m/s} \quad \text{Speed of light} = 2.99 \times 10^8 \text{m/s}$$

- As  $V \uparrow \rightarrow$  no. of photons/sec and average energy/photon  $\rightarrow$  both increases
- Total x-Ray intensity,  $I_{\text{Continuous spectrum}} = AIZ^m$  ( $Z$ , atomic number of Target)

Most of the  $K.E.$  electrons striking the target is converted to heat only 1% is converted to x-rays

Here we conclude that and then we come to X rays. the question is, how were X rays generated basically? Initially when the X rays were developed, it was developed by Rontgen in 1895s and during that time continuous X ray was developed. In addition, what is

continuous X rays? Continuous X rays means, the X rays which are polychromatic in nature and they have different wavelengths, right. That kind of X ray was developed. if that, what is how an X ray is developed? There is a tube and in the tube, there are two metal electrodes; one if you say is cathode, another if you say is anode right and these two electrodes inside a tube is kept at a very high vacuum.

When a voltage is applied between this anode and the cathode which are separated from each other; say it is increased from 1 kilo Volt to 3, 4 kilo Volts to 10 kilo Volt something like that and the voltage is constantly increasing, then what happens. That the electrodes sorry, electrons starts to generate and starts to travel towards the anode electrons generated at cathode travels towards the positive anode because of the electronic charge difference created by the voltage, right. The electron starts moving towards the anode at a very high velocity. It hits the anode at a very high velocity. when the electrons hits the anode, what happens; there is a rapid deceleration of the electrons hitting the anode and because of this rapid deceleration of the electrons hitting the target anode inside the tube, it radiates certain kind of energies of certain wavelengths, which are known as X rays. This radiation of X rays occurs in all possible direction.

If we talk about this mathematically and we say that ok the kinetic energy of the electron is equal to  $e$  into  $V$ . Where  $e$  is the electronic charge and  $V$  is the voltage that we are giving to the material and then that becomes equal to  $\frac{1}{2}mv^2$ , where  $m$  is the mass of the electron and  $v$  is the velocity that it can travel.

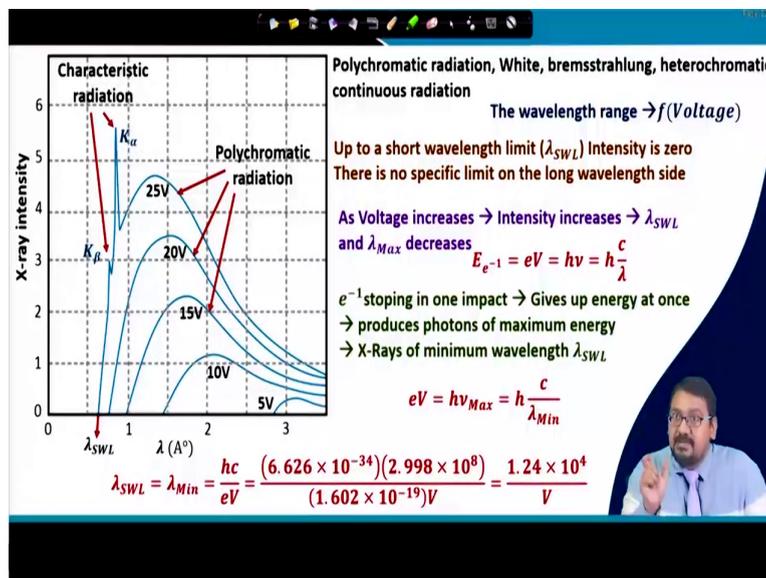
If we know the electronic charge is  $1.6 \times 10^{-19}$  Coulomb and  $m$  the mass of the electron is  $9.11 \times 10^{-31}$  kilograms. if we give a tube voltage of 30 kilo Volts you see. Using this equation, we can find out the velocity of the electrons is equal to  $\sqrt{\frac{2eV}{m}}$  that is  $30 \times 10^3$  Volts, this is the one divided by the the mass, so  $9.11 \times 10^{-31}$ .

it comes out to be  $1 \times 10^8$  meter per second is equal to one third of the speed of the light, it is very high. that kind of energy from an electron is going into the target and when it is decelerating, it is producing some kind of energy in, some kind of energy in form of electromagnetic radiation of various wavelengths, because of the deceleration and this is known as continuous X rays. As the voltage is increased, what happens that the number of photons per second that is hitting the anode increases and the average energy per photon also

increases. The X ray intensity of the continuous spectrum; then becomes equal to A, which is a proportionality constant, i the current inside the X ray tube, Z that is the atomic number, V that is the voltage and m which is also a constant, which is usually in and around 2 for most of the cases gives the intensity of the continuous X ray spectrum.

Before we go ahead, we should know that most of the kinetic energy of the electrons that are hitting into this anode target is mostly converted into heat and only 1 percent is actually converted into this continuous spectrum X ray radiation. this is also very important to understand that, very few only 1 percent of the energy is converted into X rays.

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if we look into this diagram of X rays, it is a diagram which is it is a schematic one and it is also given in most of the books in some way or in a different manner. it shows the x axis as the wavelength in Armstrong and the x y axis as the X ray intensity in some arbitrary unit, ok.

that when the continuous radiation, that is a polychromatic radiation; it is also known as white radiation, it is also known as bremsstrahlung, it is also known as heterochromatic radiation or continuous radiation. And that this continuous radiation looks something like this; if you look into my pointer for 5 Volt and when these are all actually 5 kilo Volt, 10 kilo Volt, 15 kilo Volt, 20 kilo Volt and 25 kilo Volts, Volts is wrong. I have to correct it. When the voltage is increased from 5 kilo Volt to 10 kilo Volt; what happens that, the lambda start or the minimum lambda or the usually, it is known as the lambda short wavelength lambda decreases. When it goes from 5 kilo Volt to 10 kilo Volt the short wavelength lambda

decreases and then it goes to 15 kilo Volt it decreases again and 20 it decreases again and 25 it decreases much more.  $\lambda_{SWL}$ , that is the short wavelength  $\lambda$  keeps on decreasing as the voltage keeps on increasing.

you can see, you can realize that not only  $\lambda$ ; but also if you look the maximum of the maximum of this peak, the peak maximum that is the  $\lambda_{max}$  also decreases as the voltage of the X ray tube is increased.

as the voltage increases from 5 kilo Volt to 10 to 15 to 25; what happens is that, the energy by which the electrons are hitting the target anode increases. And therefore, what is happening that as the energy is increasing; the  $\lambda$  is inversely proportional to the energy of the applied radiation.

the  $\lambda$ , because the frequency is increasing and frequency and  $\lambda$ s are inversely proportional; so the  $\lambda$  is decreasing, that means high energetic X ray beams are being produced with the increase in the voltage of the X ray tube. that not only  $\lambda_{SWL}$ ; but the  $\lambda_{max}$  also decreases towards the lower  $\lambda$  value. you see. there is a short wavelength limit  $\lambda_{min}$ , intensity is zero below that short wavelength limit for any kilo Volt applied to the X ray tube. However, there is no specific limit for the long wavelength side; you can see that in the long wavelength side, where the energy is keeping on decreasing, that is on the right side, there is no specific stop. we have seen that the as the voltage increases, the intensity increases and thereby the  $\lambda_{SWL}$  and the  $\lambda_{max}$  actually decreases and this is given by this these equations, right. energy is equal to electron volt is equal to  $h \nu$ ;  $h$  is the Planck constant,  $\nu$  is the frequency.

$h \nu$  this equals to  $h c / \lambda$   $c$  is the speed of light and that energy is inversely proportional to  $\lambda$ . the  $\lambda$  decreases, both  $\lambda_{SWL}$  and  $\lambda_{max}$  decreases. see what is  $\lambda_{SWL}$ ? Whenever the electron is striking and it is decelerating inside that target anode, it is producing this continuous spectrum, right. But if that the maximum energy can be produced if the these deceleration is maximum, right. And when the deceleration is maximum? Only when the electron is stopped at only one impact, so it can give the maximum energy right at once.

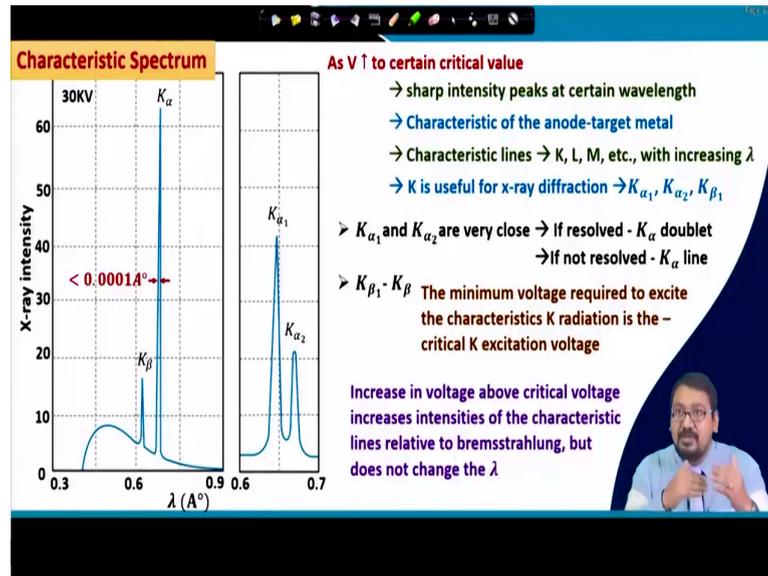
When it produces a photon of the maximum energy, then the X ray with the minimum wavelength or the short wavelength limit is produced. one can use this same equation to calculate the short wavelength limit for different voltages. And you can see that we have

given that the energy is equal to electron Volt. Electron charge into Volt of the X ray tube equal to  $h \nu_{\max}$ ; therefore, this means that the frequency will be maximum and therefore,  $h c / \lambda$  will be minimum. The  $\lambda_{\text{SWL}}$ , that is the short wavelength limit is given by  $h c / e V$ , which is the Planck's constant,  $c$  which is the velocity of the light divided by the charge of the electron and divided by the voltage of the X ray tube; that means the voltage at which the electrons from the cathode is hitting that target anode.

If we calculate the  $\lambda_{\text{SWL}}$ , it becomes equal to  $1.24 \times 10^{-8} / V$  per unit voltage; that means one can calculate the  $\lambda_{\text{SWL}}$  for different voltage 5, 10, 15, 20 or 25 kilo Volts, right. Now, that when the voltage is increased. When it is increased to 25 kilo Volt from 20 kilo Volts, for example, in this case. What happens that, suddenly there are some peaks that forms in this kind of continuous radiation curve. These peaks are for example, in this case, it is shown to be K alpha peak, K beta peak and they have a specific  $\lambda$ . This specific  $\lambda$  even do not change if the voltage is further increased to 30 kilo Volt, 35 kilo Volt or even 100 kilo Volt.

Only the intensities of the K alpha and K beta radiation will increase many a times as compared to the intensity increase of this continuous radiation. These radiations having particular values of wavelength and with a very thin integral width are known as characteristic radiations; that means a radiation having certain specific wavelength. Therefore, can be utilized for doing diffraction measurements and we are looking into these characteristic X ray radiations.

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if we magnify that part of that curve and show in terms of x; here is also wavelength in Armstrong and y that is X ray intensity in arbitrary units and you can see that the K alpha may look like this and the K beta may look like this.

K alpha forms at a little higher lambda than the K beta and K alpha has a much higher intensity as compared to the K beta. The integral width of K alpha, K beta is actually very small and therefore, it belongs to a certain specific wavelength. Now, if we magnify further, we can see that K alpha is not a single K alpha in; it does not have a single intensity, but it may have two different intensities K alpha 1 and K alpha 2 very closely, but separated. As I said in the previous section, previous slide that as the voltage is kept on increasing the sharpness of this K alpha, K beta and the K alpha 1, K alpha 2 etcetera keeps on increasing; but this particular wavelength remains the same.

This is the characteristics of that particular anode target in which the electron beams from the cathode is hitting. That means some radiations, which are coming from the K shell or because of the electronic movement from some shell to some other shell is happening; this kind of radiation is taking place. There could be characteristic lines from the K shell, from the L shell, M shell and therefore, each will have different lambdas. It is well known that, the radiation from the K shell will have a lower lambda; that means a higher energy higher frequency, from L shell and M shell it will be of a little higher lambda and therefore, it will have a lower energy.

Let us go deeper into it; that the K shell as I said can be divided into K alpha 1, K alpha 2, K beta 1 and it is shown in this schematic picture. And that K alpha 1 and K alpha 2 are extremely close together; if it can be resolved, then it is called the K alpha doublet and you can see this doublet. And if it cannot be resolved, then it is called the K alpha line and the K beta 1 is the K beta. The maximum voltage that requires to excite these characteristic K radiation is known as the critical K excitation voltage. This is very important to understand; below this K excitation voltage, these characteristic lines could not be observed, right. if we increase the voltage above this critical voltage, the intensities of this K alpha, K beta will increase; but with and it will increase with respect to the continuous radiation, but the lambda remains the same and that is we already talked about in the previous slides.

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**How characteristic x-rays are generated?** WH Bragg →

As Voltage ↑ → K.E. of  $e^{-1}$  ↑ → Discovered characteristic x-rays

- $e^{-1}$  with sufficient K.E. knocks - K-shell electron
- atom goes to an excited state → high energy state
- Outer electron from L/M shell falls in the K-shell vacancy emitting energy of a certain  $\lambda$  → atom comes to normal energy state

Probability of filling K-shell from L is higher than from M  
→  $K_{\alpha}$  is stronger than  $K_{\beta}$

Energy required to remove L, M shell  $e^{-1}$  is lower than K → K characteristic radiation cannot be obtained without L and M

HG Moseley → Moseley's law:  $\sqrt{\nu} = C(Z - \sigma) = \sqrt{(1/\lambda)}$

$\nu$  → Line frequency       $\lambda$  → Wavelength ↓ as Z ↑

Z → Atomic number

C,  $\sigma$  → constants      Siegbahn et al. → Measured wavelengths of the characteristics x-rays for all elements

How this characteristic X rays can be generated. before we say that, WH Bragg's discovered this characteristic X rays, right. Then when the voltage is increased and the velocity or the kinetic energy of the electrons inside that X ray tube increases and it hits the target anode. In addition, that if that electrons energy is sufficient enough; if it is sufficient enough, if the kinetic energy of the electron is enough to knock down a particular electron from a certain shell, say if it knocks down an electron from the K shell. If it knocks down, if this is an atom, this is a nucleus and these are the electronic shell; that is the K shell, L shell, M shell and if the electron comes. It can have the enough kinetic energy to knock down an electron from the K shell, and then the atom goes to a higher excitation state, that is a higher energy state.

When it goes to the higher energy state in order for the atom to come to the normal state, an electron from the outer electron shell.

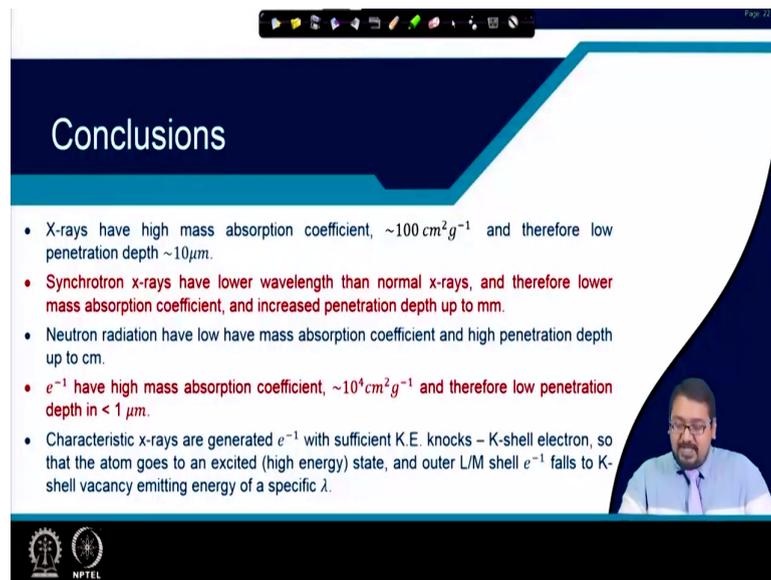
Say for example, from the L shell or from the M shell, falls on the K shell vacancy to dissolve this vacancy and in this process emits an energy of a certain wavelength and the atom comes to the normal energy state again. This certain wavelength energy that is a characteristic wavelength energy is the K alpha, K beta radiation. K alpha radiation is when the electron from the L shell falls on the K shell and K beta radiation is when the electron falls from the M shell to the K shell, right.

now that the probability of filling the L, probability of filling the K shell from the L is actually much higher than that of the probability of filling the K shell from the M shell. Therefore, all the time in all cases, all the different anode material metals, the K alpha is much stronger than the K beta radiation. Similarly when the K excitation energy of the electron becomes higher and it is sufficient to generate radiation X rays characteristics of certain K alpha or the K beta ones. Then this energy is even sufficient to excite electrons from the means, to knock down electrons from the L shell and the M shell too, producing L alpha and M alpha radiation right in a similar process.

These L alpha, M alpha radiations will have can be generated even at a lower K excitation voltage, right. This characteristic L alpha and L M alpha radiations will have a higher wavelength and a lower energy and therefore, the K alpha and K beta radiation cannot be obtained without the formation of L alpha and M alpha radiations. That Siegbahn et al actually gives the measures the wavelength of all the characteristics X rays for all the elements and they have documented it and this can be obtained from the Siegbahn et al if you look into the internet. that while we are talking about this characteristic radiation, one should remember the Moseley's law given by H G Moseley and that is that root of frequency is equal to  $C$ , which is constant times  $Z$ , which is atomic number minus of  $\sigma$ . Root of  $\mu$ ,  $\mu$  is the frequency,  $C$  and  $\sigma$  are constants,  $Z$  is atomic number and the  $Z$  is equal to root of  $1$  by  $\lambda$  right; because  $\mu$  is equal to  $1$  by  $\lambda$ . that as the  $Z$  increases, the characteristic wavelength  $\lambda$  decreases. Higher the atomic number of the target anode, the characteristic K alpha radiations  $\lambda$  decreases; this is a good thing to remember, good thing to know.

Because as the lambda is decreasing, one can get information of diffraction from elements whose periodic arrangement of atoms are closer right, are more closer and therefore, one can get information, which cannot be obtained from certain X rays where the lambda is higher than the periodic arrangement of those atoms.

(Refer Slide Time: 39:45)



The slide is titled "Conclusions" and contains the following bullet points:

- X-rays have high mass absorption coefficient,  $\sim 100 \text{ cm}^2 \text{ g}^{-1}$  and therefore low penetration depth  $\sim 10 \mu\text{m}$ .
- Synchrotron x-rays have lower wavelength than normal x-rays, and therefore lower mass absorption coefficient, and increased penetration depth up to mm.
- Neutron radiation have low mass absorption coefficient and high penetration depth up to cm.
- $e^{-1}$  have high mass absorption coefficient,  $\sim 10^4 \text{ cm}^2 \text{ g}^{-1}$  and therefore low penetration depth in  $< 1 \mu\text{m}$ .
- Characteristic x-rays are generated  $e^{-1}$  with sufficient K.E. knocks – K-shell electron, so that the atom goes to an excited (high energy) state, and outer L/M shell  $e^{-1}$  falls to K-shell vacancy emitting energy of a specific  $\lambda$ .

The slide also features a small video inset of a man speaking in the bottom right corner and the NPTEL logo in the bottom left corner.

What we can conclude here? We can conclude that, X rays have high mass absorption coefficient about 100 centimeter square per gram. Therefore, has a lower penetration depth of 10 micron, there also it is suitable to measure macro texture. Synchrotron x rays have lower wavelengths than the normal x rays and because they have lower wavelengths, they can have a lower mass absorption coefficient and therefore, its penetration depth is increased to millimeter level.

Neutron diffraction on the other hand have very low mass absorption coefficient and therefore, very high penetration depth to centimeter level. Electrons have very very high mass absorption coefficient about 10 to the power 4 centimeter square per gram, which is much higher than that of the X ray and therefore, its penetration depth is not only, not even 1 micrometer. The characteristic x rays are generated by electrons of sufficient kinetic energy, that is that must be sufficient to knock down a K shell electron, so that the atom can go into a excited or a higher energy state. And then, the outer shell electrons from the L or the M shells, falls on the K shell to fill up that vacancy in the K shell, generating a energy of a specific wavelength that is lambda. That is all for today's class.

Thank you.