Experimental Physics - II
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Lecture – 59
Frank – Hertz experiment

today I will demonstrate Frank – Hertz experiment. This is historically an important experiment.

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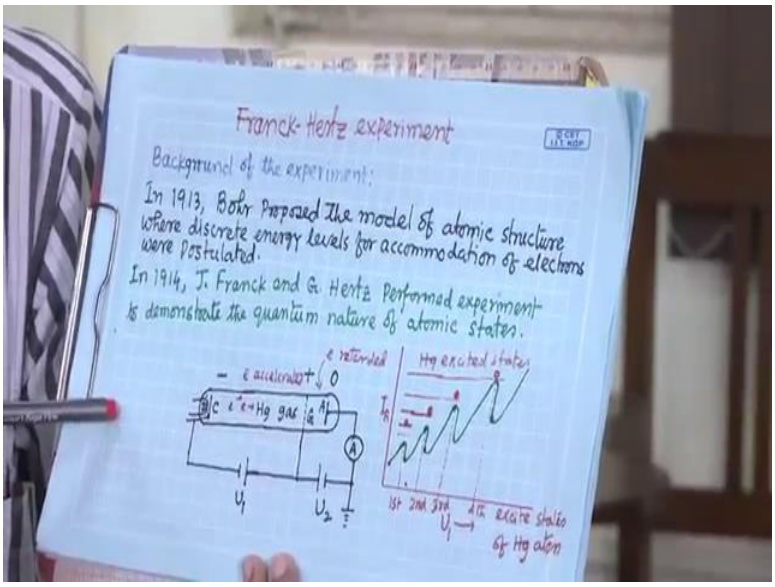

actually in 1913, Bohr proposed the model of atomic structure where discrete energy levels for accommodation of electrons were postulated. in atom there are energy levels that energy levels are discrete energy levels. that is that was the Bohr postulated that the electrons can rotate a certain energy levels certain levels and when it will rotate, it will not radiate any it will not emit any radiation. based on this postulates Bohr given the atomic structures in atoms how electrons are arranged.

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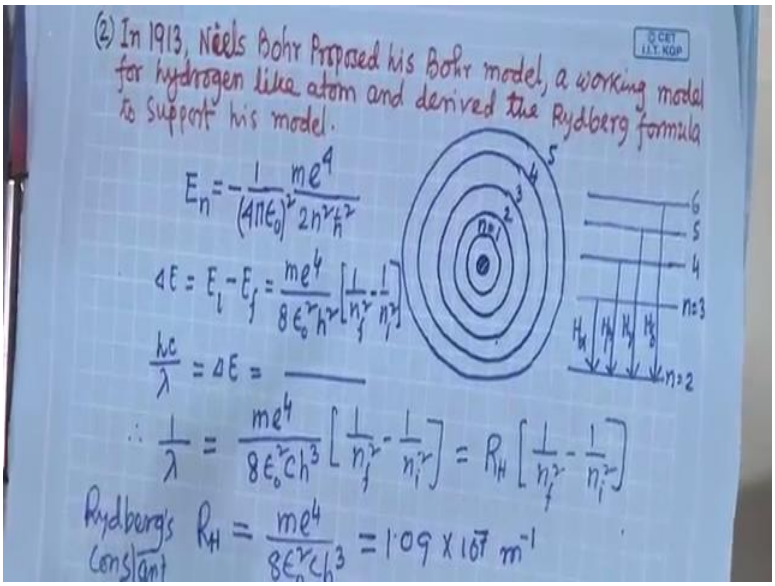

that this main point was the discreteness of energy levels actually you can think of like this is the positive charge concentrated at a particular regions. that is the nucleus. around the nucleus there are energy levels circular orbits or shells. electrons can only stay in this energy levels it cannot stay in other energy with other energy. that energy levels also we can draw with this horizontal lines.

in this case I have this is the n equal 2, n equal to 3, n equal to 4, n equal to 5, n equal to 6. n equal to 1 also there and he derived the energy of this levels. for n-th levels energy is n equal to minus 1 by 4 pi epsilon 0 square; m e to the power 4, m is the mass of the electron and e is the charge of the electron divided by 2 n square h cross square. H cross is h by 2 pi; h is Planck constant and n are the principle quantum number. that is the orbit number or shell number.

this was the quantitative expression for energy of the hydrogen like atom; hydrogen like atom means the outer most shell will have one electron and this theory is extended for other hydrogen like atom like sodium, potassium etcetera. Later on, also it is extended; it is extended it is connected to use for multi-electron system like helium and this lithium, then beryllium so for other atoms.

helium, neon, argon etcetera this is another group of atoms, it is we tell that is the inert gas. they are all shells are closed means this orbits have maximum capacity of accommodating electrons. when this maximum number of electrons are there in their

shell or in the orbits, then we tell it is the closed orbit or shell. It cannot accommodate more electrons.

helium is the 2 number of electrons, neon 10 number of electrons. they their outer most shell is closed. that is why we tell them that the inert gas it does not react with other atoms because it has no interest because this outer shell is full it and it is stable it cannot want to give electron to other, it cannot it. this atoms are not interested to share their electrons with others either do not want to except or do not want to get that is why it is how we tell them it is the inert gas.

anyway, there in 1913, that was the proposal of Bohr that we tell the Bohr model and their main important assumption was that the energy is quantized. It is the energy electron cannot take any energy. It can take only particular energy. that is the discreteness of energy levels. that assumption was experimentally verified by Frank and Hertz immediately next year.

that is why it is this Frank – Hertz experiment which demonstrated the discreteness of energy level. that is why it is the historically very important experiment. that experiment today I will demonstrate in our optics laboratory. in 1914 J. Frank and G. Hertz performed experiment to demonstrate the quantum nature of atomic states or energy levels. this is the experimental setup is very simple. this is a tube glass tube. in this tube there is a cathode which will emit electron. this cathode is heated with heater I have done here filament now electron will be emitted.

Now, in this tube this helium gas is used helium gas is used. when this electrons will move it will collide with the mercury atoms mercury atoms. Mercury atoms are available in gaseous form in this tube and this electron will reach to the will reach to the anode positive cathode is generally negative terminal and anode is positive terminal. this electron will reach to the anode and we will get; we will get some current because of the flow of this electron through this anode. we will get current that is called the anode current.

that anode current, why we are getting? Now, from the cathode electrons are emitted and that electrons through this tube will come and reach to the; reach to the anode and that will go to the that electrons it is the grounded here. some positive voltage is given it is

the grounded it is the grounded . it is the similar to negative voltage it is grounded. it is a we will get current in that is called anode current in this circuit.

Now, question is that electrons emitted from the cathode it will have some energy thermal energy. with that energy it cannot travel this length if you do not give some external energy. that is why this here we are showing this is a grid. This is the grid; grid means it is the one wire but having the holes; having the holes so that this will act as a; here we are giving positive voltage with respect to the cathode.

electrons will see the potential difference between the cathode and this grid that potential that is the positive potential electrons will be accelerated with energy e V e and this potential difference V e V. in this case it is U 1. e U 1 with this potential difference or e V U 1 tie with it energy it will come to the grid and it will pass through the holes of the grid that is why it is called grid . it is a small holes are there and here actually here we have given some negative voltage small negative voltage.

when this accelerating voltage or energy of this electron that is kinetic energy e 1, when it will be greater than the that energy that the potential U 2. when it will be able to overcome this retarded potential here negative potential means retarded potential, then it will reach here.

for this experiment what we do we give a small retarded potential so that with this thermal energy whatever the electron emitted from here. with this small energy it will not be able to reach in the anode, initially it will not be able to reach to the anode that is why we will not get any anode current. Now, what we will do? We will increase this increase this U 1 voltage; that means, I am increasing the energy kinetic energy of this electron that is e charge e U 1.

then that electron will overcome this retarded potential and it will reach to the anode I will increase the U 1 and more and more electron will reach to the anode and I will get more and more current. I will like here I have drawn it I will get more and more current more and more current. at this U 1 potential suddenly, we see the drop of the current suddenly we will see the drop of the current and then again, we are continuing the increasing of the U 1, then we are continuing the increasing of U 1 and then again current is increasing.

instead of monotonous increasing of the current it is giving us like step kind of increment of the current. that means, at certain U 1 voltage it is suddenly this current dropped suddenly this current drops a question is why this sudden drop of the current anode current is coming? Sudden drop of the anode current means the at that voltage this suddenly electrons sufficient number of electrons are not reaching to the are not reaching to the anode. and that is happening at particular voltage not all voltage it is a particular voltage.

this reason is behind this is that the mercury atoms are there is. in mercury atom it is the atom it is the atom. electrons while moving through this gas it will collide with this atoms there will be scattering. that is elastics scattering this electron will not lose any energy. that is why it is called elastic scattering, but at certain voltage we are seeing that this anode current is decreasing means electrons is losing energy somehow it is losing energy and it has no sufficient energy to reach to the anode.

most of the electron will not reach to the anode at a particular voltage. this is happening because the inelastic scattering of the electrons at this particular voltage, what is that? it may happen that at this particular at this energy at this voltage this mercury atoms it is the due to the collision of the electrons though electrons the energy of the electrons are absorbed by the mercury atoms

And, this absorption that is elastic scattering this absorption of the energy by mercury atoms it is happening only at certain voltage at certain energies. this is it may happen if this mercury atoms have discrete energy levels. when the energy of the electrons is equal are equal to the energy difference of the energy levels of the mercury atom that energy will be absorbed the absorbed by the mercury atom and the electron from lower energy level to the higher energy level it will jump

if then there are certain energy levels in the atoms in the mercury atoms and there are energy difference between these energy levels and when the energy of the electrons are matching with the energy of the difference of the energy levels of the mercury that time it is absorbed and electron will lose the energy its kinetic energy and it is unable to reach to the anode, that is why this suddenly current is dropped.

And, this is happening for a for energy different between closed energy level between the nearest two energy levels and then second one is happening it is happening between the

say this is if this one is for first and second energy level. next one will be first and third energy level, then next one will be first and fourth energy levels. it is it will be able to jump to the higher and higher and higher energy levels of mercury atom when the energy of the electrons is matching with the with that energy difference of the energy levels of the mercury.

this was observed. This type of pattern of the anode current as a function of as a function of accelerating voltage this kind of pattern was seen, and this pattern is clearly demonstrating the discreteness of the energy levels of atoms. now, this experiment I will demonstrate in our laboratory. here you can see the experimental setup.

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here you can see; you can see that tube that glass tube where that mercury gas is there mercury are there. Now, in this tube we have cathode we have cathode.

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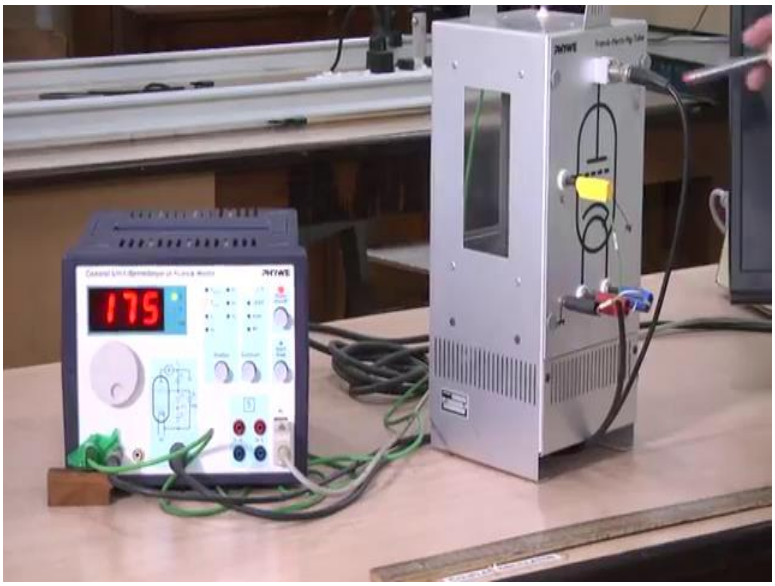

here you can see. this diagram is drawn here diagram is drawn here. I think yes diagram is drawn here. this is the glass tube from whatever I showed here this is the glass tube this is the cathode this is the cathode and U H here whatever written that is heater current that filament heater current is given to this filament and then that cathode it is the it is connected with the negative voltage U 1 you see U 1 negative voltage and then we have grid here in my diagram I have showed you the one grid, but here if there are two grid.

this is one grid, and this is another grid, but both are connected with this voltage U 1. it is same one can use one grid, one can use two grid there is no problem, but same voltage is given U 1. this is the accelerating voltage, and this is the anode, this is the anode and this anode is grounded or here it is the U 2 voltage. this is the de-accelerated voltage is given to the anode U 2 this negative voltage cover with respect to the U 1 grid voltage, it is negative.

it is the retarded voltage for the electron and U 1 is the accelerated voltage for the electron. Retarded voltage between the grid and anode why it is given I explained that with small energy electron will not be able to reach to the anode. we will not get current. here electrical connection I think I can show you. this is the power supply from here we are taking this connection this giving to the electrode.

it is the here U H is retained. heater current heater voltage is given it is power is given. here it is written U 1. here it is U 2. this from this power supply this is here it is given, and you know mercury is liquid to make it; to make it gaseous form, we have to heat it. there is option to heat this gas this mercury to make it to make it gaseous form.

here we can see there is a one thermo couple is there to measure the temperature. now, here you see in this power supply here 177 you are seeing here this temperature this is you can see T actual. this is a in degree centigrade. this is the temperature constant temperature for the mercury gas to keep mercury in gaseous form. this temperature constant temperature is kept.

And, here you can see this I can change here it is a I A means it will show here anode current anode current it is now 0 and here it is showing this U H; U H means heater current is given heater current is given this is the U H 1.2 volt and it might continue this is U 1 voltage U 1. here this is the upper limit we have put here. maximum 60 volt we can apply. that is the restriction given by the company that we should not apply more than 60 volt accelerating voltage.

And, then if I change it is a U 2 it is the here you see 2.0. that is the de-accelerated voltage, we kept it constant, we will not change U 2. some small de-accelerated voltage is given between grid and the anode between the grid and the anode and then this is U 3 there are some other options also there, but we do not need.

here what we will do. this experiment we can do in manual mode as well as automatic mode. now, what I will do here I will yes, I think I choose PC mode, no, I choose PC mode.

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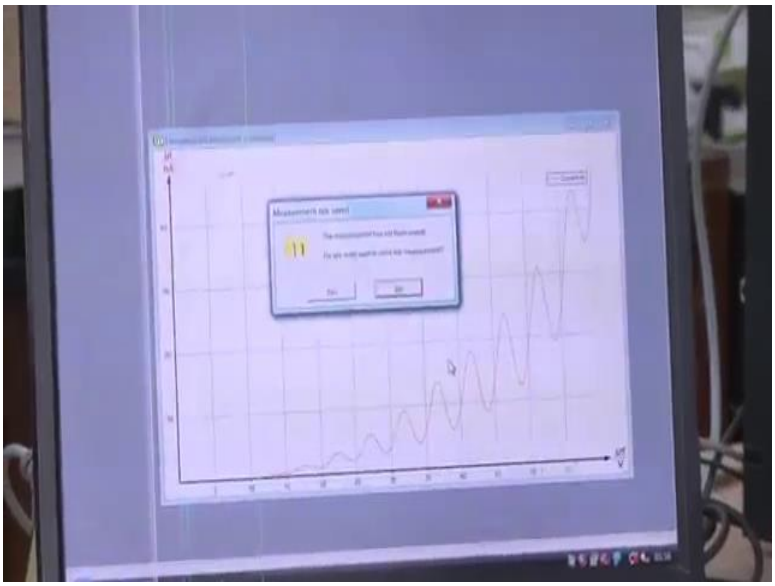

in PC mode means. here we have interfacing with the PC here we have interfacing with the PC we have interfacing the with the PC. you can I will just there is a software. There is a software, this is given by the company. you forget automation of the instrument here manually I can change the what I have to do the what is the experiment? Experiment is I will change U 1 and I will change U 1 and I will note down I will note down the current I A.

manually you can do manually you can do and then we will take the data and we will plot or the data in a graph. then you should what is the type of pattern you should get that I have shown you. instead of doing this noting down the data and plotting in graph paper here this screen I am using this screen I am using that will be displayed that graph will be displayed directly here. in PC mode I think in PC mode I will show you. in PC mode means I am using this one this screen only

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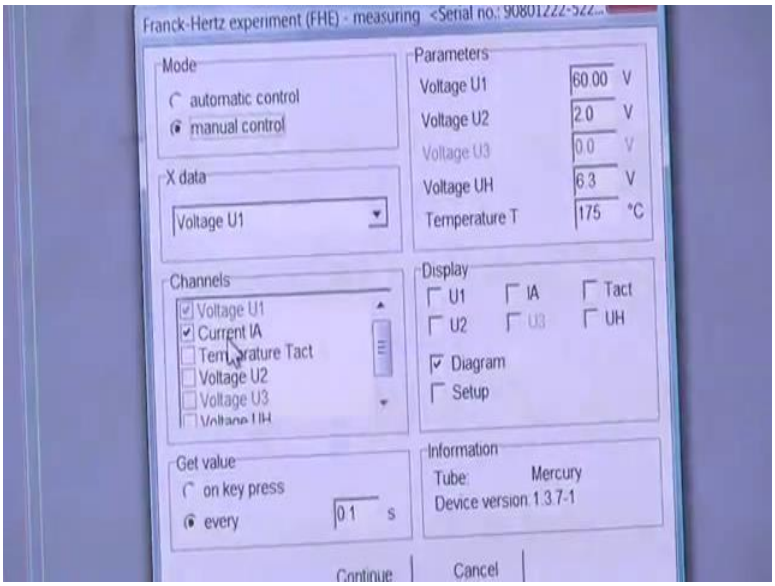

what I will do here I will select this experiment Frank – Hertz experiment I will select this Frank – Hertz experiment. here option is that automatic and manual control. I want to do manually means I will change the; I will change the U 1 and note down the; note down the I A and then I will plot. that I am not noting down

this PC will help me a just I will change the I will change the U 1 and corresponding current. that will be that U 1 versus IA that will be plotted directly on the screen. if I take this one manual, I have chosen this is the showing this it will give me current I A.

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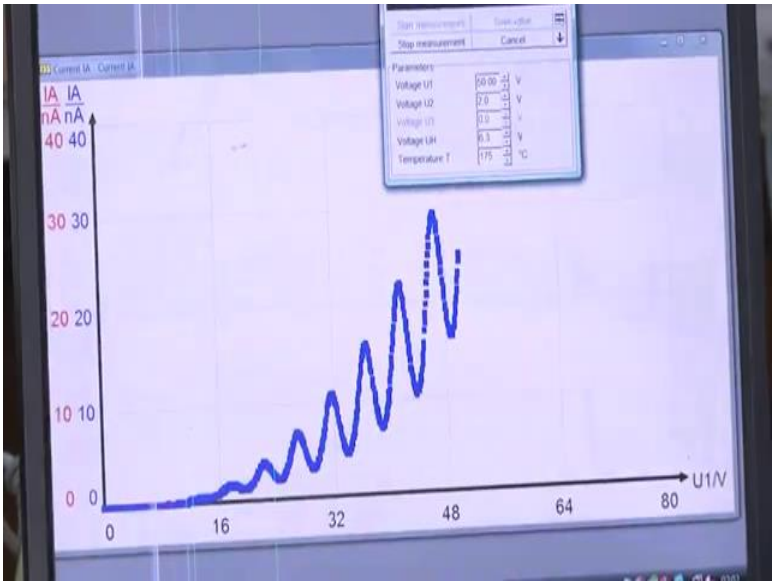

And, I will change the voltage; I will change voltage here I will make it 0, I will make it 0 U 1 voltage initially I am putting 0 and U 2 I am keeping this is following errors of a T 0 there is no voltage given I think five. it is showing me data that your temperature is 175, your heater voltage is 6.3 and U 2 is 2 volt fine and U 1 is 0 volt. I will start experiment; I will start experiment. U 1 is 0 current is here it is a 0 here then I will change; I will change the U 1 0.1, 0.2, 0.3.

Here you can see it is the current it is the plotted corresponding current is plotted I am changing 1, 1.1, 1.2. quickly I am changing because initially I need some higher voltage. now, it is 5 volt. At 5 volt you can see still IA is 0, current is 0 anode current is 0. Then, I am going fast I am changing U 1 it is the around 8 yes 8.1 I am changing; I am changing you see still it is the 0 current is 0, scale is automatically changed. Now, slightly current is coming; slightly current is coming, but not stable.

Now, current is increasing you see. I am continuously changing current is increasing and then yes current is you see the change of current I A with the U 1 voltage it is like this; it is like this. I am using the. here I am changing the using mouse to change the U 1 and you see the current is changing like this with the U 1 voltage now U 1 voltage is 34, then 35, then 36, 37, 38, 39 39. I will it is now 45, 46, 7 48. I will go up to 50 It is the 50 you see U1 voltage is 50 and then current is changing like this.

whatever the pattern I have shown whatever the pattern I have shown which we are expecting if the mercury atom has the discrete energy level this kind of variation of the anode current is expected. And, that is because of the setup of the experiment there we have applied retarded potential U 2 and we have applied the accelerating potential U 1. exactly the same; exactly the same type of pattern we are getting on the screen we are getting on the screen.

from here one can find out this. where current is dropping where current is dropping that voltage corresponding that e U1 that is matching with the energy level with the energy level one energy levels of the mercury atoms ok, then the next one. that way you are getting different number of peaks.

this manually one can do this experiment. this is the demonstration that these pattern of the anode current is nothing, but the signature of the discrete energy levels of the atom. that is the historical experiment and it confirms the postulates of the Bohr. It confirms

the atomic structure; atomic structure proposed by the Bohr. just here also one can take the do this there is this experiment. I will stop this experiment I will stop this experiment.

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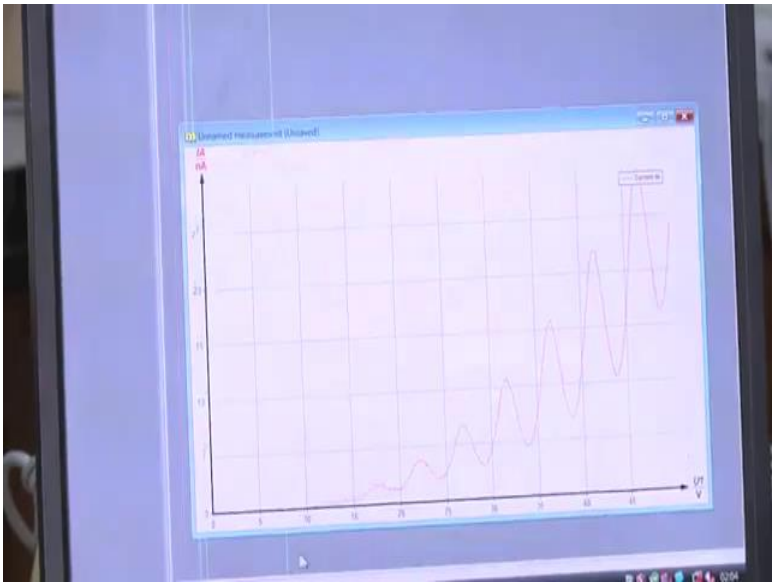

And, here whatever we have taken data. that is, one is that is one is here. this is U 1 this scale is U 1 by V means in volt and this is IA anode current by nA means nano ampere in nano ampere. this also one can do this experiment automatically in automatic mode.

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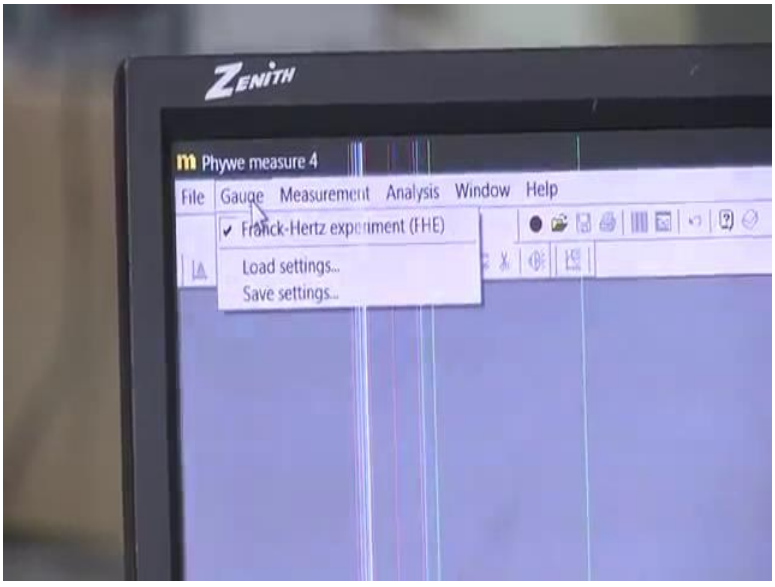

computer software itself it will vary the U 1 instep and it will note down the current IA and it will plot here. that let me show you, but this that is not important; that is not the

important for the experiment. That is nothing, but the sophistication of the experiment. without this screen also you can do the experiment manually you have to note down, but we since we have done this interfacing that is why we are using it. actually, you do not need this computer or intervene.

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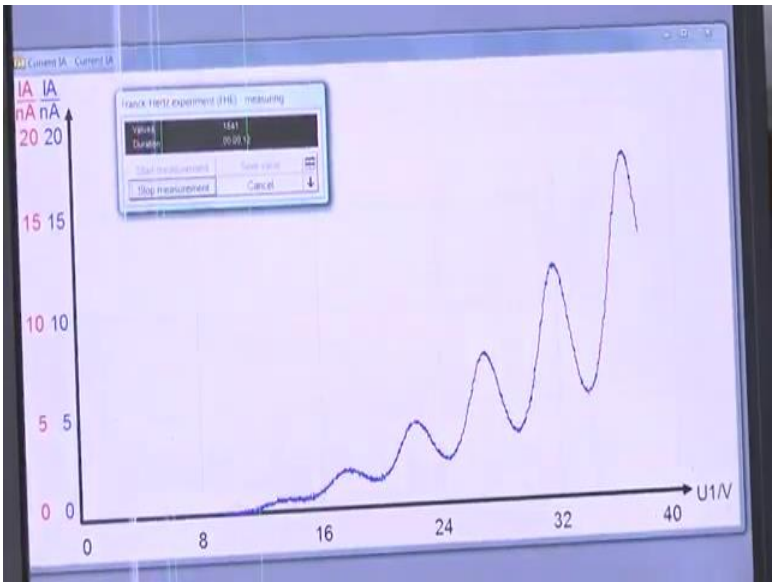

we have to automatic mode if I choose then continue you can see I start experiment you can see I am not doing anything just it will it is just changing the U 1 and plotting the current variation of anode current variation as a function of U 1 at a particular temperature of course, we have chosen. this is the experiment is done

you are getting that same whatever manually I got it is in automatic mode also we have got the same thing. And, if you do note down the data change here itself and note down the data and plot in a graph you will get this. And, from this from this peak actually we take this position here dropping position where it is dropping if you note down and you can try to match you can try to match the with the energy levels of the mercury.

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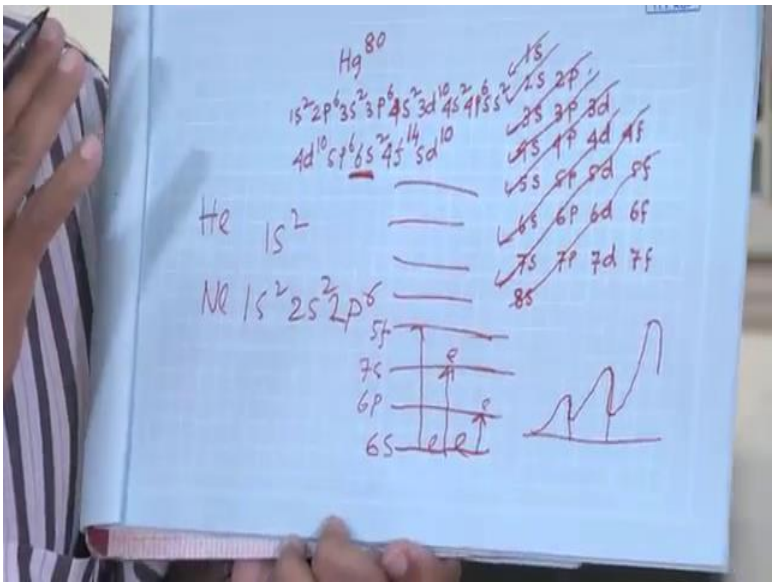

I think that I am not going to do, but just to give this one hints. mercury there is a 80 it is the atomic number. if you; here this above principle how electrons are arranged electrons are arranged in the energy levels that you know. here I have just 80 electrons I put like this. here you can see this outer most level is 6s and here this two electrons are there. this mercury it is structure electronic structure is similar to the it is similar to the inert gas you know. Helium, you remember it has two electron and it is 1s 2 Neon, it has 1s 2 2s 2 2p 6 10 electron. its structure is like this.

that is why it is the it is not inert gas, but it is the it is behave like it does not react with the other ambient atoms. and also it is easy to get in pure form liquid form pure form and it is it does not react with it is like an inert gas atomic electronic structure and you can make it easily after applying heat at 175 as I showed you can make it gas form. that is why we have used helium. not we have used. it was used that time by Frank – Hertz. that is the reason why helium was used

now this 6 level outer most energy level 6 level. this 6 6 s. Now, you can plot 6 other 6s then you have 4 f, 5 d, after that 4 f, I think then 4 f is full, 5 d is full 6 p. 6 s then 6 p and 6 p, then 7 s, then 7 s, then 5 f, then 5 f this kind of energy levels are there. here two electrons are there if you heat this electron depending on this energy kinetic energy of the electron it will jump here it will absorb that energy electron as it will jump here then if energy.

it is the first because of this you are getting this say this first drop and then you are increasing the energy, energy is sufficient it is difference is like this then it will again you are changing the U 1 it is the increasing; increasing; increasing when it will be energy will be equal to this energy difference between this two levels then it will be absorbed and the it will jump here it will jump here then again it will this way.

that is the reason of this energy drop and which is the signature of these discreteness of the energy levels of the atoms. this fantastic experiment, simple experiment, historically very important experiment. And, from this value actually one can exactly it is difficult some correction we need, but approximately you can find out this structure of the energy levels. this what are the separation of the energy levels above the 6 s that one can find out. I think I will stop here.

Thank you for your attention.