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

Lecture - 56
Determination of Velocity of Light in Free Space

Today I will discuss about the measurement of Velocity of Light in Free Space.

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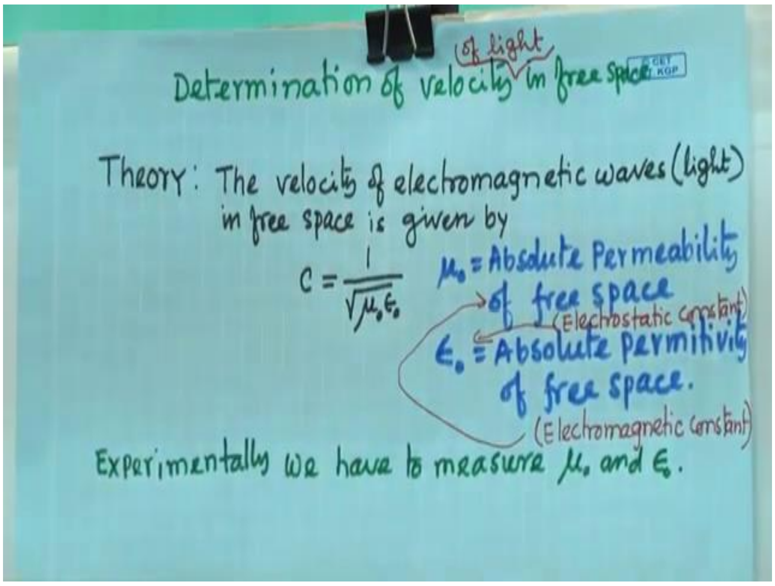

Velocity of light in free space means in air. You know that velocity of electromagnetic waves or light in free space is given by C equal to 1 by square root of mu 0 epsilon 0. Mu 0 is absolute permeability of free space and epsilon 0 is absolute permittivity of free space. This electrostatic constant mu 0 electrostatic constant and epsilon 0 no, I think this it is it will be reverse.

This one epsilon 0 is electrostatic constant and mu 0 is electromagnetic constant. It is I think this should be for this and this should be for other one. This should be for this to find out the velocity of light in space in air, from this formula, you can see that experimentally we have to measure mu 0 and epsilon 0, permittivity and permeability. We have to determine epsilon 0 or we have to measure epsilon 0 and mu 0.

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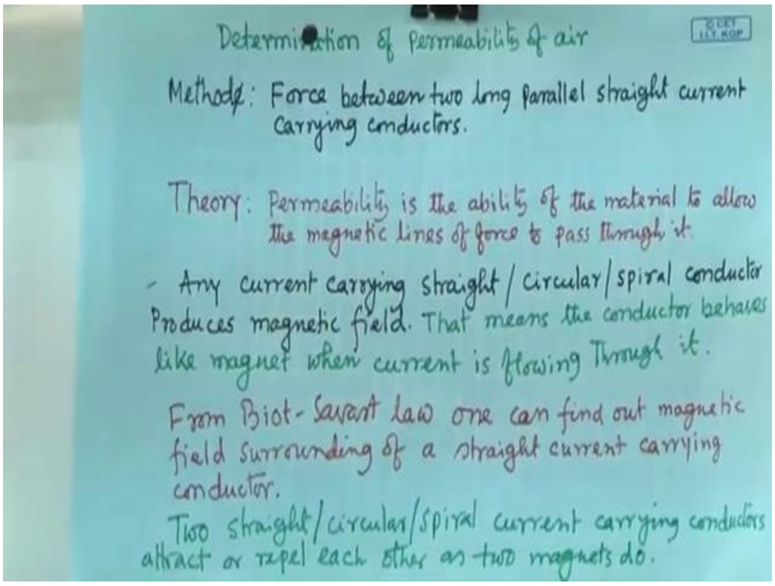

Let me discuss first how to measure the mu 0, permeability of air. In this case, we will take two parallel current carrying conductor. this force between these two long parallel straight current carrying conductor that force, if we can measure that force and from that from that force as a function of current in those these two conductors. From there we can find out this permeability mu 0. Here you see this permeability is the ability of materials to allow the magnetic lines of force to pass through it

In our case here, this medium is air or air is we treat as a free space. If you can permeability is the ability of the material to allow the lines of magnetic lines of force to pass through it. If we take any current carrying straight or circular or spiral conductor that produces magnetic field, you know this electromagnet there is a coil and in that, coils we pass current through it and then we produce this coil produce magnetic field.

Similarly, if you take the circular coil circular loop or the straight conductor, if current passes through it then it will produce magnetic field. That magnetic field we can get from Biot Savart law. From Biot Savart law one can find out the magnetic field surrounding of a straight current conductor. Two parallel straight or circular or spiral current carrying conductor attract or repel each other as two magnets do. Current carrying conductor, it will produce magnetic field as this if you take a permanent magnet this bar kind of things, we have seen this bar magnet.

This bar magnet it produce magnetic field similarly, any current carrying conductor it produce magnetic field. Now in that magnetic field, if you bring another this magnet say bar magnet. There will be repulsion or because both are magnet; current carrying conductor also magnet because it is giving magnetic field and your bar magnet it is a magnet.

It is giving also magnetic field. These both will work as a magnet and they will attract or repel each other. similarly if I take two conductor and current passes through both conductor, then one conductor it is producing magnetic field in that magnetic field another current carrying conductor equivalent to a magnet. That is there vice versa. These two current carrying conductor they are equivalent to a to magnate. They will repel with or attract with each other

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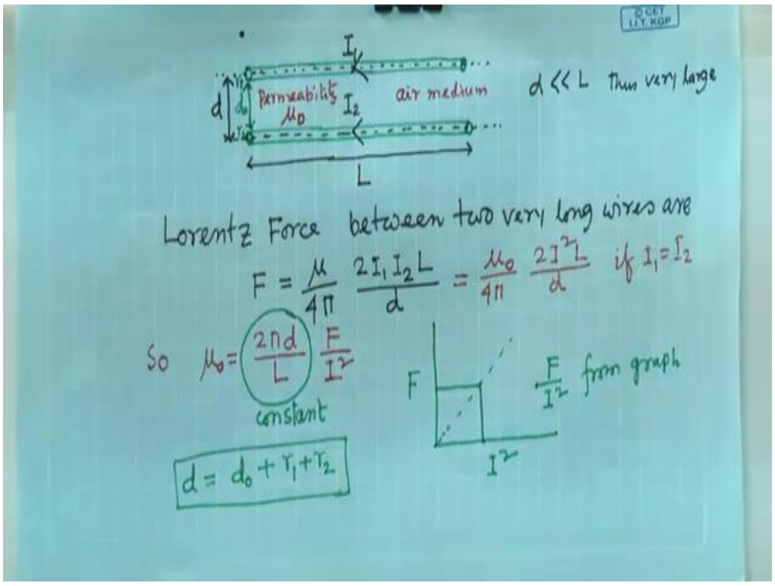

What will be that force? If you take two current carrying conductor parallel conductor. This is one conductor current passing through it is I 1 and another conductor this is a current passing through it this is the I 2. Now, these two are parallel their separation is a d. air separation d 0 free space d 0 and diameter of this conductor if it is this where L it is circular. It is a radius if it is r 1 and this radius of other one is r 2. This separation will take this d equal to d 0 plus r 1 plus r 2

Approximately one can take just d 0 or equal to d, but if this two conductor are thick better to give this correction. These two parallel conductor their separation is d current is flowing through this conductor I 1 and I 2 in this case, we assume that d is very less than L this length of the conductor. Lorentz Force between these two very long wires. very long wires with respect to compare to the separation of these two wires in that respect in that respect this length of the wire is very long.

if this conductor are very long then one can write this force between the Lorentz Force between these two conductor current carrying conductor will be mu by 4 pi 2 I 1 I 2 L length of this conductor divide by d separation of this conductor this is the force easily one can derive this force Lorentz Force. If current if current are same in both conductors. then one can write mu by 4 pi 2 I square L by d. look at this look at this formula from here, you can write that mu actually this mu 0 one can write mu 0 this you can write mu 0 because I have mentioned there mu 0 so just write mu zero.

mu 0 from here you can write mu 0 equal to this 2 and this is 4 pi. 2 pi d by L F by r square F by I square this is the expression for permeability. Permeability equal to this. In this case, L is the length of the conductor that is fixed and d is the separation of these two conductor that also if you fixed it fixed it. This part is constant this part is constant for the setup. Now the now F and I square now these if these two remains constant L and d remain constant then for different I F will be different.

We will do measurement for different I, we will measure we have to measure the force for different current how much current we are passing through this conductor? From amp meter easily we will we will note down this current. Now, how what is the force what is the force that we have to measure? How to measure a force that I will discuss, but. you are measuring force as a function of I and then you are plotting graph this force versus I square then definitely it will be a straight line and from that straight line average line you have to draw and from there you find out the slope.

Since it is, the straight-line slope will be just, take a point on this and find out F and I square. F by I square will be the slope of this graph. We have to measure F now question is how to measure F? That I will tell you. Now also we have to measure L. just since it is a longer length, we will use tape to measure this length and also we have to measure d separation of these two conducting wire. you have to measure d we have to measure L we have to measure d, then for different current we have to measure F we will plot graph we will plot graph and from that graph we will find out F by I square average F by I square the slope .

Then using a formula we can find out the mu 0. to get mu 0, we have to we have to know how to measure how to measure this force how to measure this force attractive or repulsive whatever this force that depends on current is in same direction or current is in opposite direction also you have to find out how to measure this d separation of this of the two wires at that separation what is the force that we are going to measure. I will tell you.

In this way, we can find out the permeability mu 0.

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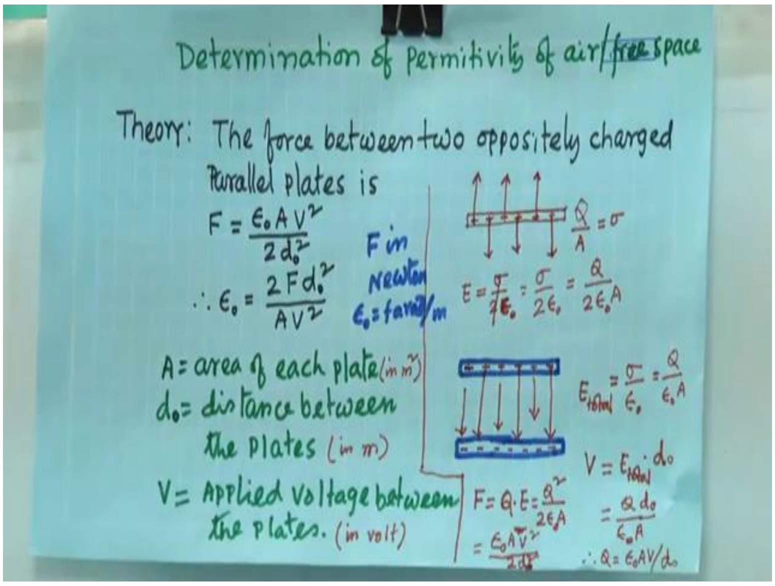

Now, we have to find out; we have to find out the for permittivity we will use two plates metal plate it is a capacitor plate. The force between two oppositely charged parallel plates is F equal to epsilon 0 A V square by 2 d 0 square. In this case, d 0 is the separation of the two plates two oppositely charged plates, it is a similar in other case the separation between two current carrying conductors here to charge carrying plates

Just this current carrying conductor are conductors these two conducts are replaced by the two metal plates. Then their separation is d 0. That d 0 we have to find out. This d 0 also one can find is this what is that, half of this thickness of the plate and half of the thickness other plate. this d equal to this the say r 1 plus r 2 plus d 0 but if separation is higher than this thickness of this plate, then one can neglect this r 1 and r 2. One can write d equal to d 0. As the same case in case of two current carrying conductor.

From this expression epsilon 0 equal to you can write this 2 F d 0 square by A V square. Now, how this formula has come that one can see, the you know that one plate it has say positive charge. It will produce the electric field. It will produce electric field in this direction and it will produce the electric field other direction. Electric field nearly. In terms of this charge density charge per unit charge per this unit area Q total charge on this plate, divide by the total area of this plate.

Q by An equal to sigma. Sigma is charge density, then for one plate this electric field in this in one direction it will be sigma by 2 epsilon 0 it is in one direction. If you put other, plate that will also produce electric field. Half so half contribution will come from this plate and half contribution will come from other plate other, half is going this outwards you know. Since we are interested to see the electric field between these two parallel plates. that is why here for one plate whatever this electric field for two plates electric field just it is E total E total will be sigma by not two epsilon 0 now epsilon 0 so half from this plate and half from the other plate.

E total means electric field in this two plates, when they are parallel and their distances is d 0 and their charge density is sigma. E total will be Q by epsilon 0 A. Since, sigma is Q by A. now, this electric field and voltage, if you apply voltage in this between these two plates if that voltage is V. V equal to E into this their separation d 0.

Alternatively, E equal to V by d 0. V equal to E into d 0 separation of these two plate. Now, E total is Q by epsilon A that d 0. Q from here you are getting Q equal to epsilon 0 A V by d 0. Now, force; force will be equal to charge. Say one plate is placed in the field of other plate. charge of this one plate is Q and field from the other plate that is that is Q by Q by 2 epsilon 0 A. Q this E is Q by 2 epsilon 0 A. that will be F equal to Q square by 2 epsilon 0 A. now, here you are getting this if you replace Q by this expression epsilon 0 A V by d 0.

You will get since below you can see epsilon 0 A is there. This will be square. Epsilon 0 A. one, I think this from square this half will go from here. epsilon 0 A V square by d square and these two will be there. That force equal to this as I have written here exactly you can see epsilon 0 A V square by 2 d 0 square as. This way one derive this one of so it is not the difficult task is easy.

In SI unit F will be this unit is Newton, epsilon 0 it is a farad per meter A is area of each plate. In meter, square d 0 distance between the plates this is in meter and V equal to applied voltage between two plates so this is in volt. Here if you look at this formula see it is a similar formula as we have seen for the as we have seen for the for the mu 0. Here also we have to measure d 0, we have to we have to know this an area of the plate they are length of the conductor here area of the plate that we have to measure and we have to measure this F as a function of V there F force as a function of I.

here F force as a function of voltage Then we plot F as a function of d square then again you will get a straight line and from that straight line you will get F by V square from the slope of this straight line you will get F by V square and you know this A and you know this d 0; d 0 you have to measure A also you have to measure. This separation is for a particular area and for a particular separation of the two plates

For the throughout the experiment, we will keep these two A and d 0 are constant and only we will vary voltage and corresponding force will measure and we will plot graph F versus V square from that graph we will find out F by V square and then we can get this epsilon 0 mu 0 and epsilon 0 so the same way same similar expression you are getting in one case this is the current and the other case this is the voltage and both cases you have to measure the separation of the separation of the of the two conductor or two plates.

In both cases, they are parallel. That d we have to measure and we have measure F voltage and current easily one can get from voltmeter and amp meter. Now, in both cases same way we measure the force. The how we will measure the force to understand that one this kind of this kind of mechanism we will use here you can see.

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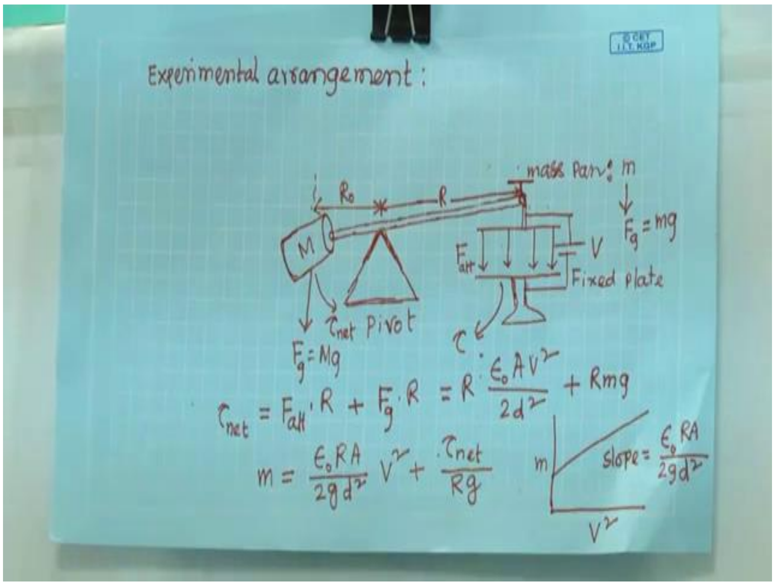

This kind of experimental arrangement will be there you see here this I have shown these two plate these two can be these two can be the current carrying conductor.

If you understand one this other one exactly same. Just we have to replace the capacitor to metal plates by the two metal conductor. Say if one if one plate or conductor is fixed and other one other one is attached with the balance. Balance always you know these two arms is there. You have seen the balance in shop here similar principal is used. Here you can see this is the people with respect to this it will it will rotate it will rotate. Here you can see this other plate or the conductor is attached with this with this lever.

Now this lever for a certain position now, you see this lever if this lever move up and down; this plate one plate or the other this one conductor. It will go up or down. this separation between these two plate or these two conductor that is whatever d 0 we are telling or d will so that will vary as I told that we will do experiment for the fixed for the constant d 0 or d what we will do? We will use laser refraction method. Now for this position, so there will be mirror in this side here at this position there will be mirror.

Laser will fall on it and they are the reflected laser beam it will fall on the on the on the screen we will use our wall so. now, I will keep a particular position, I will keep a particular position first equilibrium position parallel condition for this parallel condition what is the d 0 that we have to measure as well as, we have to now we will before applying current or voltage depending on their parallel conductor you are using or parallel plate; you are using depending on the current or voltage

Initially, we will put 0 current or 0 voltage in that condition, what is the position of this of this conductor or what is the separation of the conductor. That separation will keep constant when we measure the force. We will initialize this lever initialize this balance. For this position, what is the position of the laser spot reflected laser spot on the will mark. Now, what we will do? Now we will put a weight on it, we will put a weight on this on this side on this on the top of this

Then what will happen? It will just rotate this way. Laser reflection so that will change you know so mirror also will rotate because mirror is fixed here. If mirror rotated by angle by some angle say theta. This reflected light we will rotate by 2 theta from initial position. Now, laser beam is reflected by angle 2 theta and it will come in other position. We will measure we will measure, what is the distance of this of this laser spot from this original position ok?

if this one is capital D if this one is capital D, then if distance from the mirror from the mirror, if distance of the screen is say; v small v. tan 2 theta that will be that will be this capital D, this shifting of the light spot on the screen this capital D divide by this small V distance of this of the screen from the mirror.

That will give you tan 2 theta if this theta is small. That will be tan 2 theta will be equal to 2 theta. Now, so you can find out theta. Now, if you know if it is if you know this distance say here, I have written R, but if it is R or a small a and then just. It is rotated by angle theta then what will be the separation? What will be separation that you can find out if the separation is d 0? These tan theta will be equal to this d 0 by this R this R or somewhere I have written A

Small a. d 0 by small a or this R that will be tan theta is small that will be equal to theta. Now, this theta equal to capital D by 2; 2 V because 2 tan 2 theta or equal to 2 theta equal to capital D by the distance of the screen from the mirror. if it is capital V sorry small v. tan 2 theta equal to theta equal to capital D by V. theta equal to capital d by 2 V. that we will use for this expression d 0 d 0 by this R by this r or small a whatever we will write equal to capital D by 2 V.

From there we will be able to find out this d small d or d 0 separation and now if it bends. Now, from original position what we will do? We will put a mass we will put a mass m this from this initial position due to this mass force is mg. there will be torque depending on this distance this force due to this force and corresponded torque it will bend. How much it bends. From the laser point on the screen so from this position as I told this is the capital d

This mass this for this shifting capital D shifting of the of the laser spot reflected laser spot is due to the force F and that is equal to mg. m is known how much mass I have put. Now, now what we will do? Now, we will take out this mass. For that very corresponding weight m g and that is nothing, but the force and for that force what is the shifting of the reflected laser spot on the screen. That we know, now what we will do we will take out this mass again it will come again. Again, it will come this original position

Now, what we will do? We will apply the current or voltage depending on this whether you are you are doing experiment for epsilon 0 or the mu 0. When we will apply current or voltage. There will be an attraction of these two conductors or these two capacitor plates' metal plates now, what we will do? What will happen? We will we will, we will adjust the current or voltage in such a way that this laser spot when it will reach to the point to where we mark applying this mass on the pen. When that laser spot will reach to that point. Then we will stop applying current or voltage.

What does it mean? now, this force now this force will be equal to this mass force that mg to get that much force what is the current and voltage we are applying? That we have to we have to find out from the shifting of the reflected laser spot. this way we will measure the mass for a particular force, we will measure the force between the two conductors or two capacitor plate for certain current or voltage and that force how we are getting we are getting from this way. That force we are equating to the force due to the gravitation of very gravitational force of mass m

That way we will get force. Different mass will different mass will apply and we will we will note down the position of the position of the laser spot after applying this mass. Now, we will take out the mass and we will apply current and voltage to get the laser spot in the in the same position as we got using the mass that way this force between the capacitor plate or between the conductor current carrying conductor that force will be equal to this force mg.

In addition, as I told that as I told that this that separation between these two that we will keep constant that d 0 we will keep constant. what we will do actually what happens we will apply the mass without taking either you can take mass or better without taking mass, what we will do? If force is repulsive if force is repulsive then other way what has to do? After applying force, it has come down how much it has come down. From there now I am applying current or voltage depending on the conductor or capacitor plate so to get this laser spot on the o original position.

How much voltage or current I have to apply that force at this separation that will be that will be equal to this m g. for different mass, we have to repeat the experiment and find out different voltage and or different current and then we have to plot. As I as I told you this how to measure the measure the d as I explained you here let me.

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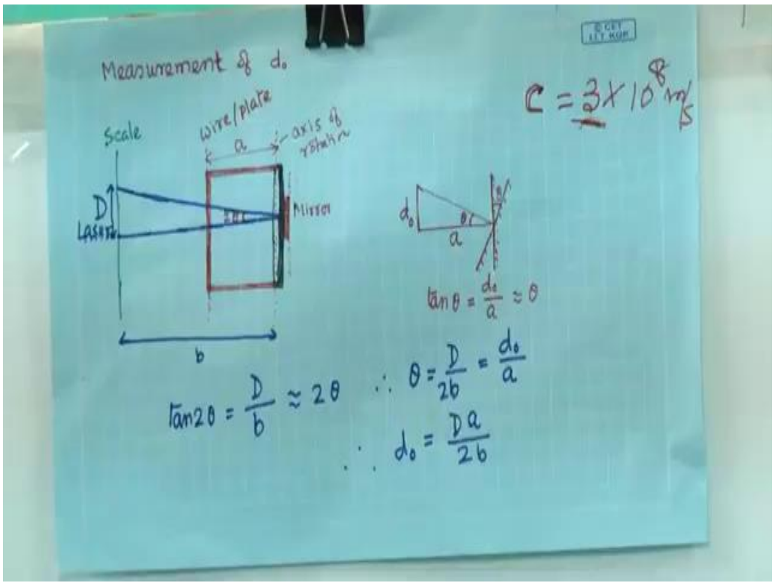

Show this same thing again. here you can see that. As I they told this is so this the lever you know. The separation there I showed R capital R here I have shown this a

This is the one wire or one capacitor plate and below there is a wire or capacitor plate. Now, separation between these two separation between these two plate or the conductor two conductor if it is d 0. Now, here mirror is there. Laser from there is a laser now laser light is falling on this mirror. it is reflected back it is reflected back Now, if this one due to weight or due to force between these two capacitor plate or this force between two current carrying conductor, if it is rotated if this one rotated because this the this the cantilever you know or lever. It will rotate like this

Corresponding this reflected light will shift by capital D if this distance is small b. this D by the small b will be tan 2 theta. Small angle I can write 2 theta. Theta will be equal to D by 2 b. Now, so what is the movement at this place? What is the separation with respect to the fixed plate or conductor beneath of this top wire conductor or the plate? That if that is d 0 if that is d 0 and this distance if a or capital R as I shown earlier.

This theta will be this theta will be d 0 by a d 0 by a. as if this mirror rotated by angle theta so then this. Here this plate or the wire it will be rotated by theta since this mirror is fixed with this with this with this lever. This tan theta will be d 0 by a. that will be equal to theta since theta is angle is small. This I can put here. From there I can find out d 0. I have to know what is capital D on the on the on the screen and what is the distance of this screen from the laser from this mirror.

b and a is this is the distance of this of this capacitor plate or the conductor current carrying conductor if that is a that we have to measure and then we can find out d or d 0. In both cases, so here same principal is used one important things is that this separation of these two conductors' current carrying conductors or the capacitor plates or metal plates. That d or d 0 that we have two measure following this mirror reflection of the laser light from the mirror

That is important task and second task is that for putting weight, it will it will it will rotate now how much it is rotated. That is capital D. Now to applying the current or voltage we will bring back it this original position, if this repulsive force or other way if you are attractive force then we have to take out this take out this mass and apply voltage or current depending on whether you are doing experiment using the capacitor plates or two parallel current carrying conductors And we will apply current or voltage to get the deflection to get the deflection of the laser spot on the on the same amount as we got applying the mass

This is the theoretical background of the experiment, how to measure permeability and how to measure permittivity and after measuring; just you can calculate the velocity of light in free space or in air that is C equal to 1 by square root of epsilon 0 and mu 0. And it is a very excellent it is a really excellent experiment from where you can see that see, how close you are getting the value of velocity of light and this value of velocity of light is known to you this is L 3 into 10 to the power 8 meter yes I think so.

No this velocity of light is, what is the value? This is I think this C equal to C equal to you see this is very elementary thing, but I forgot I think this is this is 3 into 10 to the power 8 meter per second I guess. Is it so yes 3 into 10 to the power 8 meter per second?

that is the velocity of light is the from your experiment you can see there what is your value generally, these 3 you may not get exactly 3, but order you will gets of same order this 3 instead of three it can be 2 or 2.5 or like this. This excellent experiment to get the velocity of light in air. I will next class, I will demonstrate the experiment.

Thank you.