.NPTEL
NPTEL ONLINE CERTIFICATION COURSE

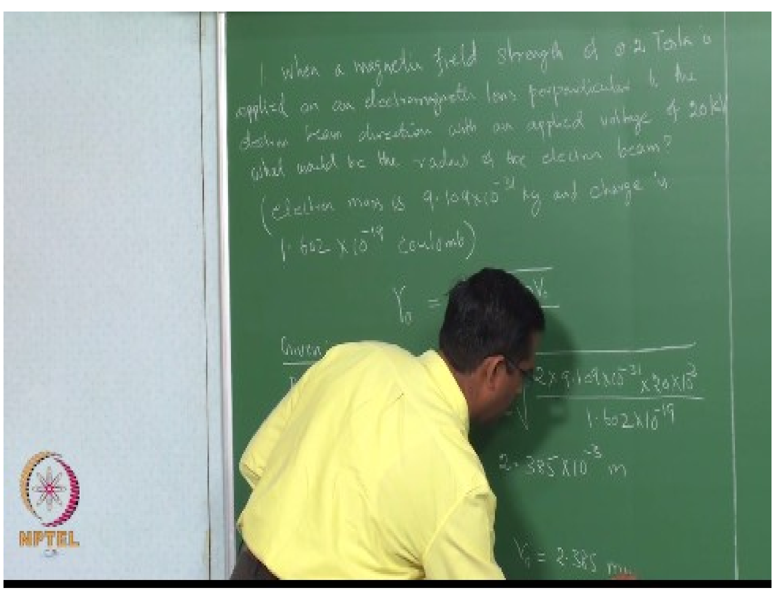
Lecture -21 Tutorial
Materials Characterization
Fundamentals of Scanning Electron Microscopy

Dr. S. Sankaran
Associate professor

Department of metallurgical and materials engineering
IIT madras
E-mail. ssankaran@iitm.ac.in

Hello everyone. Welcome to this material characterization course. In today's class we will look at some of the problems related to scanning electron microscopy. So, these problems will be useful for you to solve some of the assignment problems as well as the in the end semester or end of the course examination. So, we will look at some of the problems related to the resolution in electron I mean electron optics electron optics as well as the specific system specific problems. And also we will look at some of the applications like in SEM, how we get the resolution and what are the parameters which influence this resolutions. Related to that we will look at some of the specific problems. So, you will appreciate the importance of this concepts and then and then you can we'll just get benefited while solving the assignment problems as well.

(Refer Slide Time: 01:19)



So, we will just look at the first problem. So, the first problem is, when a magnetic field strength of 0.2 Tesla is applied on an electromagnetic lens perpendicular to the electron beam direction with an applied voltage of 20kilo volt. What would be the radius of the electron beam? (The electron mass is 9.109×10^{-31} kilograms and the charges 1.602×10^{-19} coulomb). So, what is that clue we have? We are now talking about the radius of the beam, electron beam so the radius is given using this formula. If you recall the electromagnetic lens schematic, we have written an expression in terms of

$$r_0 = (1 / B) \sqrt{(2 m V_0 / e)}$$

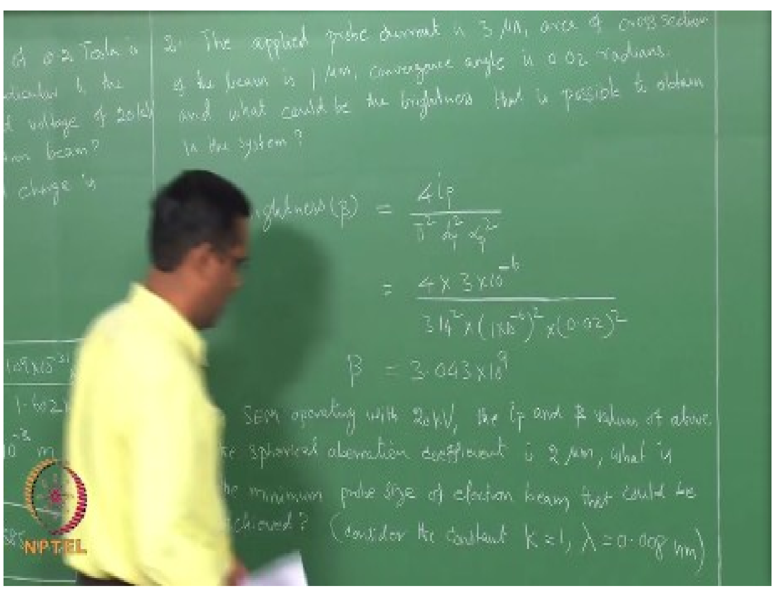
This is the formula. We can use this to obtain this. So, let us solve this. Say simple substitution. You can write by simply substituting this,

$$r_0 = (1 / 0.2) \sqrt{\{ (2 \times 9.109 \times 10^{-31} \times 20 \times 10^{3}) / 1.602 \times 10^{-19}\}}$$

$$= 2.385 \times 10^{-3} \text{ m}$$

We are keeping in volts and this is the charge. So, if you work it out. What you will get is, so you will get something like this or you can write it r_0 2.385 into 10 to the power 3.

(Refer Slide Time: 07:58)



So, this is the answer. So, we move on to the next problem.

So, in a microscope, the applied probe current is 3 micro amperes and area of the cross section of the beam is about 1micrometer, convergent angle is about 0.02 radians. What would be the brightness that is possible to obtain in this system?

So, now you have the if you recall there is a relation between the brightness and the probe current and conversion angles and so on. So, you have to just look back in the lectures the formula for the brightness and I will write

brightness $$\beta = (4 \times i_{p}) / (\pi^2 \times dp^2 \times \alpha^2)$$

So, i_p is the group current and α is the convergent angle and your **dp** is the cross section of the beam. So, simply as substitution here,

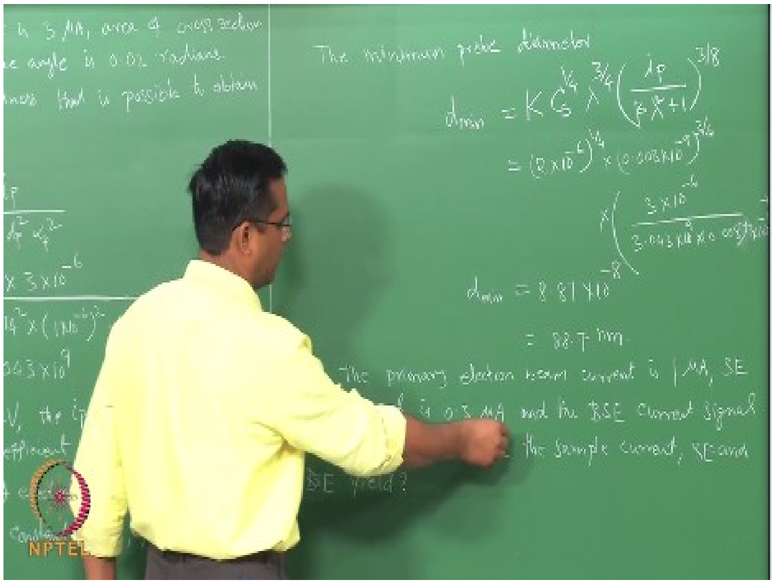
$$\beta = (4 \times 3 \times 10^{-6}) / (3.141^2 \times 1 \times 10^{-6} \times 0.02^2)$$
$$= 3.043 \times 10^9$$

So, beta β is 3.043 into 10 to the power 9. That is the value of the brightness now. We will use this brightness value to solve another problem.

So, let me write that problem. the SEM operating 20 kilovolt, the i_p and β values of above and the spherical aberration coefficient of the electromagnetic lens is 2 micrometer and what is minimum probe size (of the electron beam that could be achieved) (consider the constant k = 1, λ = 0.008 nm)?

So, the problem is, the SEM operating with 20 kilo volt having the probe current and β values of this problem and then spherical aberration coefficient is about 2 micrometer and what is the minimum size of the electron beam that could be achieved? And you can consider the constant k = 1, λ = 0.008 nanometers.

(Refer Slide Time: 15:33)



So, if you recall the minimum probe diameter,

$$d_{min} = K\, C_s^{1/4}\, \lambda^{3/4} \{(i_P / \beta\lambda^2) + 1\}^{3/8}$$

considering the aberration. It is lit this is the formula. We have seen for obtaining the minimum diameter. So, if we can substitute these values, let us see what kind of values we getting.

$$d_{min} = (2 \times 10^{-6})^{1/4} \times (0.008 \times 10^{-9})^{3/4} \times \{ (3 \times 10^{-6}) / (3.043 \times 10^{9} \times 0.008^{2} \times 10^{-8}) + 1\}^{3/8}$$

So, this is a simple substitution here. So, 3 into 10 to the power -6 divided by 3.043 into 10 to the power 9 into 0.008 square multiplied by 10 to the power -8 plus 1 whole to the power 3 by 8.

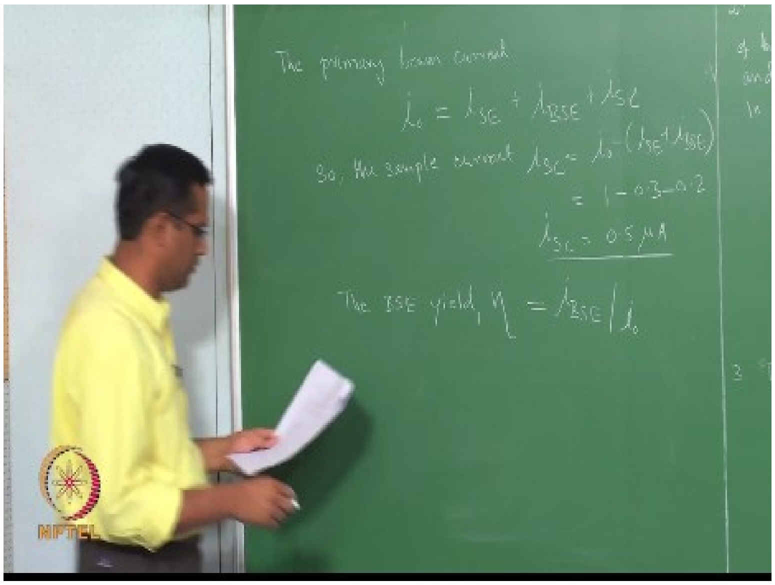
So, basically we are trying to substitute this and then you will get the values in the range

$$d_{min} = 8.87 \times 10^{-8}$$

d_{min} is equal to 88.7 into 10 to the power -8. So, I request you to check this with your own calculator or we can simply say that, 88.7 nanometer. So, this is the final minimum probe current you can get if you have the SEM operating parameters in this range.

We will solve another simple problem. So, let me read the problem. The primary electron beam current is 1 micro ampere, secondary electron current signal is 0.3 micro ampere and the backscattered electron current signal is 0.2 microampere. What could be the sample current secondary and backscattered electron yield? So, if you recall, we have the formula for this, a simple formula to calculate this.

(Refer Slide Time: 22:01)



So, the primary beam current is written in terms of addition of secondary electron signal current, back scattered electron signal current and sample current.

$$\mathbf{i_0 = i_{SE} + i_{BSE} + i_{SC}}$$

So, we can just rewrite. So, this is the first answer. The sample current is 0.5 micro amp.

$$\mathbf{i_{SC} = i_0 - (i_{SE} + i_{BSE}) = 0.5\ \mu A}$$

From the question number 2, is the back scattered electron yield which is given by which is given by

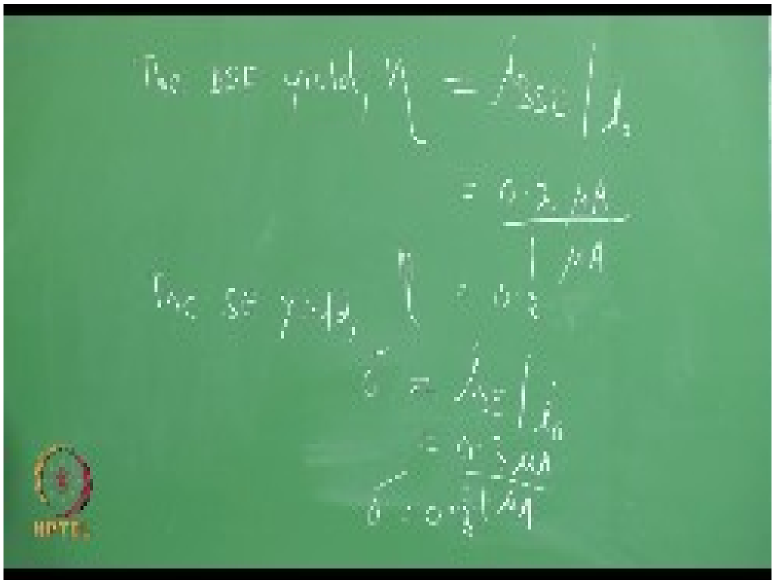
$$\mathbf{\eta = i_{BSE} / i_0}$$

that is the back scattered electron signal current divided by the primary beam current. So, again we can simply substitute this. You will get again same value.

$$\mathbf{\eta = 0.2\ \mu A / 1\ \mu A}$$

$$\mathbf{= 0.2}$$

(Refer Slide Time: 24:11)



The secondary electron yield which termed as a

$$\delta = i_{SE} / i_0$$

$$= 0.3\ \mu A / 1\ \mu A = 0.3$$

This is .2 . The yield is written as .2 hear the yield is written .3. There is no units here.

So, as simple arithmetic which involves the concept of the how the primary beam current is dependent on the current of secondary electron and back scattered electron and a sample current. A simple substitution and then we can also workout the yield. And we have also seen that, the importance of this the yield of BSE and the yield of SE decides the contrast. That we have we have seen in be some of the theoretical concepts. So, now we will move on to the next problem.

(Refer Slide Time: 25:52)

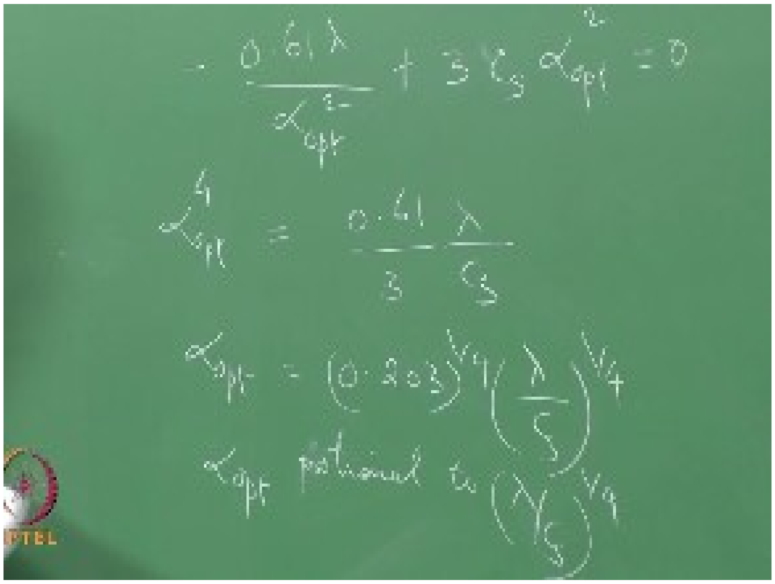
So, the question is for a given wave length of electron beam λ and the spherical aberration coefficient C_S of the lens, proved that optimum image aperture represented in terms of $_{\alpha art}$ is proportional to $(\lambda/ C_S)^{1/4}$. Assume that the net resolution is equal to the summation of theoretical resolution, that is the discs least confusion plus the disc of confusion created by the spherical aberration. So, how do we go about this? What is the theoretical resolution?

Let us consider this $r_1=0.61\ r_1 /\alpha$. So, disk of confusion created by spherical aberration, by spherical aberration $r_2 = C_S\alpha^3$. So, net resolution, if you write so,

$$r = r_1 + r_2 = (0.61\ r_1 /\alpha) + C_S\alpha^3 \qquad (1)$$

let us consider this expression as 1. So, we have just simply put the respective formula and then as per the assumption here, we have written the net resolution in this single formula. Now since this net resolution is depending upon both theoretical resolution plus the spherical aberration, we can write something.

(Refer Slide Time: 33:40)



So, what we are now saying here is, when the spherical aberration is minimized by the use of small aperture that is α_{opt}, diffraction limited resolution becomes worse with the decrease in α. So, we have to make a compromise. So, what we can do is,

α_{opt} when $dr/d\alpha = 0$

i.e $d/dr\, [(0.61\, \lambda / \alpha_{opt}) + C_S \alpha^3] = 0$

So, we are trying to see or we are trying to differentiate this expression with respect to α and see what we get. So, you get this. So, from this we can write,

$(-0.61\, \lambda / \alpha_{opt}^2) + 3\, C_S \alpha^2 = 0$

$\alpha_{opt}^4 = 0.61\, \lambda / 3\, C_S$

$\alpha_{opt} = 0.203^{1/4}\, (\lambda / C_S)^{1/4}$

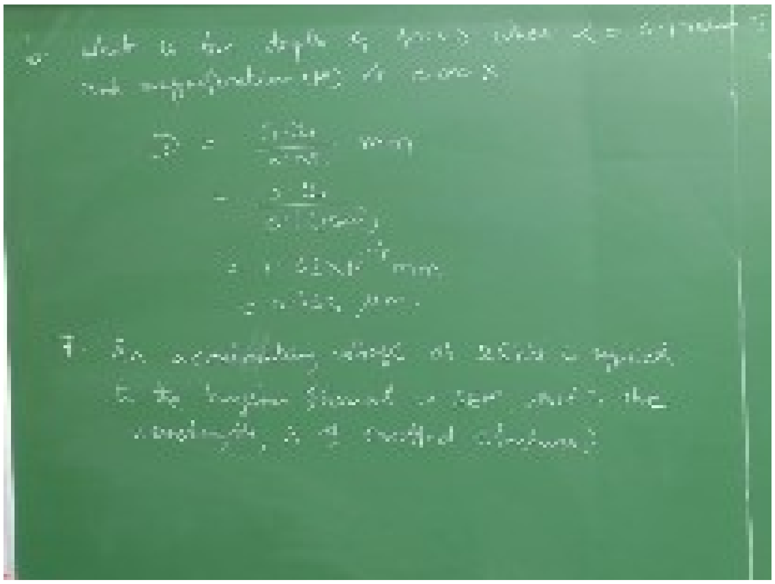
α_{opt} propotional to $(\lambda / C_S)^{1/4}$

$r_{opt}\ \alpha\ \lambda^{3/4}\, C_S^{1/4}$ for optimum resolution.

So, for optimum the solution. So, α_{opt} is proportional to λ to the power 3 by 4, and C_S to the power 1 by 4, which gives the expression for this given condition. If you assume this, and the disc of least confusion will be proportional to these quantities. So, that is what the physical meaning here. The assumption made here will result this kind of an expression.

So, now you look at another simple problem involving the depth of focus and depth of field. So, what is the depth of focus when semi aperture angle(α) is equal to 0.1 gradients and the magnification(M) of 15,000 X?

(Refer Slide Time: 37:39)



So, we have seen and this in fact we have derived this in the SEM class with the schematic you can recall. The depth of focus can be related to this.

$$\mathbf{D = 0.2 / \alpha M \ \ (mm)}$$

So, you simply substitute this.

$$\mathbf{= 0.2 / 0.1\ (1500)}$$

$$\mathbf{= 1.33 \times 10^{-4}\ mm}$$

$$\mathbf{= 0.133\ \mu m}$$

this will be in mm.

So, that is a very simple problem. Another problem, let us quickly right.

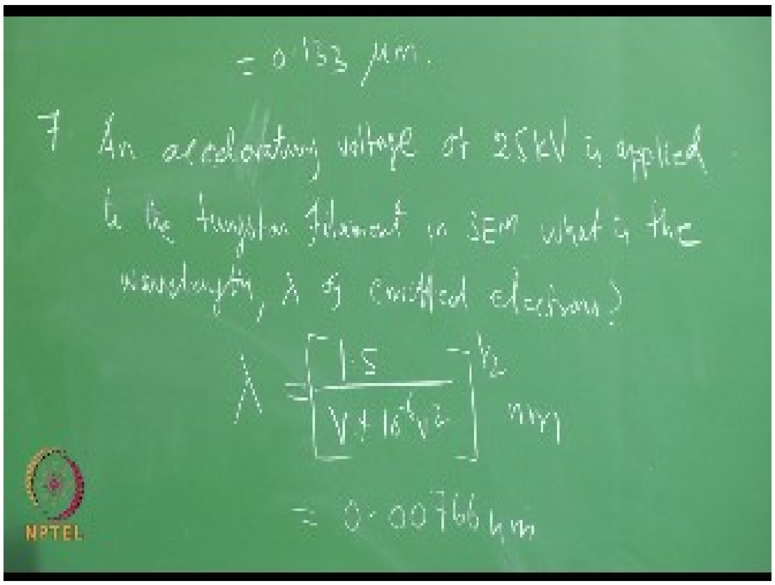
So, an accelerating voltage of 25 kilovolts is applied to the tungsten filament in SEM. What is the wavelength λ (lambda) of the emitted electrons?

So, it is again very straight forward formula. You have lambda which is relating to the acceleration voltage. So, very standard formula.

$$\lambda = [1.5 / r + 10^{-6} V^2] \quad nm$$

$$= 0.00766 \text{ nm}$$

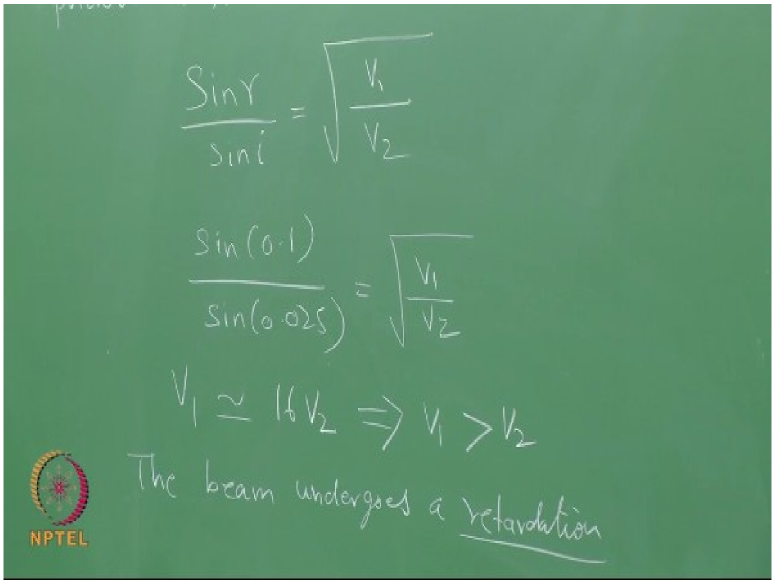
(Refer Slide Time: 41:41)



We have seen that so straight away you will get 0.00766 nanometer for this kind of a voltage. For 25 kilo volts, you will get in this range.

And finally, the question is, an electron beam refracts at an angle of .1 radians when the angle of incidence is 0.025 radians. On passing through a region of potential difference $V_2 - V_1$, does the beam retard or accelerate through this potential difference?

(Refer Slide Time: 42:14)



If you look at the or if you recall the very beginning of the electromagnetic lenses, we talked about the Snell's law and then we said that there is no difference between light or the behavior of light optical system as well as the electron optical system. They are also the same. In in that respect, if you recall, we have written a formula like this. So,

$$\sin r / \sin i = \sqrt{(V_1 / V_2)}$$

and then if you recall that schematic where the electrons are passing through the electro potential lens how whether it is retarding or accelerating depending upon the voltage of the applied, the voltage applied to this system.

So, we can simply substituent see what happens here.

$$\sin(0.1) / \sin(0.025) = \sqrt{(V_1 / V_2)}$$

$$V_1 \approx 16 V_2$$

$V_1 > V_2$ (Then the beam undergoes a retardation)

Then the beam undergoes a retardation. So, that is what we will see. When the voltage V_2 is greater than I mean V_1 is greater than V_2, then the beam will undergo retardation. So, with all this small small numerical problems, I suppose you are able to solve the assignments as well as you are able to solve small small numerical problems. And I hope these things this exercise will help you in the final examination also. If you have any specific queries, you are welcome to interact with us and we will respond to your queries thank you.

IIT Madras Production

Funded by

Department of Higher Education

Ministry of Human Resource Development

Government of India

www.nptel.ac.in