Experimental Physics - II
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Lecture – 58
Thomson experiment to determine the specific charge of an electron (e/m)

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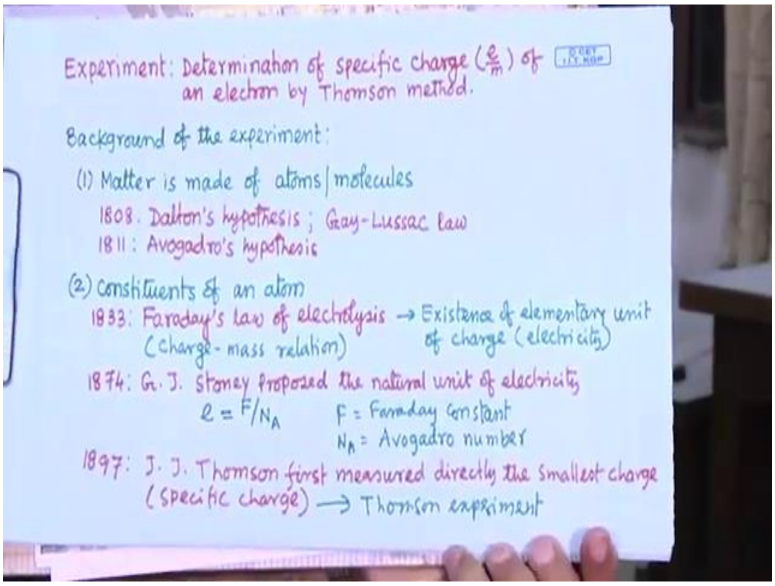

today I will demonstrate one experiment that is Determination of Specific Charge of an Electron by Thomson Method. is very popularly it is a we call it e by m, measurement of e by m; e is the electronic charge and m is the electronic mass?

what is the background of this experiment; why this experiment is so important? background of this experiment; if we just see the history, so matter is made of atom when we came to know or when, so that was also it was hypothesis. first this matter is made of atoms or molecules. that is a first this from Dalton’s hypothesis and Gay Lussac Law in 1808. that time, so they give this hypothesis that, matter is a made of indivisible, we cannot divide; so smallest particle, so that is a atoms or molecules,

we cannot divide them. that is a smallest elementary particle for the matter. that time that they told, and then 1811, so they Avogadro hypothesis, one gram mole of the any matter contains fixed number of the smallest particles; atoms and molecules. that is the Avogadro hypothesis, it is the 1800 around starting of the 1800, so matter is made of atoms, so this concept and atoms cannot be divided further. it is a smallest particle or element of the matter. that was the concept during this beginning of 19th century. then this yeah; what is the constituent of an atom, what is there? in 1833 Faraday's laws of electrolysis, it is tells about the existence of elementary unit of charge,

there is a charge in the, there is a charge attached with the atoms and molecules and that charge attached with the atoms and molecules. there is an elementary unit of charge. charge cannot be less than that elementary charge, that type of concept and charge mass relationship, there is a relation between charge and mass of the matter. that came to, we came to know from the Faraday laws of electrolysis; then 1874 G J Stoney proposed the nature of the unit of electricity.

that e equal to this elementary charge, elementary unit of electricity, so e equal to F by N A. F is from this Faraday's electrolysis, this is called faraday constant and N A is the Avogadro number, that charge, so Stoney mentioned proposed that this the elementary unit of charge will be this, and J J Thomson first directly measured the smallest charge that is specific charge, charge per unit mass, that is the Thomson experiment, it is a he did that experiment in 1897,

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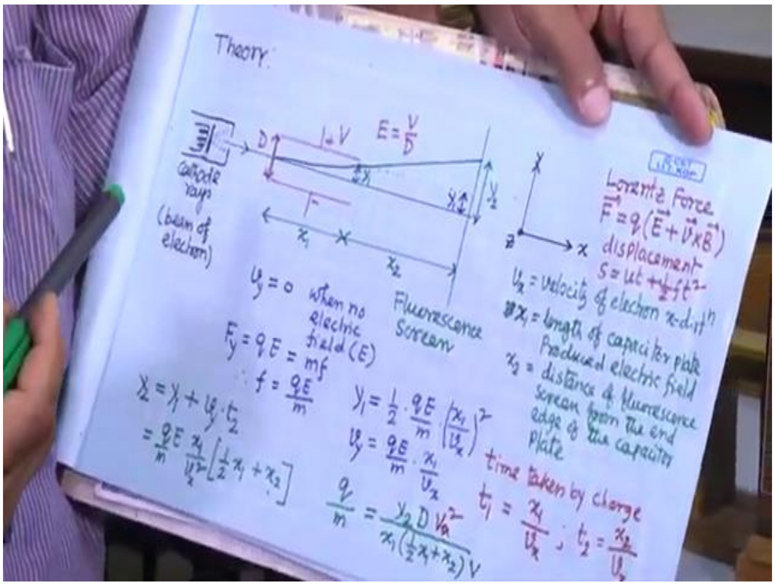

that Thomson experiment what is that experiment; that we will demonstrate in our laboratory. let us see the theory of that experiment. this you have a generally we will use cathode ray tube, CRT cathode ray tube it gives the in cathode ray tube what is there? there is a filament and then cathode, electron, so this cathode will emit electron; now that electron there is a if P acceleration voltage is given in the cathode ray tube, so that the electron will move with some velocity V along the x direction. velocity is V x. it is moving along the x axis and there is a screen, fluorescence screen in the CRT tube. that this electron will come and hit on the screen,

at the canter of the screen it will hit. we can see this position of the electron on the screen. Now, if you use this two capacitor plate, so if you apply electric field; how to generate electric field? If you take two metal plate and apply voltage between these two plate, then there will be electric field that is V by D. D is the distance between this two capacitor plate,

there is a two plate. this plate length is x 1 and this separation of the plate is capital D and from this plate it is a we are telling y plate it is a we are telling y plate. from this plate the distance of the screen is x 2. from these edge. from here to here, this is the distance of the screen from this plate from here, so x 2,

electrons are moving, cathode ray are moving it is a made of electrons with velocity V x. Now, we have a capacitor plate, this we are telling y plate; there are another sets of capacitor plate in CRT. that we tell the x plate. if you take another direction x, then this will be z direction, but forget that one. we are taking this is the x direction, this is the y direction and perpendicular to this that is the z direction

now if we apply voltage; means if you apply electric field, so what will happen? there will be force, Lorentz Force which will act on this charge particle; if electron charge is q. Lorentz Force is defined by that F equal to q E plus V cross B; V is the velocity and B is the magnetic field, e is the electric field,

since there is no magnetic field here. due to this electric field q E will be the force and this electric field this direction is along the y direction. that force electric, due to the electric field, so that is q E and this force is m mass into the acceleration f. f acceleration is q E by m. this is the, so then electron when it will enter into this plate region. it is velocity along the x axis V x is along the y axis V y velocity is 0.

when it will reach at the other end of the y plate. what will be the velocity as well as what will be the displacement of the charge of the beam along the y axis? initially V y equal to 0, when there is no electric field, And now y 1, here y 1 will be you know this u t plus half f t square; u is the initial velocity, t is the time, initial velocity along the y direction is 0.

Y 1 will be equal to the half f t square. half f; f is the t square. if it is timed, if this beam is taking time to come from this point to the other point, it has to traverse the x 1 length and if it is velocity is V x along the x axis. time will be taken that is t 1 equal to x 1 by V x here that; it is taking time to. initial velocity along the y axis is 0, V y is 0.

Now, after time t 1 when it will reach at the sense, so what will be it is velocity and what will be it is displacement, ok? displacement will be half f t square, t 1 square and velocity will be V y here at this point, velocity V is u t plus f t; u plus sorry, u plus f t; u is the initial velocity along the y direction that is 0 and this f t; f is q E by m, t time t 1 . t 1 is x 1 by V x, that will be the velocity, V y at the other end of the capacitor plate and displacement will y 1.

after that there is the other end, other side there is the electric field, what it will do? there is no force elect on this charge when it will come out from this capacitor area. no force, no acceleration, so it will move with this velocity ok, in the same direction it will move ok; here it is parabolic and then with this slope at this end this with this slope it will move, and it will hit the screen at this place,

these displacement if it is Y 2 from this position Y 2 is equal to total displacement from the centre, y 1 y 1 y 1 plus, so it will move with velocity V to V y. And how long it will move? the time it will take to move this x to distance by velocity V x along the x axis, time t 2 is x 2 by V x; x 2 by V x with during this time, with this velocity V y ok, with this velocity V y, so it will move along the y direction

this will be then your velocity V y into time t 2. velocity V y is. if we use Y 1 is where I got this one and V y is this one and then t 2 is x 2 by V x, so here x 1 x 2 by V x square. y 1 plus this, so here q E by m is common and V x square is common. q E by m V x 1 by V x square we have taken common, so here half x 1 plus x 2. from here you can write q by m equal to Y 2 and E is nothing, but V by D, if I put V by D. Y 2 D, then V x square divide by x 1 being bracket half x 1 plus x 2 and divide by that is V this is the q by m or E by m and formula in formula what are the things? Y 2; that means, this displacement after applying electric field for a particular voltage V, so what is the displacement? that we have to know, we have to measure; second for what voltage the displacement we are getting. the voltage that we have to know, and you see x 1 x 2 and D that this parameters are constant for a particular setup, for a particular CRT, Cathode Ray Tube,

this value will be supplied by the manufacture; x 1 means what is the length of the capacitor plate; what is the distance of the screen from the capacitor plate ok, as we have what is the separation of the capacitor plate. these will be supplied by the manufacture of the CRT. Now from CRT also Y 2 I can get, also V how much I am applying, so that we will know; but now only this V x that is unknown that how to measure that V x ok, we have to measure this V x. then we can find out q by m.

now to measure the V x, we use magnetic field, because this in magnetic field also there will be this electron beam will experience Lorentz Force and due to that there will be displacement.

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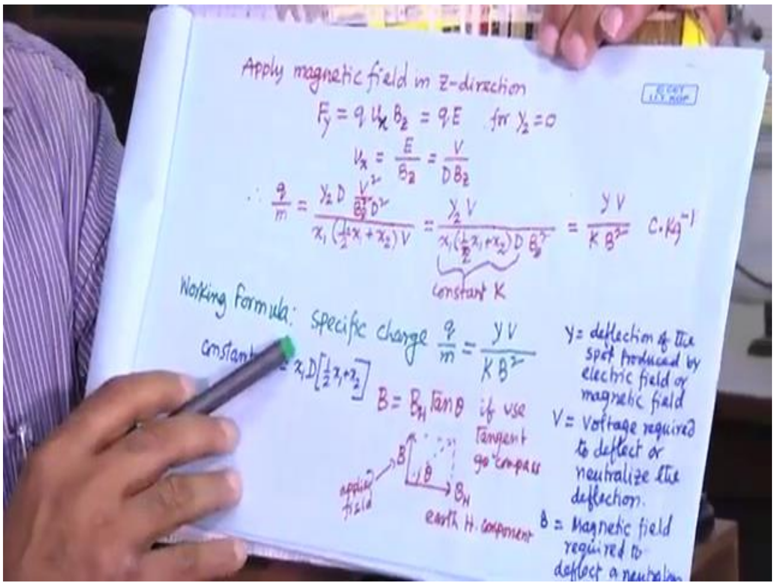

that V x we have to find out. for finding out the V x, we will apply magnetic field in the Z direction ok, so along the x direction this electron beam is moving, V x velocity.

Now, along the Z direction if I apply magnetic field, so V cross B. that force into q; that force will be along the y axis, electric field also it is a along the y axis and corresponding force was acting along the y axis. displacement of the electron beam we got along the y axis. now, if I apply the magnetic field along the z axis, then since V cross B, V x is along the x axis. there will be force on the cathode ray along the y axis.

what we will do, we will apply magnetic field and we will change the magnetic field and choose the magnitude of the magnetic field in such a way that, the y displacement whatever y displacement. electric field whatever it is force due to electric field the whatever the direction. magnetic field direction we will choose in such a way, so that force will act in opposite direction, And this we will apply the magnetic field, the magnitude of the magnetic field in such a way that the force due to the magnetic field in opposite direction will be equal to the force due to the electric field.

when we will know that these two force are equal, so we will know. electric field whatever it made the deflection Y 2. due to magnetic field, so this it should displace the same amount in the downwards. it should come to the centre; that spot should come to the canter again, in that condition these two force will be equal and from their you can find out V x.

V x is E by B z equal to V D E is V by D. V by D B z. q by m equal to Y 2 D; now here we have written V square, this not velocity it is the voltage square, B z square D square; because V x square was there, so that we replace by this and this term is there. ultimately, we are getting Y 2 V by x this term into D. this is the constant for a particular CRT and B Z square.

if this is the constant for a particular CRT, so we can write K. Y, so in general we are writing Y deflection on the screen Y voltage V divided by K B square. we will apply the electric field means we will apply the voltage whatever the voltage we are applying. and for that what is the displacement? this we have to note down and to nullify this displacement what is the magnetic field, we have to apply. that we have to note down and K we can calculate from the supplied data from the manufacture. we can calculate q by m,

working formula for this experiment is q by m equal to Y V by K B square. Now, we will use permanent magnet to magnet bar magnet we will use and we will use this compass you know this compass it is a needle directed towards the north and south due to the earth magnetic field and that earth magnetic field we know that is that if say it is B H earth magnetic field due to this needle was this along the north and south.

Now, if I put the magnetic field this two bar, if I keep and corresponding magnetic field is B. for this B and this earth field, so this needle. we will move; we will move with some angle theta. if we can measure the angle theta then B equal to B H tan theta, because B by B H equal to tan theta. B equal to B H tan theta. B H is the earth magnetic field. that we know now from the compass we will see we will measure the, we will note down the angle theta. we can calculate the field apply to the to our experiment,

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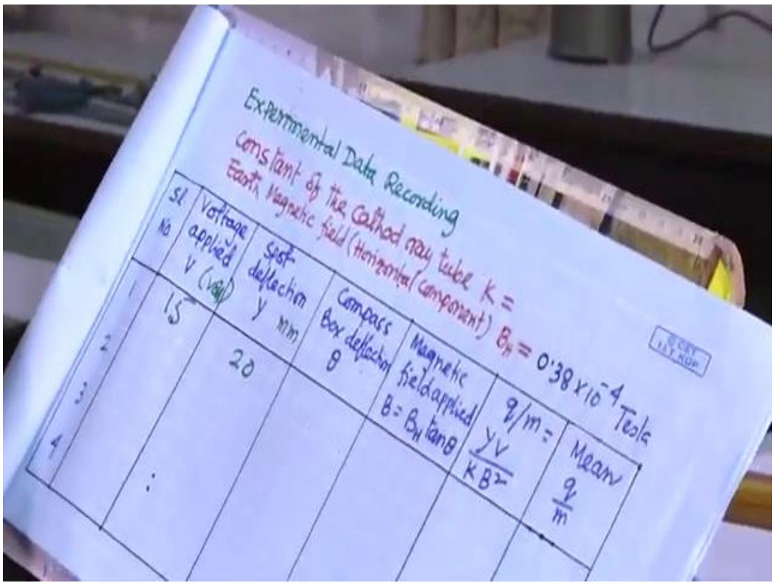

B we will get this way. I think yes; if we proceed for taking the experimental data, so experimental data recording. constant of the cathode ray tube K equal to, we have to write down because I can show you in manual it is a given, so this is the manual given by the company.

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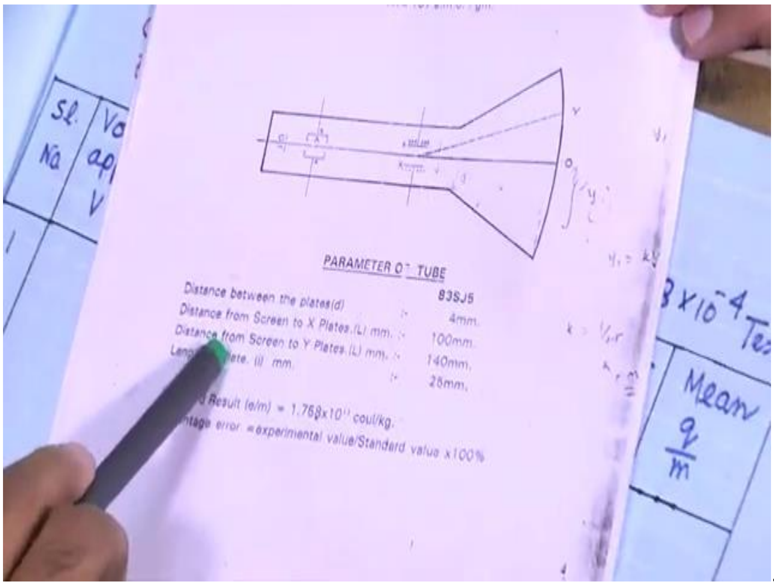

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here you can see the distance from screen to Y plate means here this capacitor plate ok, L means I have taken the that is x, that is x 2. x 2 is 140 millimetre and length of the plate, so that is here small l. I have written x 1. x 1 is 25 millimetre and distance between the plates that is capital D I have written. that is 4 millimetre.

this data is given by the company for the tube, CRT tube, from this data we can calculate K, since this formula is there for K. one should do that and write this constant here K equal to this and earth magnetic field, this original component B H equal to it is given 0.38 into 10 to the power minus 4 Tesla, fine. Now what we have to do, we have to take data.

just in CRT tube you apply voltage V, for that what is the deflection of the spot, we have to note down and then you put the magnet, means magnetic field and for that what is the deflection of the compass. that to bring down the spot at centre position means deflection will be 0, net deflection will be 0 in presence of electric field and magnetic field. we will note down this for that this theta, so corresponding magnetic field you will get. you can calculate q by m equal to Y V K B square.

this type of 3, 4 measurement you should do, repeat the measurement for different value of V and take the mean of that.

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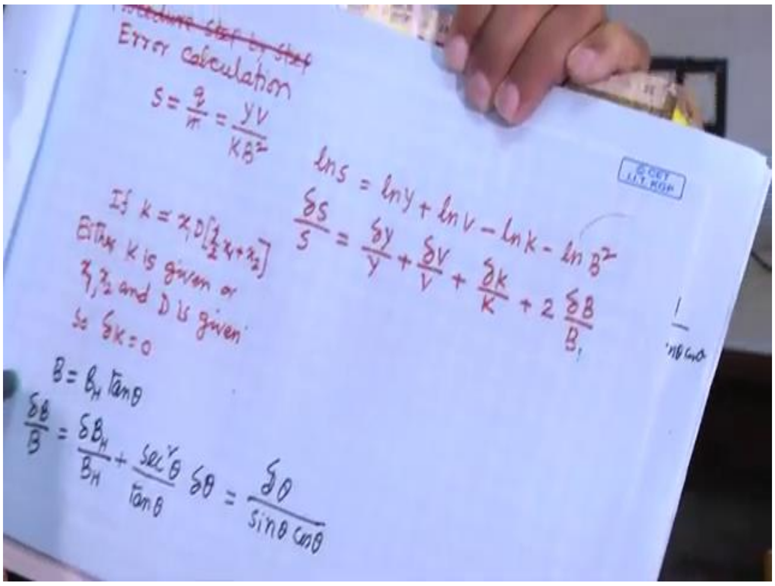

that is the experiment and of course, one can calculate the error calculation one can do. So, this specific q by m, this is the specific charge if it is S, so Y V by K B square. take log and then del S by S equal to del Y by Y plus del V by V plus del K by K plus 2 del B by B.

So; obviously, this K is calculated one from supplied data, so there will not be error. Voltage, that power supply whatever we are using, so their voltmeter is there, so what is the smallest least count of this voltmeter, what is the least count of the screen scale from where we are taking reading. that we have to note down and B is B H tan theta, so del B by B is del theta by sin theta cos theta, ok

we are measuring from compass; we are measuring theta. what is the least count of that compass scale, so that we have to note down and theta you know, so we can calculate this del B by B, then ultimately you are getting the percentage error or maximum probable error, I will show you now the experiment how to do it.

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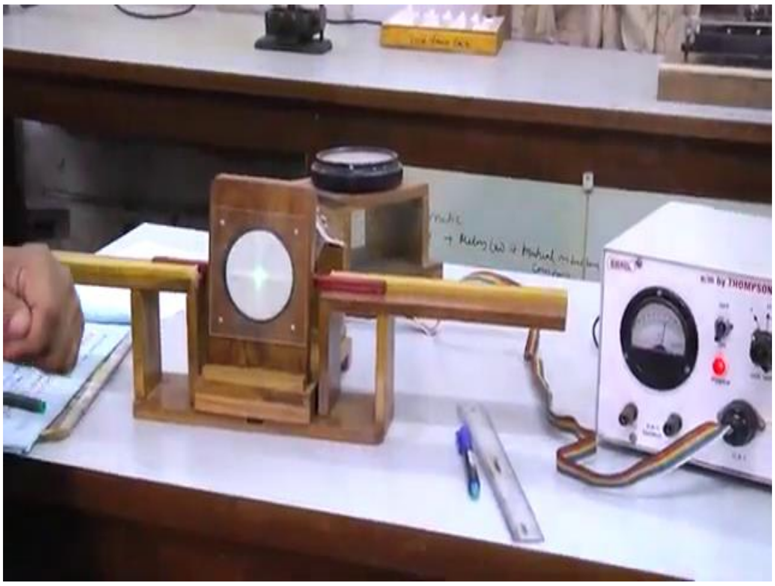

this is the experimental setup for here written, you can see e by m by Thompson method, ok

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this is the cathode ray tube, CRT tube. in CRT tube; this is the screen, this is the screen and that tube, this tube I can show you in principle, in experimental physics one, there I have shown the tube and discussed in detail. here insight there is a cathode filament cathode and then there is a pre acceleration for the cathode ray and then in between there are capacitor plate. all power is given from here, all power is given from this source here is a written you see this deflection voltage; deflection voltage, means in this cathode ray tube there are two sets of plate, one is for Y plate and another for X plate, so there are plates here. one is top and another bottom. it will produce electric field along the, say y direction, another if it is z here, they are considering z direction, but in my theory, I have considered this is the x direction. anyway, no I considered that z direction because x direction I have taken this direction, but it does not matter.

So here there are another sets of plate, this if I put it in 0, so this x shift y shift, you can just you can put at the canter position, here there is a scale, it is the millimetre scale you know. it is a smallest division is 1 millimetre. So big, I think I have to keep a middle; there is a big yes, I think there is a big to yes. one as to keep, so it is a because I am, so one has to keep at the canter,

now what we have to do?

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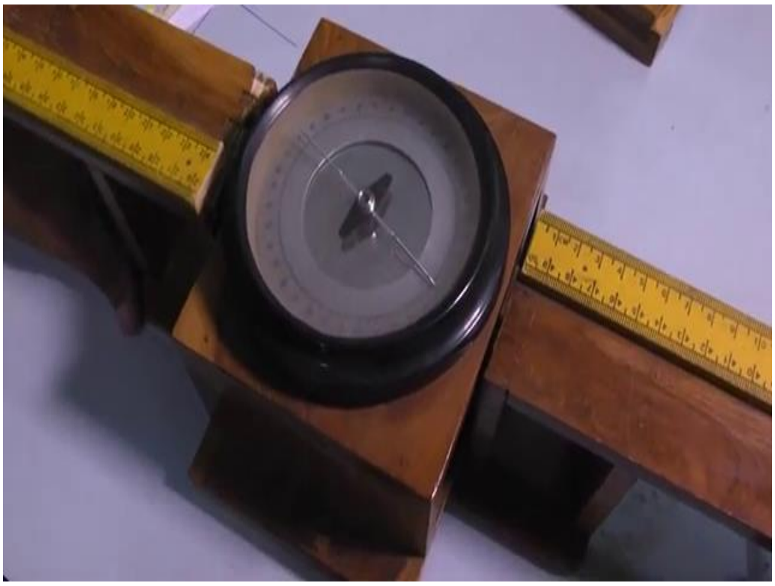

actually, before starting experiment I have to, so this is the compass. I have to keep, find out the north and south direction. I will put it here and the setup I should keep, yes along the north and south direction, so that needle will be at the 0 position. I am trying to make it 0 position, I am trying to yes. this is the 0 position you can see ok, needle is at 0 position along the, so now this direction is at the, so my setup is elongated or directed along the x axis and along the north and south direction fine.

I will not disturb this alignment. So now, what I will do? I will take out this one without disturbing the other one ok, I will keep it here, Now this I will put here because reason is that, so when I will apply magnetic field I will use these two platform for putting the bar magnet, since I have to find out the magnetic field using the compass, so that is why I initially I have setup that.

Now, here what I have to do now it is, there is no electric field, electron beam is coming and hitting at the centre. Now I will, as I told that there are two sets of parallel plate along this direction and along other direction. I am choosing this direction. this are y direction, Y plate I am choosing here ok; that means, I will apply voltage to the Y plate. here now voltage is 0; it is a 0 voltage Now, I am giving voltage to the Y plate, and you can see this it is moving ok; say it is I will keep at this position,

this shifting is 20 millimetres. This shifting is, from here you can see the shifting is 20 millimetre and corresponding voltage how much, you have to take reading from here. It is here I can see this is 10, 20 in between the 15; it is the 15 volt yes, it is the 15 volt. I have to note down the electric this voltage 15 volt. I have to note down the voltage is 15 volt. I have applied voltage 15 volt.

one should take accurately just roughly I am taking first observation 15 volt. V is in volt one should write ok, 15 volt and Y deflection it is a say millimetre, so 20, 20. now to make it 0, I have to apply magnetic field.

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I have two bar magnet, you can see. North Pole and South Pole, South Pole and North Pole ok; so, I have to put this way North Pole, if this one North Pole. South Pole I have to keep other side the South Pole. there will be magnetic field in between. here I am putting this say here. There is a scale, I have to keep in equal distance, here 43. from here this is I think this is a 1, 2, 3, 4, 5, 6, 7. it is a 7, here also I think here I have to go for 7 division, so 1, 2, 3, 4, 5, 7, so here here I have kept North Pole and here I have kept South Pole,

now I have to change this two if gap I decrease, so field strength will increase. I will change the distance equally. one I move and then another I move. this way equally I will move you see, now this spot should the spot are moving down, yes. yes, now it is in centre ok, it is in centre. It is come down, it is in centre,

So electric field is there, now magnetic field I have applied; this magnetic field due to this magnetic field, so what about the force in acting in this direction? force will be in this you can find out, you see electron velocity this in this direction. if this is x axis and now my magnetic field is in this direction ok, so what will be the force direction V cross V. it will be in this direction or downwards. it is a downwards, just opposite to the electric field direction force of the electric field direction,

now keeping that magnet, I will remove this. now, I am facing difficulties that, here this displacement I have taken 20. for that I have use this 15 volt. this is this quite high electric field and for that I have to take higher magnetic field and this magnet is really it is a close up to this point. I cannot take an out this. So anyway, so let me just take out this field that. I disturb that one, so you have to take out this one or I think what I should do I should apply a lower voltage and repeat the reading. instead of keeping this at; keeping at, let me keep at 10 volt and for that you find out the magnetic field because otherwise I cannot take out the yeah it is too close, yes, it is at the centre.

what about the 15 volt I wrote. for that it is a I could not take the, take out this one because magnet was very close. it is a, what is the volt; 10 volt and for this remove the magnet and what is the displacement you should find out. I have put at remove a place. it is a displaced in 10, displacement is 10; 10 millimetres approximately just I am taking.

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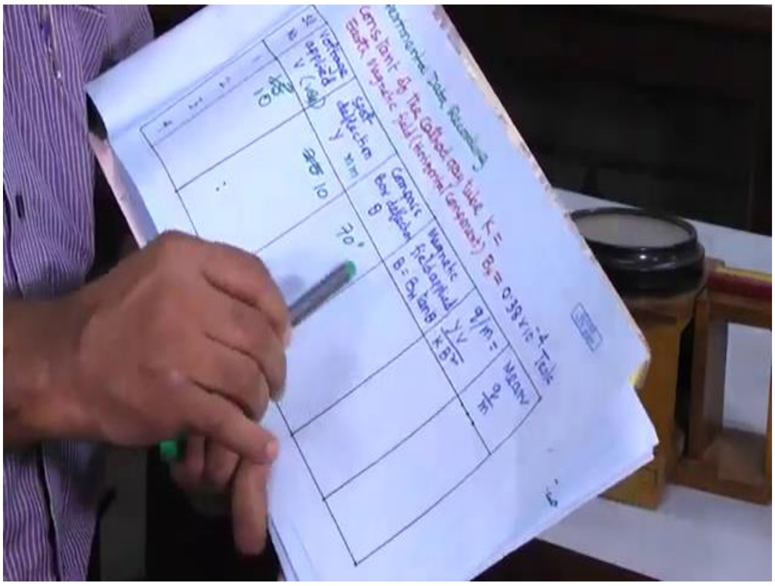

now I have to find out the magnetic field require to make it null. I put North Pole this side and South Pole the other side I am moving this two to make it 0 ok, yes, it is a 0. So, it is a 0, now I have to take the reading of the this magnetic field. I think it has; I will take out this one and here I will put the compass.

Now, I can see this angle is 70; without magnet it was at 0, now we can see it is at 70. angle that theta is 70, angle theta is we can we have to note down this compass deflection that is 70 degree. So, V, we can find out or 70 degree, now, you can calculate. then this you do the experiment for 10 volt, do the experiment for 8 volt, then 6 volt, then 4 volt, four sets of experiment you can do and find the q by m and take average of the q by m,

I think this is the very nice experiment and one can get the result and compare with the standard result for e by m; that is the available in the data or from Google search you can find out e by m and compare your result with this standard result I think I will stop here.

Thank you for your attention.