Experimental Physics - III
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture – 54
Electron Diffraction

Today I will demonstrate one experiment very famous experiment this Electron Diffraction. We are quite familiar about the diffraction two types of diffraction Fresnel diffraction and Fraunhofer diffraction lot of experiment we have discussed in Experimental Physics II.

Some experiments I will discuss in experimental physics III also. Diffraction, interference, polarization these are the property of wave. Now in quantum mechanics actually after 1900 century not century 9 after 1900.

These quantum mechanics or quantum physics started you know this Planck’s constant. It is it is of it is the 19,000 1901 in that year that Planck use a constant h. that is the beginning of the quantum physics quantum mechanics.

quantum mechanics that is de Broglie hypothesis this that is based on particle wave dual nature Wave, so wave behaves like a wave also it can behave like say particle other way particle can behaves like a particle that is normal, but it can also behave like a wave

This duality of particle wave. very famous concept in quantum mechanics. That electron is a particle that is quite known to us it is a like point particle, but it has, but quantum mechanically everything we explain in terms of considering the wave considering this wave. Schrodinger wave Schrodinger equation from there this will consider psi this wave function for solving the hydrogen atom problems.

Wave mechanics quantum mechanics also called wave mechanics anyway. electron in common sense it is a particle, but it is also a wave. That we can demonstrate. Now, so before that let me just discuss the working principle or aim of this experiment.

Therefore, electron diffraction aim of the experiment is calculate the wavelength of electron beam energetically accelerated electron beam. What is the wavelength of the electron beam for a particular energy of the beam? That we accelerated the charged particle using the anode voltage; when electron emits from the cathode and determine the inter planar spacing of a crystal. If electron is the wave. Like X ray x rd X ray diffraction, usually X ray we use the crystal to see the diffraction of the X ray grating crystal means here it will act as a grating. for diffraction grating diffraction experiment is very quite familiar to us. Light is falling on the grating.

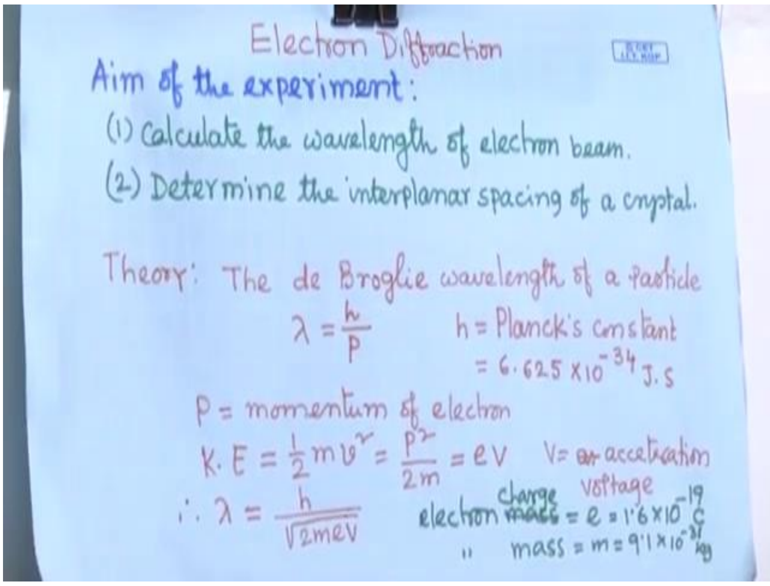
Then we are getting the diffraction pattern similarly in X ray instead of light if you take X ray. Then optical grating will not work will not show any diffraction condition for diffraction is that wavelength a grating element it has to be equivalent.

It has to be comparable to the wavelength of the light or waves electromagnetic waves or it may be other waves also this for crystal we have seen that this it is a planar spacing is in the order of angstrom few angstrom 3, 4, 2, 3, 5 angstrom it is a less than one nano meter. x ray wavelength is also it is a it is a less than the nano meter it is it is a it is in angstrom order. Therefore, that is why that crystal works like a grating in case of x ray.

If in case of electron. electron this it when it we are telling it will if it behave like wave and it is uh. It will have wavelength and if that wavelength is comparable to the gratings it is not optical grating it is some something else. if it is comparable.

If you find some grating the wavelength of the electron will be comparable to the grating element then we can see the electron then we can see the diffraction, then we can tell electron also behave like a wave

(Refer Slide Time: 07:21)



From de Broglie theory, de Broglie wavelength it is particle behaves like wave. What will be the wavelength of this particle that is called de Broglie wavelength of a particle of an electron or whatever? That is lambda equal to h by P h is Planck constant, P is the momentum of electron momentum of electron.

Kinetic energy is P square by 2 m that is the kinetic energy that half m v square kinetic energy half m v square that is P square by 2 m one can write. this kinetic energy will be equal to the accelerated energy due to the acceleration, where accelerating voltage is applied e v.

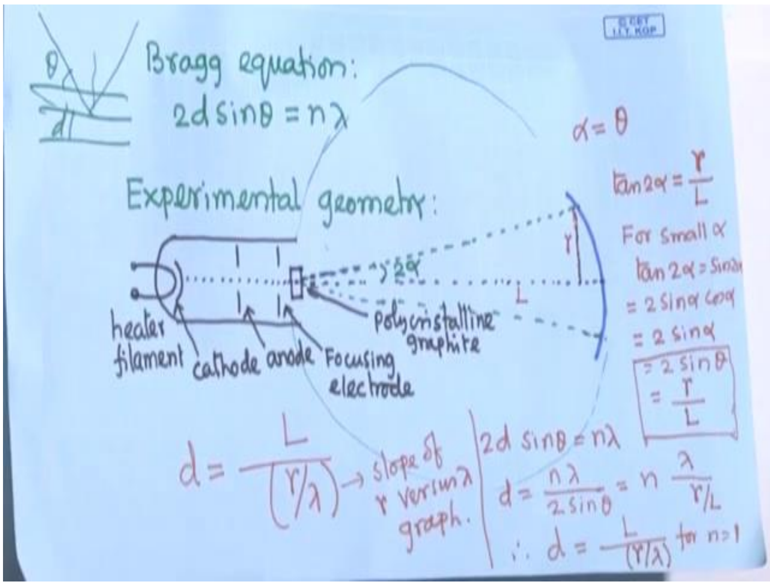
Energy of that electron will be e v accelerating electron will have will have the energy e v. that energy will be equal to the kinetic energy of the electron. From here if P equal to h by lambda from here you can get and put here. You can write lambda equal to h by square roof of 2 m e v.

m is the electron mass that 9.1 into 10 to the minus 31 kg and e is the electron charge that is 1.6 into 10 to the minus 19 coulomb h also we know the value. If we put here. all are constant except this accelerating voltage. this lambda will (Refer Time: 09:32) on the voltage.

Higher the voltage lower the wavelength lower the wavelength energy will be higher that is the frequency will be higher energy will be higher. So wavelength is proportional to the 1 by root over v 1 by root over v accelerating voltage

If you know the accelerating voltage of an electron beam then you can find out calculate the wavelength of the electron beam

(Refer Slide Time: 10:21)



We need proper arrangement for this experiment means we need arrangement for accelerating electron which will provide; which will provide us the electron beam equivalent wave having particular wavelength lambda.

now if it is whatever we are telling that is there is a accelerating electron beam it if depending on this energy accelerating voltage it will have the wavelength it is a wave electron wave Now, if we put this wave on a grating here in this case also we will choose the energy in such a way that it is a wavelength is in nano meter order.

Lambda is in nano meter order then this crystal have this I think not all crystal some crystal have higher interplanar distance this graphite. we will use in this case this graphite material graphite crystal and that crystal will act as a grating. Now, we have a crystal it is a grating to the electron beam.

Now, these grating the electron beam will fall on this crystal then there will be diffraction it is not X ray diffraction it is electron diffraction then we are telling electron diffraction. Now, we should be able to see the diffraction pattern. Now, diffraction that is famous Bragg equation that is 2 d sin theta equal to n lambda

Here for in case of crystal I think all of us is quite familiar with this Bragg equation. You have a crystal, you have a crystal plane. X ray are falling and then this Bragg reflected say diffraction under some condition it is we tell the reflection

This angle is theta not with the normal not with the normal. There should not be confusion and this is the planar distance d, this is the planar distance d; interplanar distance 2 d sin theta equal to n, n is the order diffraction order and theta is the diffraction angle diffraction angle.

We have a formula for wavelength if we know the v accelerating voltage we can calculate lambda. we will get lambda. We will select a particular voltage in a cathode tube because cathode tube is used to produce the electron beam. we have a particular lambda for a particular voltage and then after crystal we will if we want to see the diffraction pattern.

We have to either we have to put screen or we have to; we have to use the detector etcetera. In our case, we will use speed. I will tell you. then we can see where we are getting Bragg peak. Now, this equation has to be adopted with the experimental geometry. In our experiment, we will use one cathode tube we will use one cathode tube.

Heater filament will be there now a cathode it is a material of you know what function. Electron will be emitted from the cathode surface electron is emitted now here say we have to. for acceleration we have to. We tell the anode that electron if we if keep this one is positive voltage compared to the cathode one. electron will be accelerate

Electron will be accelerated. we will get electron beam now here we have used this focusing electrode to focus the electron beam to make it if converging the electron it will diverse in different direction to converse the electron. We will get an electron beam and that electron beam will fall on our grating.

That is polycrystalline graphite material polycrystalline graphite material; now it can be single crystalline it can be polycrystalline. Why polycrystalline is taken that I will explain what will happen. Crystal graphite crystal it has a different plane atomic plane we designate we give the name of this planes with mirror indices.

1 0 0 plane or 1 1 0 plane 1 1 1 plane etcetera thousands and thousands planes are there. when I will tell 1 1 1 plane means it will represent a set of parallel planes ok; a set of parallel planes these planes are equidistant and that planar distance is d. Now another plane say 1 1 0 this another sets of planes its planar distance are different if earlier one is d 1 1 1 this we can write d 1 1 0

but in crystal the angle between these two planes are fixed thousands and thousands planes are there in crystal, but the interplanar that interplanar distance angles are fixed Now, you have a single crystalline material means with respect to the surface of this same material. if I define a plane if I define a plane.

That plane parallel to the surface say 1 1 1 plane. Whole materials have the have the this this 1 1 1plane whatever I explain this is the it is parallel to the surface 1 1 1 plane

Another plane is this way, other plane is this way this is fine. However, so now this material is fixed now with respect to the electron beam if it is. Surface is parallel to the 1 1 1 plane. This angle is 90 degree theta will be 90 degree in this case theta is 90 degree. But with another plane it is a 1 1 0 plane. angle will not be 90 degree it will be different ok, but it is fixed it is fixed

If we keep a crystal fixed X ray is falling normally, say on this surface then angle all angle angles with all planes are fixed now to get the diffraction this condition has to be satisfied.

Lambda is fixed for a particular lambda for a particular plane say 1 1 1 plane we will get diffraction we will get diffraction constructive interplanar at angle theta only but 1 1 1 plane it may not be at the proper angle. then one has to rotate the crystal to match with this to find out the suitable angle for satisfying this equation, but in case of polycrystalline.

To avoid the rotation of the crystal. If I take the polycrystalline film polycrystalline film means that whole materials that as I told 1 1 1 plane of this material is parallel to the surface of the material, but for polycrystalline it will not happen for polycrystalline. it is the crystalline, but many crystalline grains are there

On surface. For a some grain 1 1 1 plane of that grain will be parallel to the surface, but another grain 1 1 1 plane is not the parallel to the surface. It is an it will have some angle

It will have some angle with the surface so; that means, if. Polycrystalline means thousands and thousands grains are there in the material and each grain is crystalline, but the with respect to one grain another grain have the for same plane have the orientation. Generally for polycrystalline.

Many grains are there. we tell that this continues. Grains are randomly oriented. for each plane continuous variations of angles will be there with respect to surface so; that means, with respect to the this electron beam or the electromagnetic wave. these in case of polycrystalline what will happen for each plane continuous it will see the continuous variation of angle 1 1 1 plane 1 1 0 plane 1 0 0 plane

Theta is continuously variable here in natural way then what will happen. For a particular wavelength and for a particular plane say 1 1 1 plane. Continuous variation of angle theta is there. With appropriate theta, theta variation means is the direction. For an appropriate theta this condition will be satisfied and; that means, in that theta in the direction there will be diffraction there will be diffraction ok; for other angle for other angle for that plane there will not be any diffraction

Now, so here I showed you this these type of variation, but it can be this variation it can be the other way also what will happen. for a particular plane when satisfying this angle. It will satisfy it will vary. it will satisfy this angle over a cone; over a cone here that is what is I have shown this this is the incident normal one with respect to this if this is the angle. This is the angle of diffraction then over a cone. because if this orientation of the plane in is continuously varying in all direction.

Because so many grains are there, so we assume that there is a there are continuous variation of angle of a particular the plane and that then it is same because these other planes are fixed with respect to these planes. If one plane varies continuously uh for all angle, it is. it is it will be it will happen for all other planes also

These will happen this will happen. this over a cone. Say this is the angle theta. now, keeping this angle theta satisfying this. I am not violating I am not violating the condition I am not violating the condition over a cone. This theta will satisfy over a cone

Now, so this diffraction I will get for a particular angle for a particular plane over a cone Now, if I put a spin here just normal to this on this normal to this. What I will see I should see a circle I should see a circle this will be for a first order n equal to 1. for a particular plane say it is 1 d 1 in an interplanar spacing is d 1. I will get 1 cone 1 circle.

For another d theta will be different. I will get other cones with different angle. With different angle depending on the; depending on the d for different planes d will be different and theta will be different. I will get concentric circle on the screen each circle will represent a particular plane having the interplanar spacing d.

For d 1 intreplanar spacing d 1, d 2, d 3. Number of a circle we will get. Each circle for a particular interplanar spacing d this the cathode ray tube and here if we here if we use a use a phosphorescent screen some, which will. if electron beam falls there.

It will illuminate it is like cathode ray tube or a cathode ray oscilloscope they are on screen, phosphor screen we use. It is due to illumination. We see the position of the electron getting on the screen that we will see as a b spot means that material emits light, because of the heating of the electron on this phosphorous screen.

here if we use a circular here use a here if we use a circular not circular spherical this is something spherical ok spherical screen then here we have written 2 alpha diffracted at 2 alpha alpha theta is alpha is equal to theta these theta.

Here we have written 2 alpha that is reason is I think it is quite known to us in case of X ray diffraction also we plot we diffraction at 2-theta angle or 2 alpha angle if incident angle is alpha then diffracted angle. It is the here this one it is if we consider the reflection if you consider reflection if we take a mirror then if incident angle is theta it is reflected. I think let us consider this is normally fall on this

It is reflected normally now if mirror rotated by theta then this reflected light will rotate by 2 theta. It will rotate by 2 theta that is the common known phenomena. Because of that this angle is diffraction angle here it is a diffracted at 2 theta angle or 2 alpha angle alpha equal to theta.

On screen, I will get circle here. this circle radius of this or radius of this circle is r small r and this distance of the screen from the sample is L. L in this in our case it will be diameter of this sphere but we are writing capital L. from here you can write tan 2 alpha; tan 2 alpha equal to r by L For small alpha tan 2 alpha equal to sin 2 alpha sin theta equal to tan theta for small angle.

sin 2 theta we can write 2 sin alpha cos alpha not theta sorry theta and alpha same, but here I have written alpha. 2 so for small angle cos alpha is 1. It will be 2 sin alpha it will be 2 sin alpha. Why we are writing this way because here we have 2 sin theta. Alpha you can write. This we can write 2 sin theta equal to r by L 2 d sin theta equal to L lambda. d equal to L lambda by 2 sin theta 2 sin theta is replaced by r by L

now d equal to just L we can write on top denominator to L by r lambda I can just take like this r by lambda for n equal to 1. we will only see the in our experiment first order. That is why I have written n equal to 1. to find out to find out the interplanar spacing I have to know this capital L

That one can either supplied or one can measure and these r by lambda. What is r by lambda? It is now lambda is if I change the voltage anode voltage accelerating voltage. I will get different wavelength and if I change, the wavelength for a particular spacing d for a particular d theta will change

For a particular d I can get different I can get different circle different circle diameter radius of the diameter will be different; that means, radius of diameter radius of the circle is a function of the wavelength

If we vary the anode voltage means vary the lambda then we can get different we can get different angle of diffraction theta for that r will be different. we will we have to measure r as a function of lambda. We can plot r versus lambda graph and the slope of the graph will give you give us the r by lambda.

We have to find out the slope of the curve, slope of the graph r versus lambda graph their slope we will use here and this l we have to measure or it is given. we can calculate d this d; it can be d 1 then for next for the same wavelength next circle will be d 2 etcetera that we will see and measure that is the simple it is a very nice experiment and it is one can just check one can just demonstrate the dual nature of particle and wave. I will demonstrate this experiment in the lab in next class.