Rocket propulsion
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Lecture No # 39

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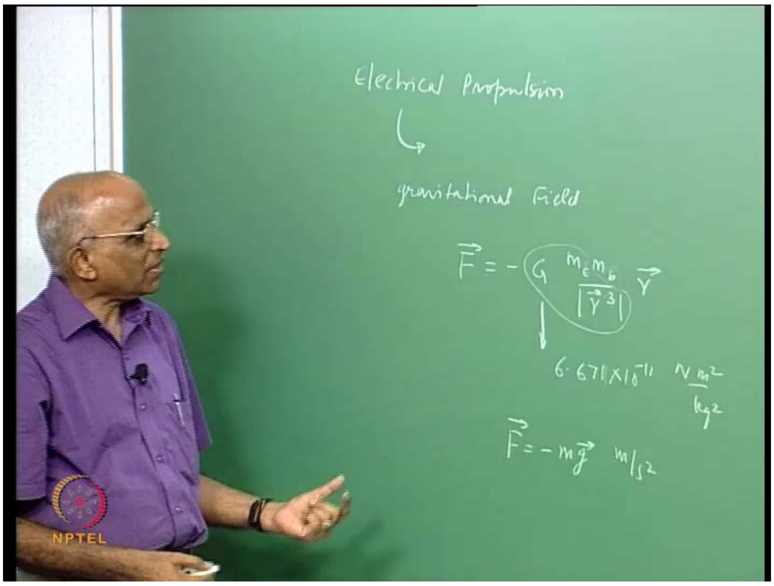

Good morning, I think we will start this class on electrical propulsion. You know when we said propulsion and we construct different forms of propulsion, essentially chemical inert gases and stuff like that. When we use electrical power for pushing, we say electrical power, because propulsion we said comes from the Greek word propeller, meaning pushing forward, and we use electrical energy for pushing. I think we must be little bit clear about how we can do it using electricity; and therefore whenever we say electrical propulsion, next go through the basics and see, whether we can understand something about propelling in some way. I go back a little bit, ask myself one question I say the, talked in terms of, let us say gravitational field. We covered this, we started with this in fact, we say planets are moving, Newton's or the moment of the planets, he saw the apple he fall. He formulated the universal law for gravitational, which is minus G into m 1 m 2 by r square. If I want put into terms of directions, I put vector hear, I put a cube hear, then I put then I put the vector over hear.

This was the universal law for gravitation and the gravitational constant we saw was 6.671 into 10 to the power minus 11, and the units were Newton meter square by kilogram square. Why am I talking in terms what is gravitational field, when a mass is up there, may be on the surface of the earth. It is built with some field or rather, I can put the mass of the earth here, and then the mass of the body which is in on the surface of the earth or somewhere, and I substitute the radius of the earth to denote this, and I get the value F is equal minus mg, and this g is what you call as a gravitation field, forces is vector and the vector comes from this. Therefore, you see there is field, a vector field which attracts a body and gives way to the mass of the body. In other words in force is a Newton, mass is on kilogram, g was in meter per seconds square, and therefore, is loosely talked as acceleration due to gravity, but there is no acceleration, it just a field which is available.

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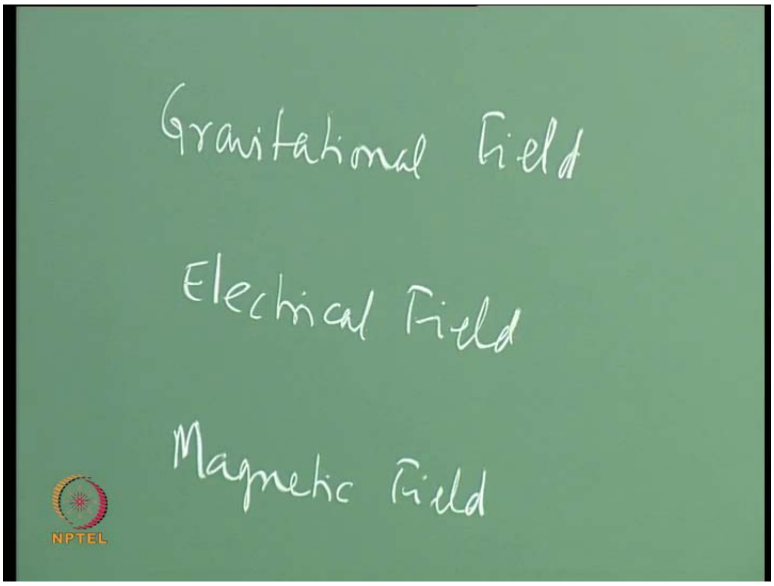

Therefore, just like we talk in terms of a gravitational field, can we think in terms of other field, especially coming from electricity or in some way magnetism stuff like that. We can talk in terms of may be an electrical field just the same way as the gravitational field. We can talk in terms of a magnetic field. Are there any other fields we can think of. Maybe we should spend some time, when we review the whole things what we have studied, may be some people talk in term of casime forces, some other forces they say thus 0 degree Kelvin dark matter which is available in space, is capable of doing some work.

What are these fields we are talking of. Maybe we have to review it in some way, and since most of us are in mechanical and aerospace, and our basics in electrical engineering is somewhat might be somewhat rusty, as I thought let us a go ahead and look at the units. Let us try to see what a electrical field could be, what a magnetic field could be, whether we could use it in some way to push a rocket, that's what I will be doing in this class, and while doing so, in the same way we derive propellence, chemical propellence have this characteristic. A low molecular mass and high temperature is what we require. Can we put some requirements for things when we want to push something using electrical and magnetic fields; that is what I will be doing in today's class. Let us therefore, take a quick look at the forces. Let us say, you know see matter let us say, we talk of me as a body and electrically neutral, may be you rub me very hard, remove some electron from my surface my body, I say become positively charged.

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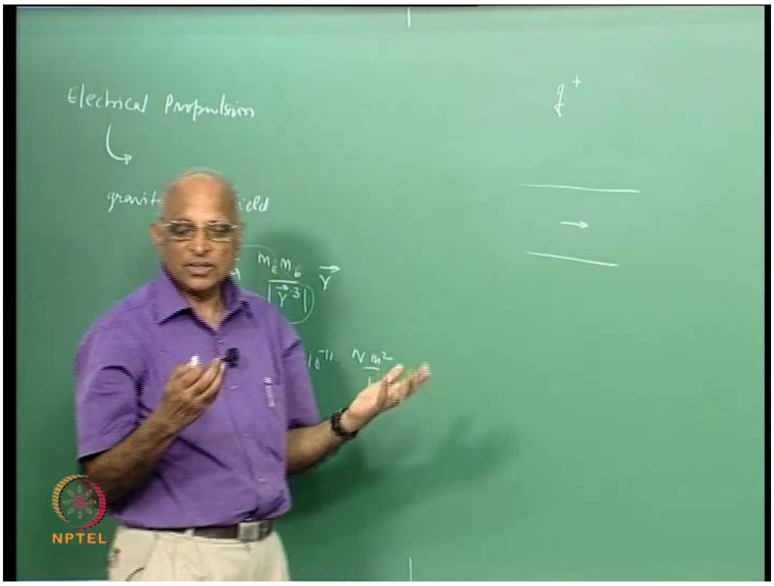

I get charge q, which I say could be positive. In fact we must remember that, charge whenever we have; maybe I have tube let us say. I have a tube containing, let us say oxygen gas. Oxygen gas is very dry and it is pumped at high velocity through a particular tube. It is quite possible, that size gas is dried and oxygen consists of an atom, which is electrically neutral, may be by their rubbing action on the wall. I could even ionize, or I could give some charge to the oxygen. And it is quite possible that this surface could also become charge, because it is getting conducted, and I could get a spark in this. These are something which has to keep in mind. Therefore, we let us not getting to those details, all of us know in a dry climate, if you wear the nylon shirt and we you remove it, sometimes it is charge and here the some discharge taking place. So also, yes an electrically neutral body or any substance could either get charged.

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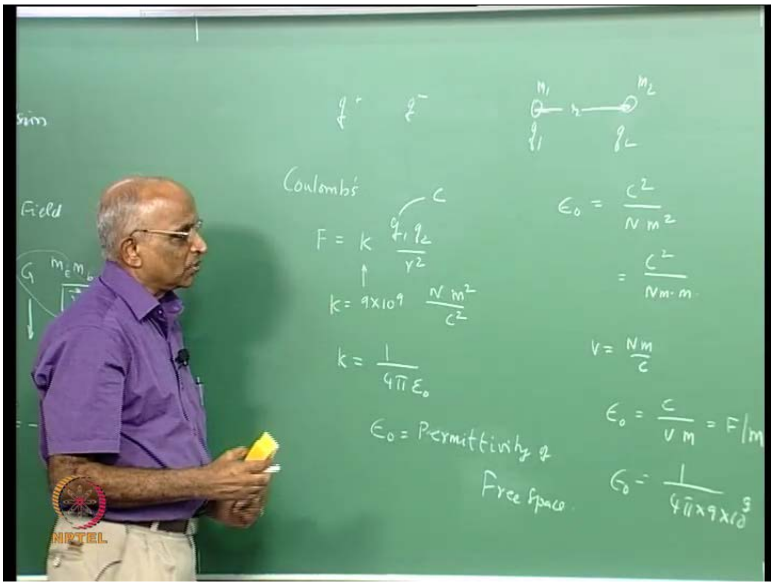

And if I remove and electron from the body, well it becomes positively charged if I donate an electron, or remove a positive charge it becomes negatively charge. Therefore, either some loss which govern the forces between the charge bodies, and all of us studied this in physics, in high school day, may be you say coulombs law. And coulombs law is very similar to the of law of gravitational field, or the universal law for attraction of forces, and coulombs law is something like forces equal to, some constant into the product of the two charges, divided by distance square. This is formulated by coulombs which bears his name, and is possible to derive this law. Let us try to get some feel for this. We say if you do a series of experiments, or if you derive it, the value of K works out to be 9 into be 10 to the power 9.

And now I should have some units for charge. The unit for charge is again coulomb c, and therefore, all what I says two like charges of this same q 1 and q 2 will repel each other, unlike chargers attract each other, therefore will not put in sign over here, other than that says force equal to Newton divided by r is in meter square divided by coulombs square, and this is the value of K, and this tells us the attraction between or repulsion between two charges q 1 and q 2, whose charges are q 1 coulombs and q 2 coulombs.

This is very clear and this is what we studied as coulombs law earlier, but I am more interested in a feel and more interested in force, therefore we look at this expression in slightly different way, and people they in especially in physics they try to express this constant, in a way wherein I can say the space can impact or 8 15 hold charge or rather case return as 1 over 4 pi into epsilon 0.

All what we are saying is, I have a constant K, instead of using a constant K they put in term of constant, epsilon not, where epsilon not is defined as permittivity. Permittivity of free space, what is it epsilon. See what is epsilon denote, the ability of the space between these two charges, let us have the charge q 1, I have the charge q 2. The ability; that means I have q 1 here. I have another body of mass m 2, let say mass m 1 having q 1 here, mass m 2 having q 2 here, they are separated by distance r over here. We are talking of epsilon, is the permittivity of the space between these bodies; that is the ability of the space to hold the charge; that means it permit something, this is known as epsilon not, and therefore, the unit for epsilon not.

If we are going to say yes, I need the units of this, it must be opposite of K, because it is 1 over K goes as a epsilon, pi does not have is units. Therefore, the unit of permittivity of free space should be coulombs square by Newton meter square. And let us write to the puts units little more clearly, because coulombs is charge, Newton meter is work done. Therefore, I can also write it as coulombs square Newton meter into meter. And now if I were to again say, Newton meter is the work which is done, coulombs is charge, and how do we define potential difference between two bodies. Work done in taking unit charge, from a lower potential difference to higher potential; that is the work done in taking unit charge from one potential to other, therefore, I can write voltage as equal to work done in taking unit charge.

And therefore, I can write this equation epsilon 0 permittivity of free space as equal to coulomb, divided by work by voltage into voltage is the potential difference, that’s the work done in taking unit charge from a smaller potential to higher potential, which is v volts higher. And when it, see charge by potential is the capacitance farad, it is farads divided by meter. Therefore, what is it we see the force is given in terms of the permittivity; that is the ability of the space to hold the charge, in terms of epsilon 0, and product of the two charges divided by r space, r 0, therefore, let us summarize it on this side. We say yes, I defined permittivity of free space, in terms of farads per meter. And this the value of permittivity of free space, is going to be 1 over, 4 pi into 9 into the 10 to the power of 9 farads per meter, this is the value of epsilon not. But this is free space what we are talking of, if I have a space, which is difference, like I have may be some air, some moisture all these things are available.

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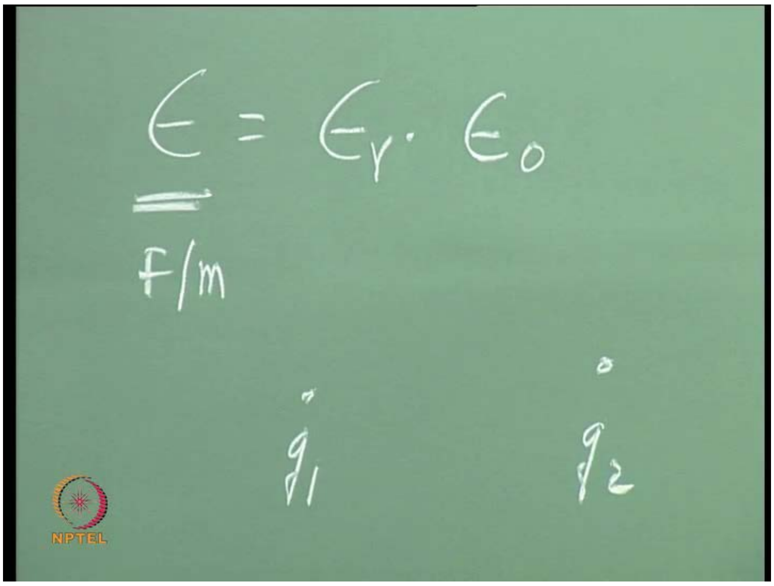

I say the permittivity of the particular space is equal to the relative permittivity into epsilon not, and therefore, I get the value in farads per meter, for any space between two charges q 1 and q 2. We will keep this in our mind, because in a when we do a problem. We must able to relate the problem, may be in vacuum I use the permittivity of free space, in medium which I have something else, I have to use relative permittivity. This is just a number, we says how much more is they permittivity of the particular medium compare to the permittivity of free space. But, I was interested in something else, not really in permittivity, but permittivity is basic thing, whenever we talk of, and this is for free space, whenever we talk of, may be attraction due to charge, we must keep in mind. Yes I have 1 over 4 pi epsilon 0, q 1 q 2 by r square. The only way, only reason why I tell this in this form is, we are used to studying coulombs law, as f is equal to constant into and q 1 and q 2 by r square, and therefore I thought may be through the constant I must come to the, value of the permittivity of free space. Well this is one side of the story, let us now tried to still see whether I can, get something as a field are something coming over there.

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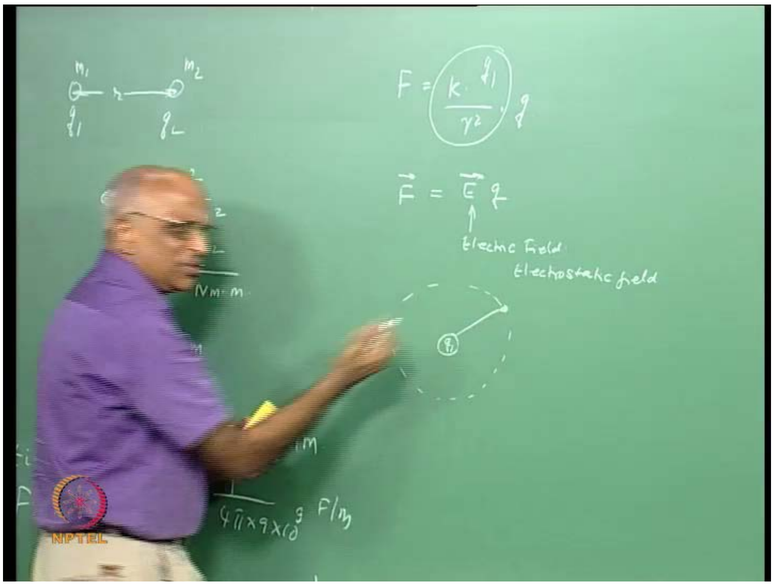

What is it we say, force is equal to, again we keep this as K into q 1 by r square into q 2 or rather, now I am telling myself, supposing I were to put a charge q, in an electrical field I have still not define electrical field. In a field, in which I have charged already q 1 available, and at a distance r and I say well, this is something which tells may something like field which is available. I put charge there, am sorry there is no q square here K is equal to q 1 q 2 by r square. Therefore, E q is equal to something like a force. In other words, if I have a charge q 1 and at a distance r from it, I say yes I have the effect of this on this and I want to express, effect of q 1 at a distance are in terms of field, I say well my field could be you.

And since force is vector, well field is vector, and this is what we called as a electric field. The strictly, it should be called as electro static field, because all what we are saying is I have a charge q 1, the reference, may be at a distance r a ray from it. I put my body on which I want to determine the force. I know the force is equal to q 1 by r square into the particular constant, which I call as an electrical field, and strictly since this object or this charge is at rest. This charge is also not in motion. It is strictly actually an electro static field. It's not dynamic, it is not something which is moving, if this charge is held stationary, this charge is held stationary. The field e attracts are repels it, either towards it or pushes it away, depending on the sign of the field, and the value of q what you have.

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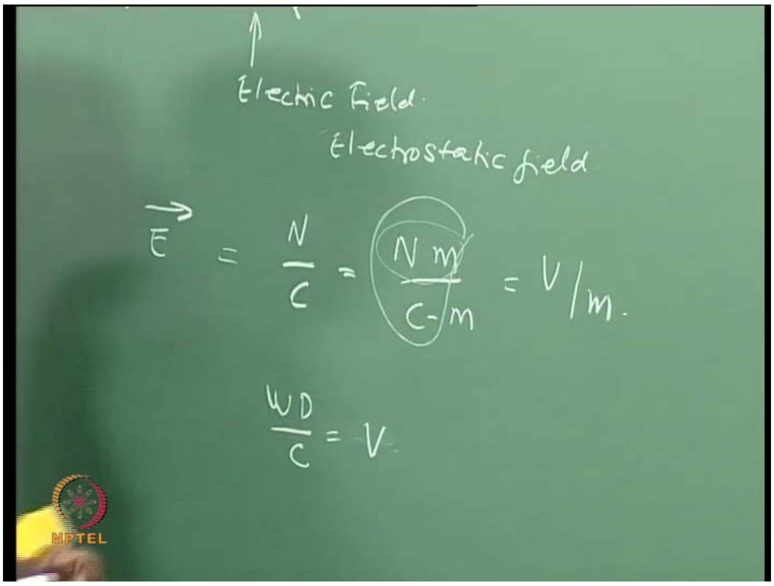

If I were to put this down, what is going to be my unit of the electrical field E. Analogous to what I had for g. For g we said g is equal to meter per second square, what is going to be unit for E; that is electrical field. I can write it in terms of Newton, divided by coulombs. And in an Newton pi coulombs instead of that, let me multiply the numerator or multiply the numerator by meter, call it as coulombs into meter, and now I find Newton meter is work which is done, is taking in a charge of C coulombs, therefore, a work done per unit charge is voltage, and therefore per unit charge; that means work done for taking C charges, that is Newton meter per coulombs, is equal to the work done, because per unit charge is what is voltage; that is voltage, and therefore I can write voltage per meter. Therefore, the unit of the electro static field is strictly Newton per coulombs, which can be written as Newton meter per coulombs meter, which is voltage per meter.

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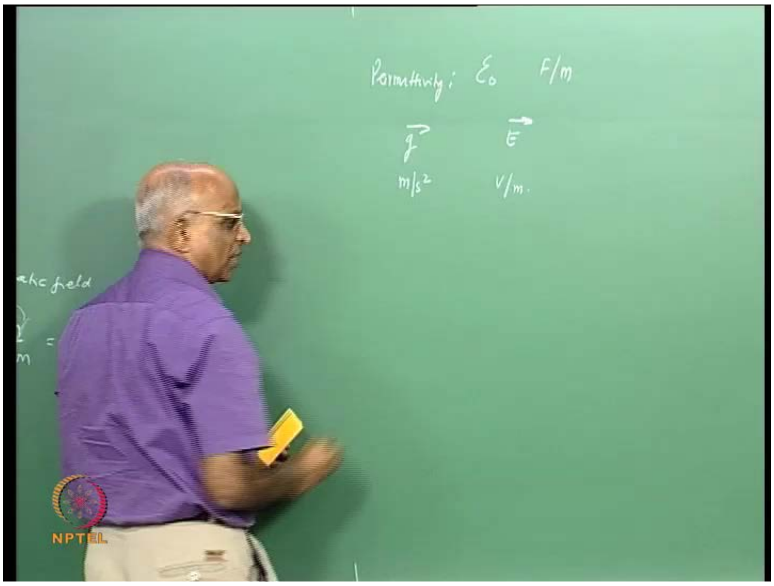

And therefore, I say that the field E, let us say that field g, field E electro static field is written in terms of volts per meter, just like the gravitational field is written in terms of meter per second square.

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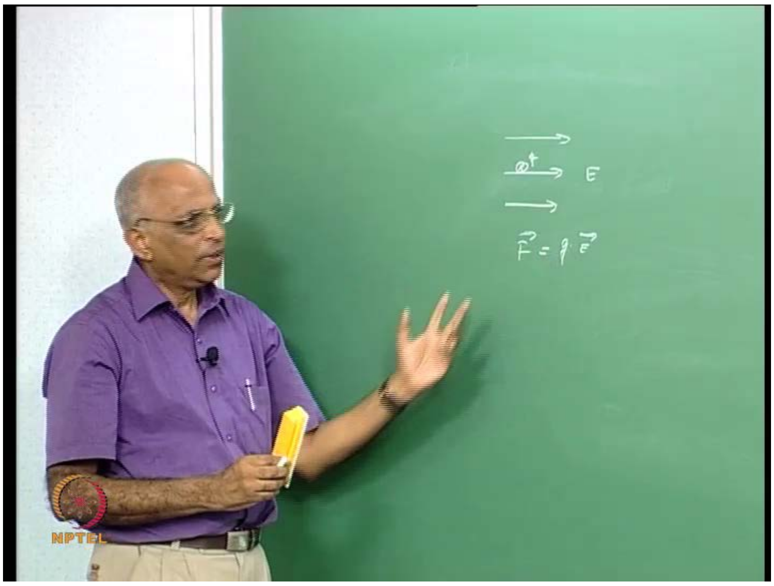

Therefore, now I can tell, if I were to put a charge, if I were to characterize an electrical field an electrical field in terms of let say E. And if I were to put a charge q in it, I will experience of force equal to q into E in the direction of field itself. I think this is what we constitute is an electrical field. Therefore what are things we have said so far. Well whenever we talk in terms of some charges, we talk of permittivity of the space, which is in farads per meter. The force is anyway in Newton, and the field electrical field is a voltage per meter. But, you know whenever we talk of electrical field, you also know in earth we have on magnetic field, how do I define a magnetic field? I think that also must be done, that also must be fairly well understood along with the units.

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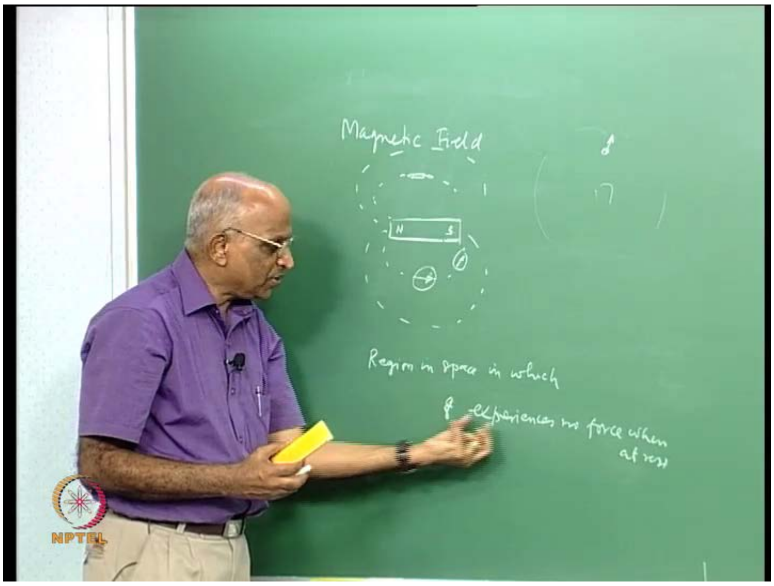

How do I define a magnetic field, and in what way is it different from an electric field. Any guesses on that. See all of as studied this, but may be several years ago, how would you define a magnetic field. See after all, all of us, when we have studied with magnet may be north and south, we know may be some field is associated which we called as magnetic field. All of us also know on the earth, there is something like a magnetic field which is available, how do you define it. There must be something like a field, a field should have units, a field must have something it must be a vector, because there is some changes taking place, how going define a magnetic field. See there are certain things, you know we have done this experiment. Supposing at put a dipole here, we know that a dipole it does not really move, supposing I put another magnet, it aligns along the field, this I know, like I put a compass over here. Compass needle does not go along this, but compose needle aligns itself along the field. If I put the compose here, well the compose shows that, that is the dipole aligns itself along the magnetic field, that part is clear.

But how do I define magnetic field, in contrast to the electrical field, which we just talked of. Like for instance, again it could be a region in space. Any region, may be or over here. I considered magnet here, I have a magnetic field here. Now if I were to put a charge here, there is no change the charge does not experience any force, but were the charge going to move in some particular; that means a region in space, in which, let say a charge q experiences no force, when at rest. If I were to put a charge here, well I don't see anything, but, if the charge were moving, then it experiences of force, then that field is known as a magnetic field. Therefore, let us say a magnetic field is define as a region in space, wherein in that space, if I were to put a charge and that charge experiences no force, when it is at rest and what is the force its experiences when it is at rest, that is the electrical field, but if that charge were to move in the particular field, it experiences of force and that is known as a magnetic field. Let write to understand it a little more through an equation, because that mix me simpler.

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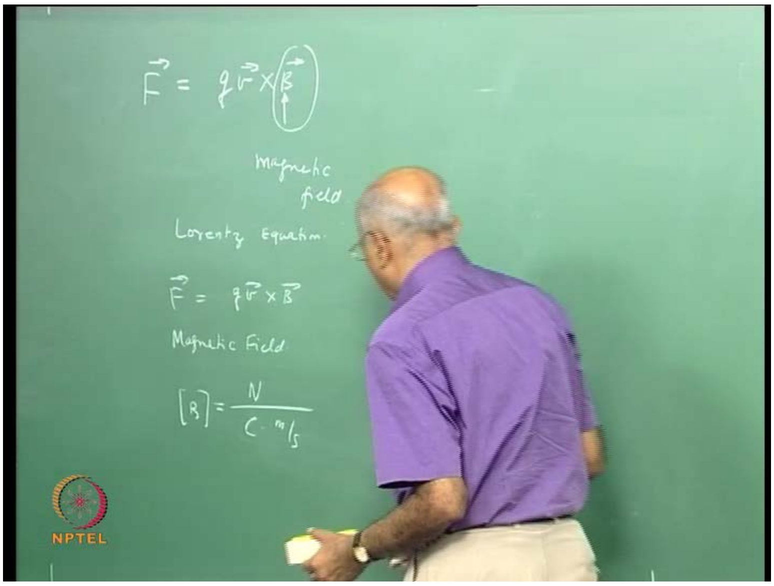

In other words I have something like a force coming, and this force comes when the charge q moves with a certain velocity. And the direction of force is normal, to the direction of motion, and also normal to the direction of the magnetic field, which I denote now by B. In other words if I have a field, which is may be like this, and if were to move the charge, in this particular direction. Well, I have a force which is coming either out of the board or inside the board, or rather I say that the thing is curl of this vector, curl of these two vectors, I have the vector cross product over here, and this is what is known as the, is then known as a magnetic field. This particular equation which defines the force in a magnetic field, due to motion of charge in it, is also known as Lawrence equation, equation for force.

Just like, we have the coulombs equation, for electro static force. This is for forces in a field, therefore what is it we are telling. Well I have something like a force, which comes because a charge is moving, and when the charge is moving in a magnetic field, well I get a force over here, or either I have a product of q v and this. Therefore, what should be the unit of magnetic field, how do you say the earth has so much magnetic field. Therefore, I have to now take the values; I say F is a Newton, q is coulombs, velocity in meter per second a square. Well this must be a unit B. How can I express it, can I simplify it and put it in a way which is easy for me to understand and interpret. Well I say Newton per coulombs into meter per second.

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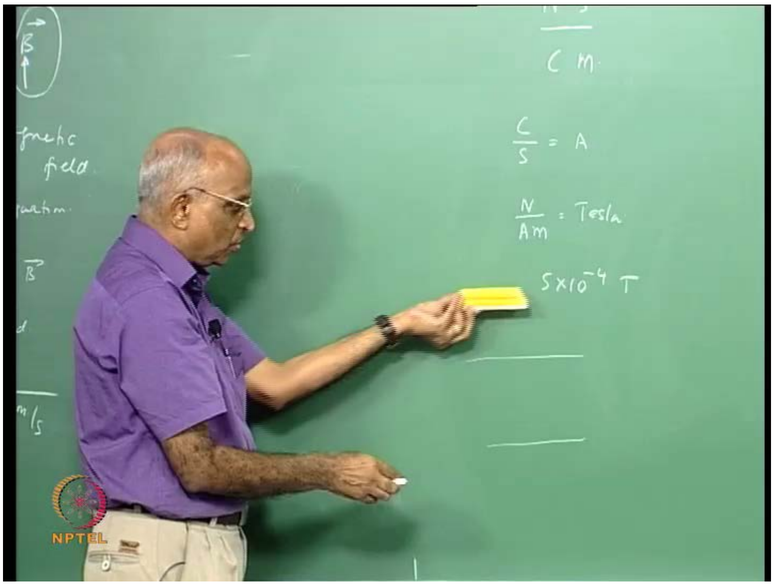

I write it to as let us write it to down here Newton second by coulombs meter. Can I put it in terms of something. I find that coulombs is charge, second is time, coulombs per unit time what is current ampere, and how is ampere define is a current which is the dc by dt or ampere is the current per charge per unit time, and therefore I can write it as Newton per ampere meter, and Newton per ampere meter is called as Tesla. Therefore, the unit for the magnetic field B is Newton per ampere meter, which is known as Tesla, and therefore we say; well the magnetic field is expressed in terms of Tesla, which is

Newton per ampere meter. I think we should get units clear, because whenever we have calculated s some forces.

You know we have to use units or rather I don’t even mind if you use unit like Newton per ampere meter, but we must get a fields for these numbers, what is the value of the magnetic field on the surface of earth. It something like 5 into 10 to the power minus 4 Tesla is field here. We talk of may be magnetically levitated trains and all that. We say yes I have reels in which are magnetically levitated, and the above the reel the train is going up in air with some gap and all that. You have very strong magnetic force of order of the few Tesla; therefore we say this is a weak magnetic field of the order of 5 into the 10 to the power minus 4 as is on the surface of the earth. Now the last thing which we have to think in terms of unit is, before we look at the propulsion part of it, how do I define a field?

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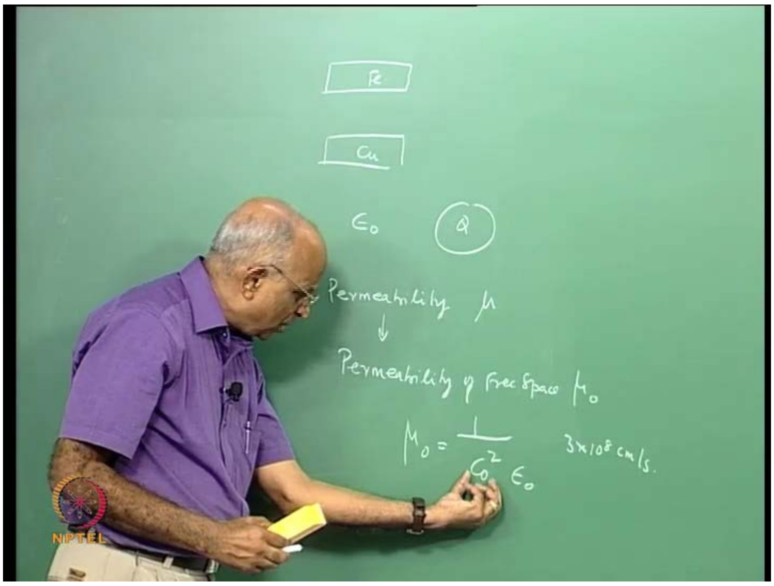

See after all you know a piece of iron gets magnetized easily. A piece of copper does not get magnetize like what iron get magnetized. Therefore, what is it we must, can say something like; I have permittivity of free space. Can I defined some quantity, some quantity, let us say q which will take can magnetic effect; rather we say a substance is more prompt to magnetization, we call as permeability, what is permeability let me repeat again. The ability of a body to get magnetized in a magnetic field; in iron gets easily magnetized somewhat its easily magnetized, air does not get easily that magnetized, therefore we call as permeability and it's denoted by mu.

And permeability of free space, is denoted by mu not, and using basic quantum physics. It can be shown, that mu 0 is equal to 1 over, velocity of light in vacuum C naught square, into something like the permittivity of free space, because electrical and magnetic field are related in some way. It comes through the relation, the velocity of light in vacuum, which you know is equal to 3 into 10 to the power 8 meters per second. And we have already calculated the value of permittivity of free space; I can calculate the permeability of free space. And using this permeability for any substance, I define the relative permeability of mu are in the same way as I define the relative permittivity of body.

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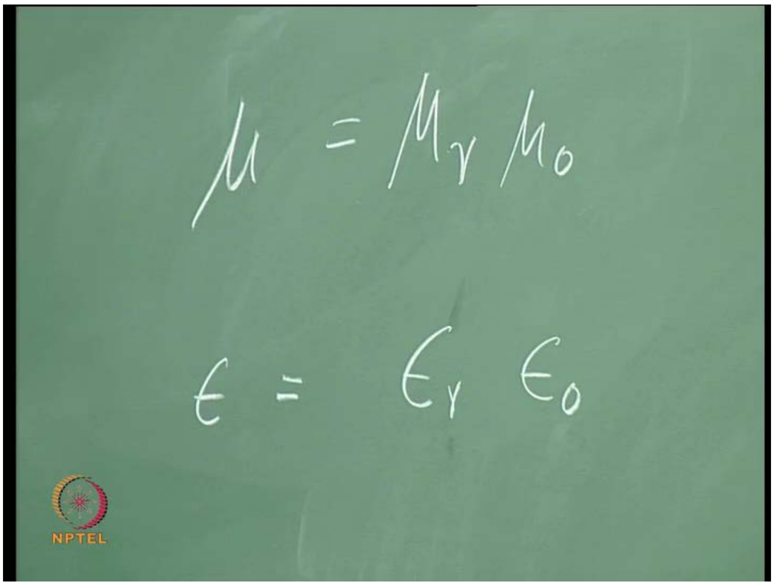

And I say mu are into mu zero is equal to permeability of the body, just like we say permittivity of space or permittivity of something, is equal to permittivity of free space into the relative permittivity. Therefore, we can get the value of this; you know C naught that is in vacuum speed of light is 3 into 10 to the power 8 meters per second. We already calculated this is 1 over 4 pi into 9 into 10 to the power 9. I can get the value of permeability of. You are correct; I should have written it as meters per second. The velocity of light in vacuum is 3 into the 10 to the power 8 meters per second, 3 into 10 to the power 5 kilo meters per second, 3 into 10 to the power 8 or 3 into 10 to the power 10 centimeters per second, you are right. Therefore, how will I define the units of permeability. See because units are important without units we cannot do a problem, or we will not be able to understand something.

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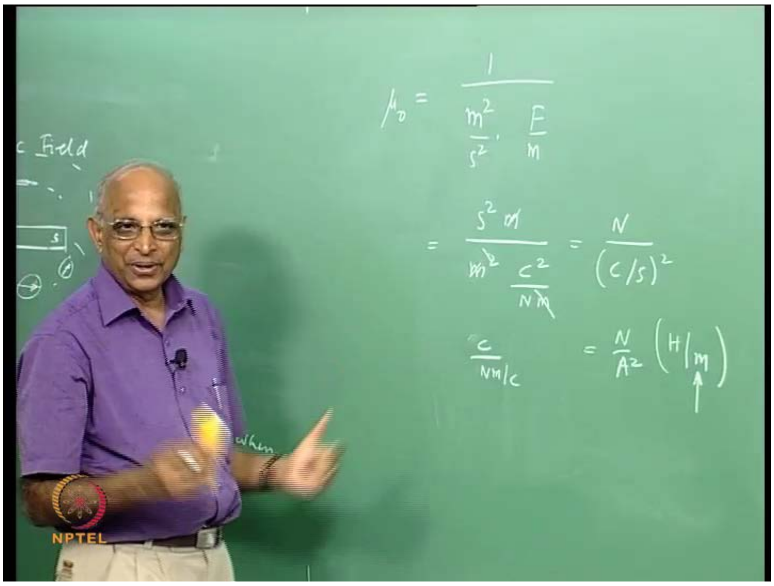

Therefore, let us say the units of mu not is equal to 1 over C naught square, 1 over meter square by second square. And what was a units of permittivity, we already I think wrote it here, farads by meter which was equal to, let us put it down first farads per meter. And now I simplify this, I bring second square on top, meter over here, meter square over here. And what was farad, farad is the charge per unit voltage C by v, and what is v, v is a work done Newton meter, therefore, I have work done, that is charge per voltage; that is I get the value here, but when I say farad. Farad is equal to charge, that is coulombs by voltage, voltage is equal to Newton meter per charge over here.

I get coulombs square over here. Now let us be very clear, we found farad is equal to charged by voltage, voltage is equal to work done per unit charge, and therefore the unit of farad should be C square by Newton meter. This is equal to meter square from here, I have already taken this over here, and therefore I cancel this over here, and therefore now I get meter, yes meter also go off. Meter square this becomes. No let us do one at time. Yes meter, meter square goes off and this is equal to Newton by C by S square or rather this becomes charge per unit time in second is Newton by ampere square. And this is what is the units for permeability Newton per ampere square, and this is also denoted by Hendry per meter, in electrical engineering they denoted by Hendry per meter.

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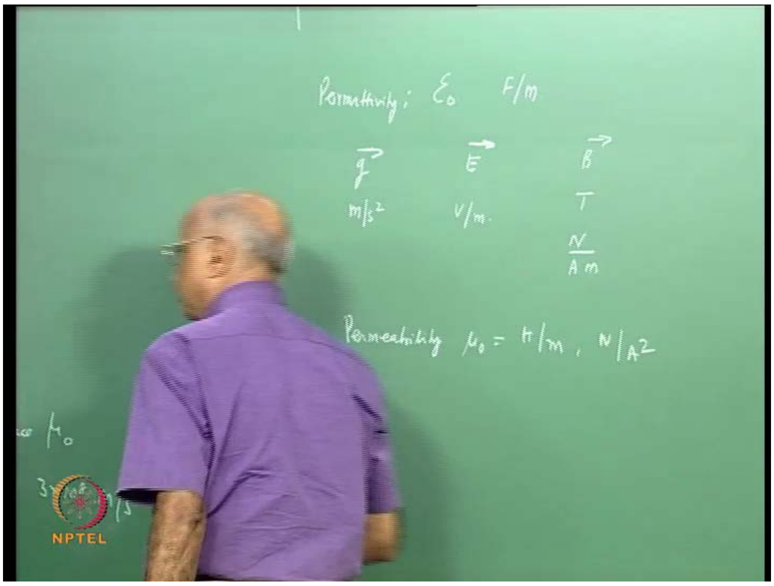

And therefore, now I add the permeability units. Permeability of free space, which is written in terms of mu not has units of Hendry per meter, or rather it is also equal to Newton per ampere square. I think if we are clear about whatever we have learnt so far. It will be possible for us to find out; yes this is the force, this is the thrust, this is all we calculate in engineering, but you will also know, see we always talk in terms of induced field; we talk of induced magnetic field.

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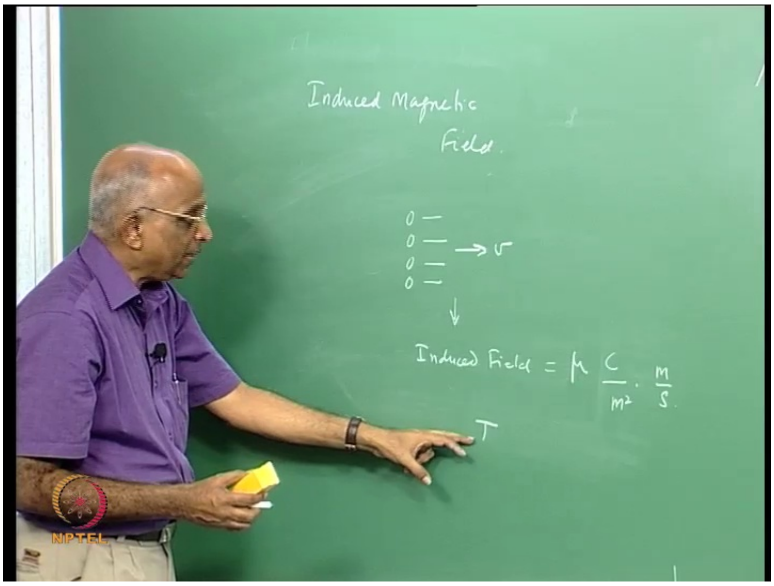

And we also we talk in term of magnetic field produced by magnets itself, what is the difference. Whenever you have charge, let us say charge so much coulomb, per unit area its moving with some velocity v, that means I have a charge which is moving with some velocity, then it is possible that this producers a particular field, which is call as an induced field. In some text book, it is denoted by H, but we will see what is the unit of this before we put the value down. All what we are saying is, it is not necessary that only a magnetic can produce a magnetic field. We always in terms of electromagnetic field, it's also possible that the motion of charges, can produce a field, which we says a induced field. And an induced field is defined as, we have to talk in terms of permeability, into something like the motion of electrons, which is equal to, let us say coulombs charge, which is moving, per into velocity charge coulombs per unit are per meter square, moving with a velocity meter per second.

Now if you see the unit of this, it will again come to the unit of Tesla, therefore whether the field is induced by electrical charges which are moving per unit area; that means per unit area I have, charged which is moving at a velocity, that also gives me the net field in Tesla. Therefore, the field due to the magnetic or due to induced field, can be describe in terms of Tesla Newton per ampere meter. Therefore, what is it we have done so far. Let us take a quick start, quick review what we are done, so that we can now go to the problem of how to use these forces. We just say analogous to the gravitational field g. I can also have electrical field E, whose unit is voltage per meter. I can also have something like magnetic field, whose unit is Tesla, and this Tesla something like Newton per ampere per meter.

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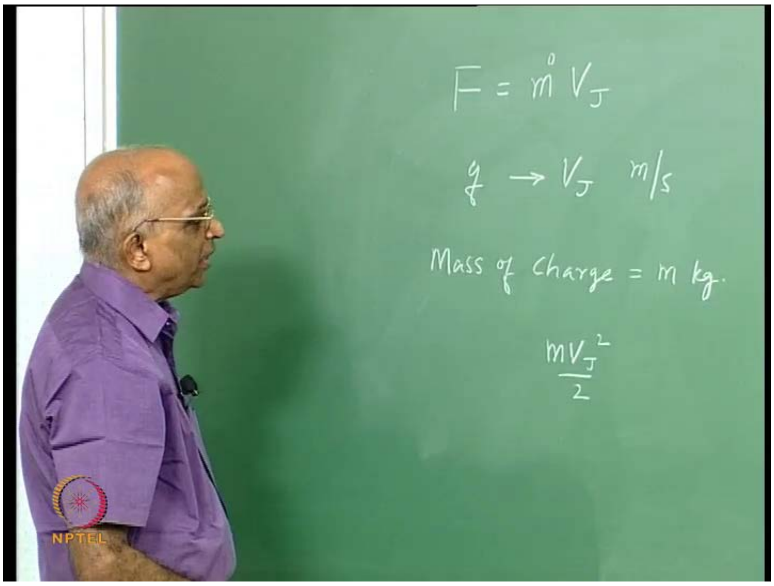

And I can use the electrical field E. I can use the magnetic field V, and this magnetic field can also come from the induced field due to the motion of the electrical charges, and this is all what we have said so far. Now I would like to use, the electrostatic field E and the magnetic field, to be able to generate a particular force. Therefore, can I go to the next step. This is all the brief review, of what we must know, relating to the fields and also, something relating to permittivity and permeability. Permeability is something which induces magnetic properties in the medium; that means we say it is something which induces a magnetic field. Permittivity is something which holds or which can contains charge in the space, this is the definition.

Having said that, let us now come back to our story. May be look at propulsion, may be force we say, force is equal to m dot V J. Now all what I am trying to say, well I have a charge q, it could be positive are negative charge. If I can move it or accelerated it through V J meter per second, and if the mass of this charge, it is the mass of m kg, is to be accelerated to velocity of V J meter per second. Therefore, the kinetic energy to be given, is equal to the m into V J square divided by 2. We can write this value, we would like to relate this value, to the electrical field. And how do we define and electrical field.

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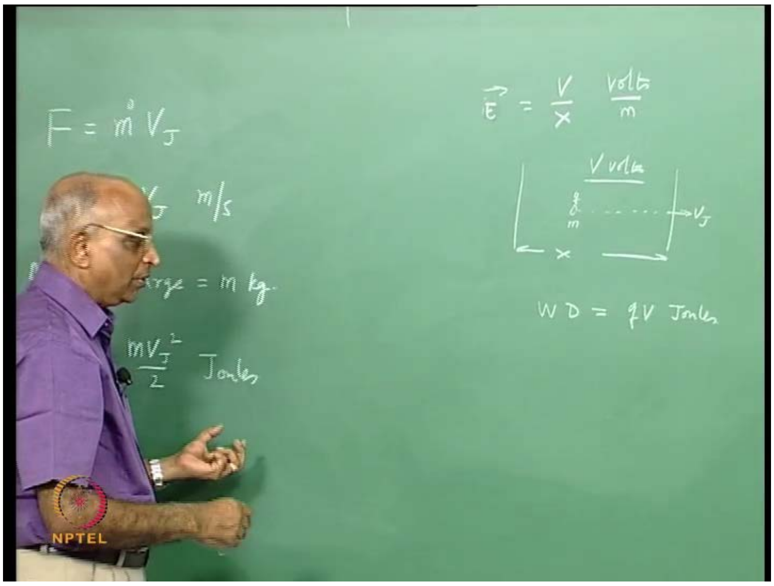

We define the electrical field E as volts per meter, or if I have particular distance, let us say X. The potential difference is let say V volts, then I can write the electrical field E, is equal to V volts divided by X is so much volts per meter is the electrical field. In this electrical field, if I put a charge and I accelerate the charge of mass m, the charge being q and I am able to accelerate to V J, and interested in find in expressing a relation, between the electrical field and the kinetic energy, which I am supplying to the particular charge of mass m, how do we define voltage, to be able to do that I would like to take a look at the definition of volts again. We define volts V, as the work to be done to carry a unit charge, through a potential difference of V.

What I am trying to says, the work is done by the charge of mass m, having a charge q, which I getting accelerated by the electrical field, and the electrical field is given by V by X. Now what is the work, which is done by the electrical field I have; work done by the electrical field, what does do. It takes a charge of q through a potential difference of V, and potential difference V volt is defined per unit charge what is the work done, therefore work done by charge q, q V so much joules, is what is the work done by the electrical field. The energy which the body gains or the work done on the charge, is m V J squared divided by 2, and I equate these two expressions, to be able to determine the value of V J.

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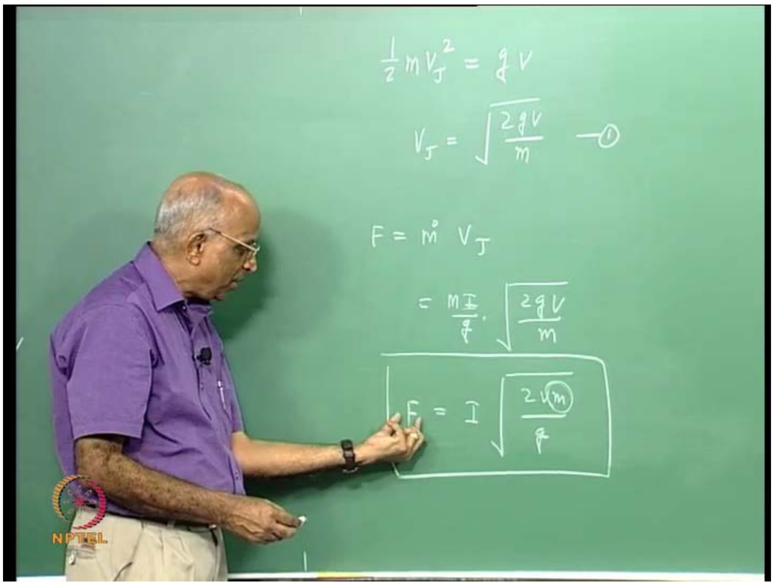

Let me put it together or rather I get half m into V J square, is equal to q V, or rather I get a value of V J is equal to under route 2 q V by m, by equation 1. And what was my equation for the thrust F. F is equal to m dot into V J, and this I can write it as, m into I divided by q, into the value of V J which is equal to 2 q V by m over here, or rather this becomes equal to I, I take it out side, m comes on top, q comes at the bottom into under route, what is it I get. I get q comes at the bottom, into 2 V into m, is equal to the thrust, and this is the thrust what I get by moving a charge in a medium. In other words if I need a propellant to be able do this type of job.

I need for any meaning full thrust, I need the mass of the propellant must be large, otherwise if I have a very small mass I get a high J velocity, but ultimately the thrust what I get is going to be very small. Therefore, the requirement of my propellant, if I were to generate of force, using this particular charge and voltage as it were, will be large, or I need a large value of current, or I requires the charge for given mass should not be very high. Let us look at some properties, of the propellant what I would require, just like we said for propellant for chemical propulsion, should have low molecular mass, should have high temperature.

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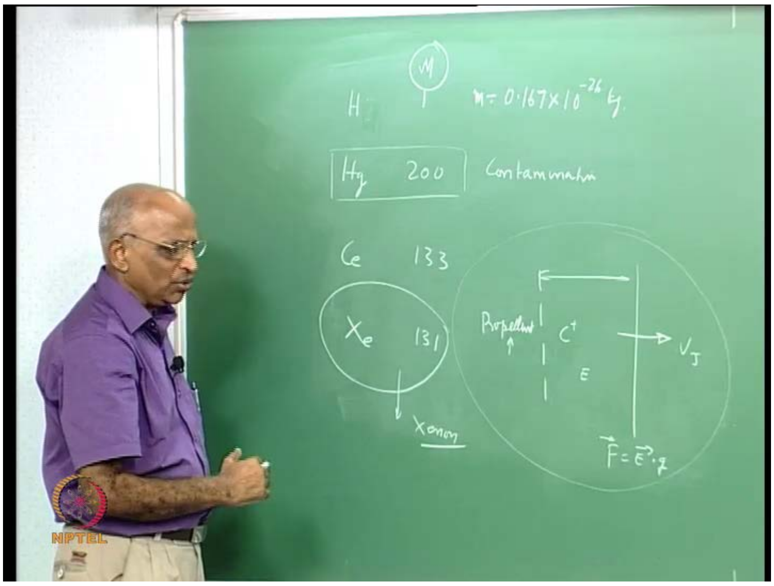

So let us try to see, let us say hydrogen as a molecular mass, compare to other substances, let us say hydrogen atom has one. May be I take drastically mercury has around 200. I take another substance cesium, I will say why I am choosing this little later, 133. I take an inert gas like xenon, equal to 131. All what I am saying is the, with reference to hydrogen as one. The mercury atoms is 200 time heavier, cesium atom is 133 times heavier, and xenon. And if the value of the hydrogen atom, if the mass of, the mass is equal to 0.167 into 10 to the power 26 kg. I can calculate the mass which is 200 times something like 0.33 into 10 to the power minus 24, minus 24, minus 24. We find that the molecular mass of certain substance like mercury, cesium, xenon are very much higher, and we would like to use such substances in the cases of electro electrical propulsion, or electro static propulsion, in which I am using force derived from charge into potential difference.

Therefore, compare to chemical propulsion, where in I need a low value of molecular mass. I am looking at substances which have higher molecular mass, therefore if I were to use, may be let us say we have still not described, what the propulsion system will compressed of, we know, but we know more or less. I have to first take a substance, like a propellant. I have to convert propellant into gas or may be make it charged in some way. Then I have to put a field over here; that means a voltage difference here, a potential difference which will give it a velocity. And may be put such a potential difference such that I get high heat velocity, and this is what gives me something like a electro static propulsion, but we have to say how I get it you know. All what I am saying is, I have a propellant, I have to convert the propellant in to charge, I have to acquire the charge here I put a field E here, so much volts per centimeter, and which gives me the value of force is equal to the thing into the charge over here.

Therefore, if I were to consider this, all what I am saying is, I will be better of using heavier substances like this mercury, cesium, xenon and all these three have been used earlier. Mercury is liquid material but, you no its vapor is something which is dense, and used in space craft's it coats the surface of space craft and causes contamination; whereas, cesium is little reactive even though it can be easily ionized. It is more difficult to use, and the general trend today, is to use xenon which is noble gas. Where do we use xenon in real life, maybe we see this boarding which have some colorful display and all; that is noble gas xenon. Therefore, we use xenon in the case of propalence, but cesium is also used and in the older electrical propulsion systems, mercury is also used. Therefore, what is it we are talking of, we are telling ourselves.

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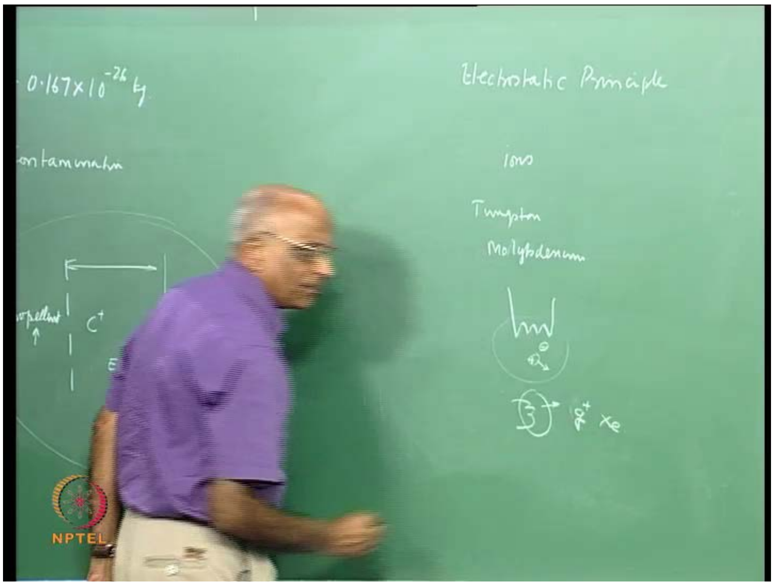

Well, the electrical propulsion system, using electro static propulsion system, we generate ions. And how do we generate ions? We have some material like tungsten, molybdenum. You know what they do is when you heat this metals, these are known as low work function metals. When you heat it, it gives out the electrons, when you give out the electron and you have this medium, like xenon gas surrounding it, when it heats xenon neutral atom, it dislarges one more electron from it, and it gets positively charge, therefore it is easy to make use of, you heated tungsten, you put tungsten here, in medium of xenon are something, and its possible for you to get charge particles, positively charge particles, of xenon coming over here. And this point in time I must also tell you we talked in terms of the molecular mass of the particulates or the gas or the propellant used for electro static propulsion to be large. Now should we used proton, should we used positive charges, should we used negative charges. The mass of the proton is about 1850 times the mass of an electron. In other words the proton was very much heavier than an electron, and therefore it is desirable to use the proton, rather than an electron to generate thrust.

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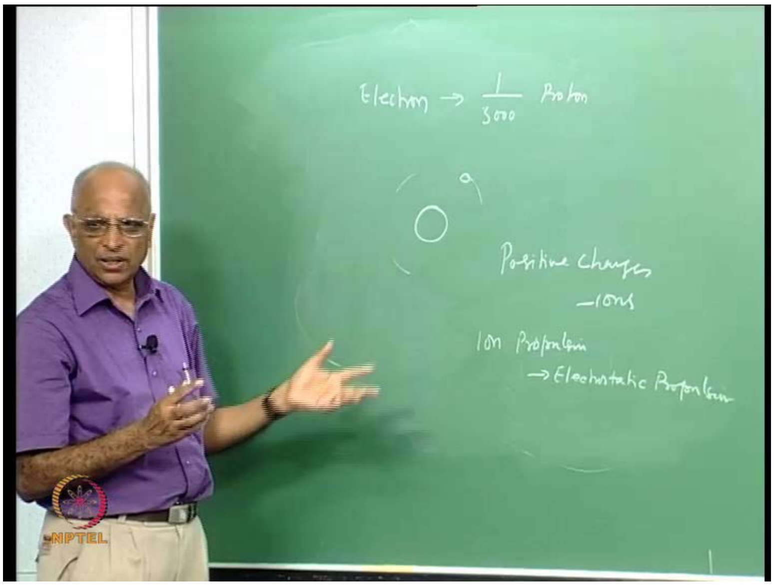

And therefore, when we talk in terms of ion propulsion, basically what we are talking is in terms of electro static propulsion. I will continue with this in next class, but all what we did in today's class was, we reviewed the units which we should be using, whenever we talk of electrical fields and magnetic fields. Then we went to the step of trying to derive what must be force, which we can be deriving field, which is electro static field. We find forces given by this, we find the mass of the charge must be significant, and for the mass of size of the charge to be the significant, is necessary to use to ion, rather than negative charge an electron, and that was the reason, even when we talked in terms of may be early in 1900, when the rocket equations, Tsiolkovsky made the rocket equation. He also talked in terms of electrical propulsion, but he wanted to, at that time they were making these tubes and all that, the mobility of electrons was known. They tried to make use of electrons for propulsion, and found that we are not able to get force, but the moment is start using ions, namely positive charges, it is much easier to get force from it. And we will continue on this with the next class. We will look at the type of system what we have, how it generate the force, and we will see the problems involved in it, and this is all what will do in the next class, thank you