Rocket Propulsion

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Module No. # 01
Lecture No. # 40
Electrical Thrusters

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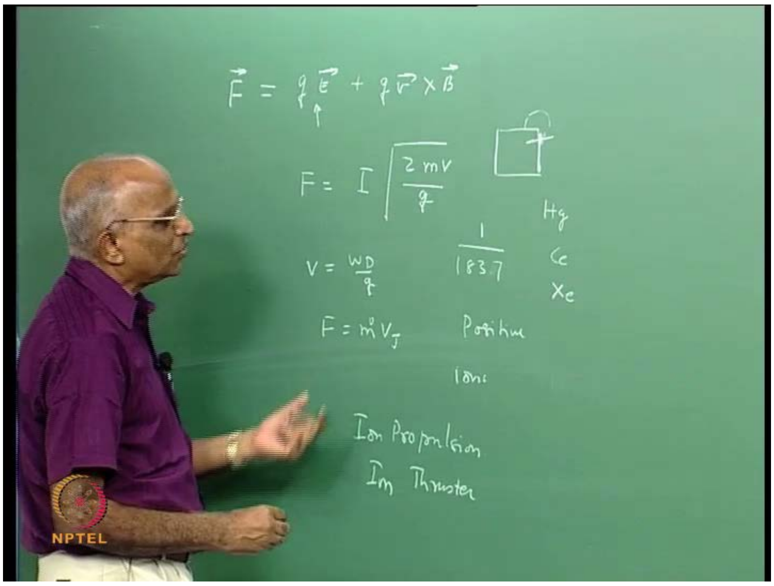

Good morning. You know in the last class we talked of electrostatic forces namely we said charge into the voltage gradient which was the electrostatic or the electrical field and we also said, we could have large moving in a magnetic field cross d is the net force what we get in a charge. This was what we called as Lawrence equation. D is the magnetic field in Tesla e is the electrical field in voltage per meter and charge is in coulombs and force is also a a vector. We continued with this and we found that the force what we could get in the case of the electrical field could be written as the current into something like two into something divided by q into the mass into the voltage right and how did we get this? We got something like the potential difference voltage was equal to the work done per unit charge and therefore, we were able to write q v over here and from this form this relation and also from the relation force is equal to m dot into V J is what we go this particular relation and this force is in Newtons, I is in amperes voltage mass and the charge over here.

We found that it is essential for the mass which we are charging to a to level of q coulombs should be substantial so that we get some force and we said electrons which weigh something like one over 1837 or 1838 or 1837 we will say. One over this is the mass of an electron. That means, if a proton is 1 1 kilogram or 1 unit the mass of an electron is something like 1 over 2000 of a proton and therefore, it is very difficult to have electrons which will give sufficient force and normally positive charges are used for generating the forces and we cannot use the electrons because there mass is so small that I do not get any impulse at all.

Therefore these positive charges are what are called as ion ions and therefore, such mechanism of using the electrostatics namely and electrical field for generating of force is also known as ion propulsion. At this point in time, I will also tell you we call it as an ion rocket, but, the type of forces which are generated are so small that instead of calling it as a ion rocket we call it as ion which generates some thrust or ion thruster. Therefore, when we talk of low thrust rockets we call it as a thruster instead of a rocket. But, anyway you could call it as an ion rocket. It depends on the person who uses it there is no very very hard and fast rule that it must be called as a thruster and not rocket or stuff like that. But, generally you find the low value of thrust when a rocket produces its known as a thruster and all the electrical rockets like electrostatic rockets generate low thrust we call it as a ion thruster.

Having said that, we also went one step further and said if I have to use this electrostatic principle and generate an ion rocket; now I call it as an ion rocket because I know I am going to use positive charges and we said yes we would also like to have substances whose molecular mass is larger or whose atomic mass is larger. And therefore, I rather have heavy substances like may be mercury, may be cesium, may be xenon. Mercury we said is something which which contaminates these surfaces of space crafts because what what happens in a space craft?

If I consider let us say, I just put it down here I considered a space craft it consist of lot of sensors may be an earth sensor, may be sun sensor and these sensors are all all all glass type of things. You know it consists of optical quality glass which gets the radiation from the earth and therefore, an earth sensor and if mercury is let of from the space craft it will go and form a monolayer on it and it will make opaque. And therefore, mercury sort of contaminates because mercury is generally not used. It was used in the earlier space crafts and is no longer used. May be cesium was also used, but, no longer used because it is a reactive metal and something which is universally used today is xenon which is a noble gas.

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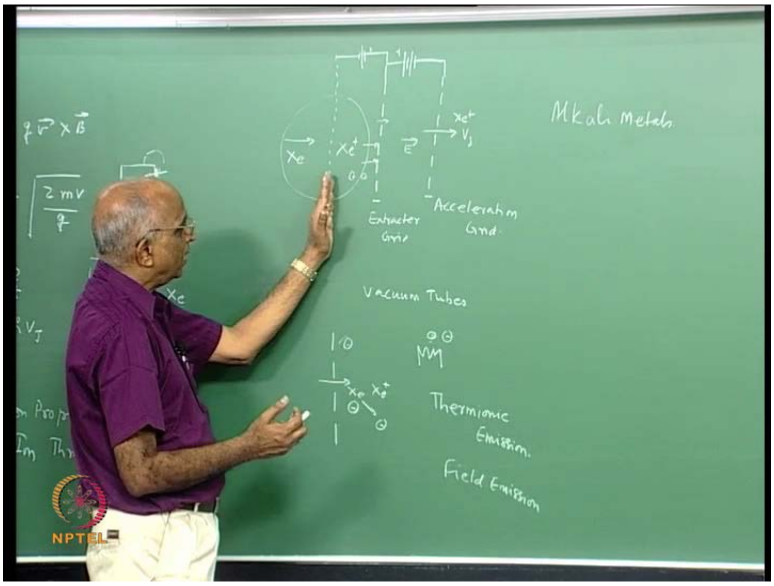

Therefore, how will a construction of an electrostatic rocket look like? Well, I need to pump in this particular xenon gas. I need to generate positive ions of xenon and then maybe I put something like a negative grid over here, something like a screen which is negative such that it will attract the positive ions towards it and again I put another screen over here which is still more negative. That means, I have voltage difference between these two. This is more less negative than this. That means, it is positive compared to this and therefore, whatever xenon ion is being attracted by this, from this source because I am generating the xenon ions here. I want it to extract therefore, I call it as an extractor grid.

It extracts all the positive things. It attracts and and brings it here. This is still more negative and therefore, what happens is because I have some negative space here or rather I have a field here, electrical field between this and this it is pulled here and it is accelerated and out goes the ions that is xenon ions at a high velocity V J. And therefore, this will be the construction of a ion rocket or ion thruster. Therefore, now if I were to put a thing here; well I put a negative value of charge here, I put battery here a high voltage here, may be I, this is my positive, this is my negative. I connect it here. May be I connect another one here with respect to if I am going to have a grid which is passing this and this grid generates the positive ions. I will come back to this generation in a moment.

Well this is going to be negative here, going to be positive negative here and therefore, this attracts and this thing which is still highly negative is what is known as an acceleration grid. See, I have assumed that xenon positive ions are created here and how do you create the positive ions? See, you all grew up in a in a generation where in we did not have these vacuum tubes. You all grow in a generation with semiconductors and all that.

Previously we did not have these semiconductor tubes and we had what was known as vacuum tubes which consisted of diodes, triodes and all that and what was done in those cases? We had some something like a filament preferably of tungsten which used to generate when I heat the tungsten, the work function of tungsten is low. So, that when it is heated it could create electrons; that means, something like negative charges.

Therefore if I could have a grid made of tungsten or even molybdenum for that matter and I heat this particular grid; may be electrons are generated from this grid and these negative ions when they hit against the flow of xenon gas which I am passing through this over here; the xenon ion, neutral xenon ion is hit by a negative charge and this fellow knocks of 1 more electron over here, makes the xenon positive. And this is how I could create it using a sort of a resistor which is heated which I call as something like thermionic emission. It is not only thermionic, but, when I have here I have a gas which is flowing and I generate some ions therefore, whenever I am creating I am knocking of 1 electron; that electron is also available and this in this space I have lot of these electrons which are going to hit the xenon more and more. And therefore, I have something like a field dimension. In this particular field I keep on generating more and more ions.

Therefore, at this point in time I can tell myself; well by having a grid which is a low work function material and work function material low means I could use tungsten, I could use molybdenum. Well I could also use the alkali metals. Alkali metals are metals such as calcium and these also have a property, we call it as a work function property such that when it is heated, it releases the electrons and therefore, I release electrons. It interacts with the neutral flow of a xenon gas creates positive ions and by field dimension the xenon ions grow and therefore, this is being attracted by an accelerated grid and this is what gives me the thrust.

Therefore I have something like a grid to generate ions, a grid which is extracting the ions from this flow over here because I would like to attract the ions more than more and more. Once it is attracted the accelerated grid further pushes it at a high velocity V J and therefore, such type of construction is known as gridded.

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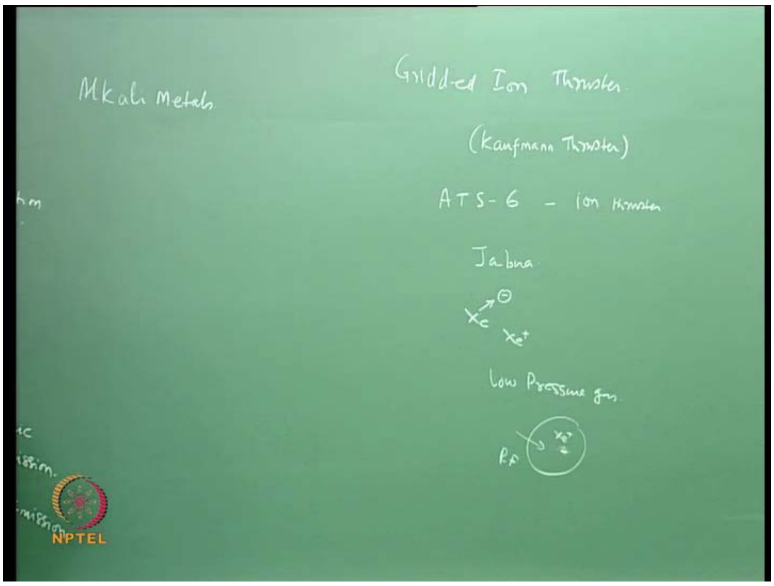

I have a 3 grids gridded ion thruster. This was started by person known as Kaufmann and therefore, it is also known as Kaufmann thruster. This ion thruster has been used in several missions starting from even 19 mid 70s and in fact in India we used one particular satellite known as application technology satellite made in USA by Hughes Corporation ATS 6. You know this was used as an experiment you know before we got into INSAT for may be communication purposes and all that we need to we needed to do an experiment because in India most of people were in villages and we never knew whether a satellite like INSAT would be useful.

Therefore in the period 1975 to 1980 or so, we got a satellite on loan from US which is known as ATS 6. It being programs for the villages different villages in the country and that was when we saw well the INSAT satellite would be useful in improving let us say the education in villages, may be the health care in villages and we had very backward villages like in MP places like Jabua wherein they were all tribals. And we put some power sources demonstrated that a satellite will be useful in improving the quality of life and that is and in this particular satellite they also demonstrated ion propulsion or ion thruster.

Therefore, we see yes a gridded ion thruster can be used, but, are there, is this the only method of generating ions here? After all I need to generate ions. To generate ions it is also possible that in substances like xenon which in which I can easily knock out an electron out of it and make the xenon to be positive; that means, I remove something it net becomes positive. I can use something like low pressure xenon, low pressure gas and into this low pressure gas supposing I were to heat the gas and how do I heat the gas? I sort of oscillate something like I put radio frequencies in it. I put, I have a volume of gas I put radio frequency into it I sort of excite the gas and heat it and in that case when I heat it; gases like xenon tend to form may be positive and electrons negative. And I use the same attractive forces and do this. In other words, I use radio frequencies also to generate positive charges.

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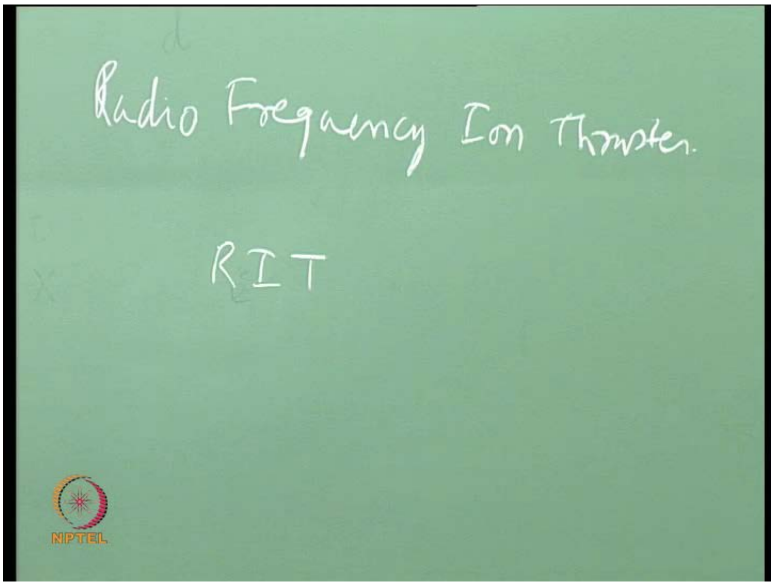

And if I use radio frequency; well the thruster is known as radio frequency ion thruster. May be I will write it here or it is known as RIT. It has also been flown. Therefore, we are talking of some of these electrostatic type of mechanisms wherein I could use gridded ion thruster, may be radio frequency ion thruster or even I could think of some other configurations.

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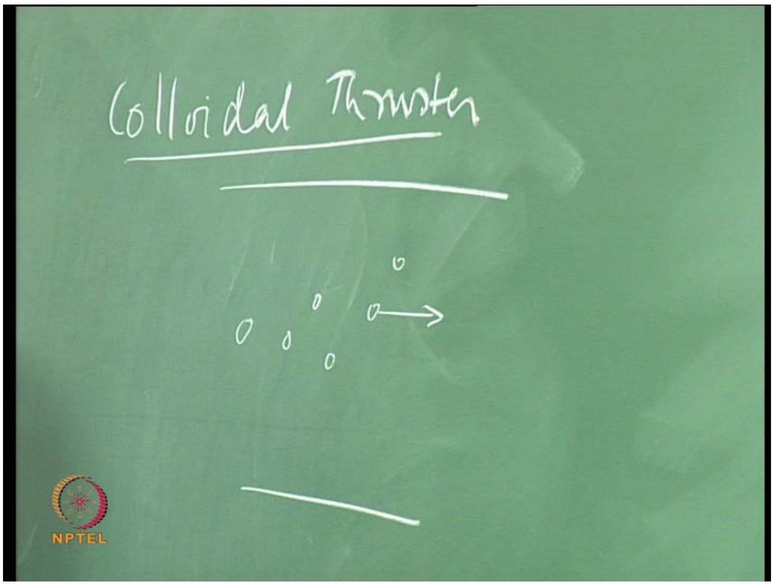

In fact, you have this rocket pioneer by name Yuri Kondratyuk who developed something known as a colloidal thruster which again works on the electrostatic principle. Here you have a colloidal. What is a colloid? You could have something like let us say fine droplets which are which are scattered or something. These fine particles of dust or droplets which is something like an aerosol are charged and this charged particles if in an electrical field could be accelerated and this could be used to provide thrust. Namely, you charge the colloidal and these colloid particles once they are charged, you put it in an electrostatic field and you generate thrust and this is what is known as a colloidal thruster.

Using the electrical field as it were, if I can generate charge in a particulate; I can accelerate it and I can get a particular thrust. Well, this is all about electrostatic, but, I think having studied it, let us see are there any other specific problems in this. Is it something which is so readily usable and are there some improvements in it? Because you know I we do not see ion propulsion being used as much as some other forms of electrical propulsion. And the reason being may be what is happening? Let let us see what are the problems. You are having these accelerated charges accelerated ions hitting against this particular grid which is something like a sieve something like an open thing over here, a sieve over here.

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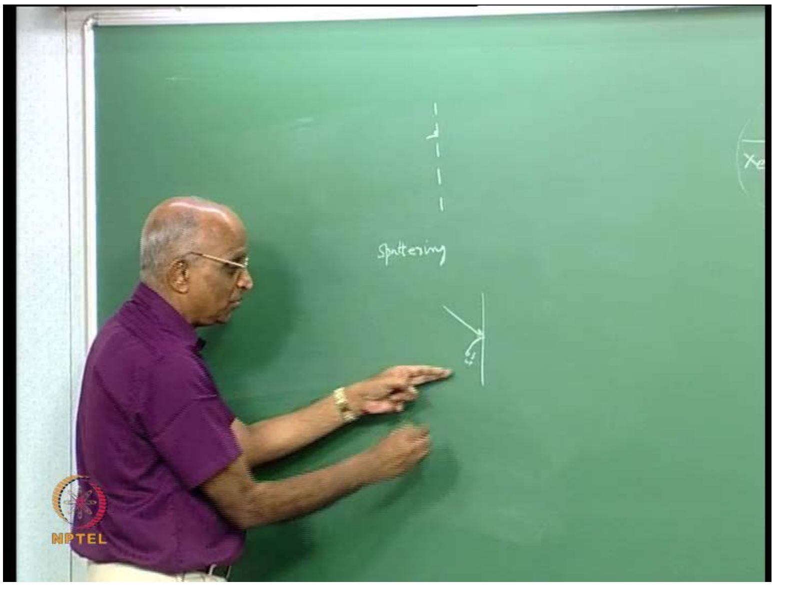

And when these things are hitting against it gets sort of it removes the metal and this is known as sputtering. That means I pass high high velocity charges. High velocity charges when it impacts here it corrodes the metal and it is known as sputtering.

I think we must remember this word sputtering because when we talk of nanomaterials; one way of making nanomaterials is I take a material, I allow high high velocity charges to come on it, I generate particulates which are very fine particulates which are nanoparticles. Therefore, this sputtering sort of erodes the thruster and the life time of the thruster reduces.

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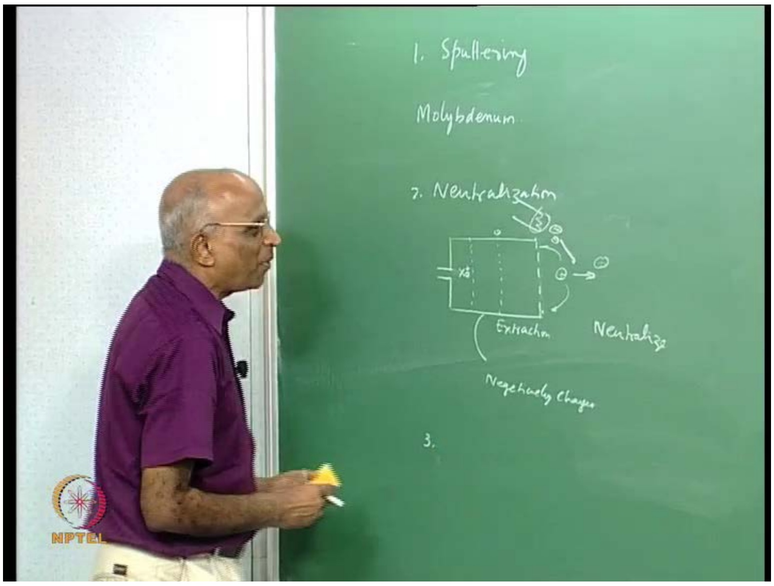

Therefore, one problem I can immediately say is a problem of sputtering. But, how do you correct for sputtering? Maybe I can only reduce it. I use something like instead of using tungsten, if I use molybdenum it is less susceptible to sputter and therefore, I use something like a molybdenum grid.

There is a second problem and this second problem is common to almost all types of electrical thrusters. Let let us see this problem. You know supposing, let us say I have this particular container. Now I now put the thruster like this, I allow the charge to come over here and now I create the charge over here xenon positive. I put extraction grid over here to get that thing out and at the end of it, I put the acceleration grid and we said may be the voltage of this could be something like 1.5 k v with respect to 0 here and this could be negative with respect to this by some let us say few few 100 volts.

Now, what is going to happen? The positive ions are going out being accelerated at high velocity. All the electrons are getting accumulated within. that That is somehow here and how are positive ions getting generated? You are removing electrons from it, you are removing the positive charges from it. So, therefore, thruster becomes negative negatively charged because what is it we are doing? In this system I am I am getting the positive charges out the things becomes more and more negative it becomes negatively charged and therefore, when it becomes negatively charged.

Even though I am pushing it out there is a tendency for these things to get retarded pull back as it were and therefore, if I leave the charge like this the negative charges will decelerate and cause it to come and therefore, it is necessary for me before I push it out to be able to neutralize the positive charge. And how do I neutralize the charge? All what I do is, I put another cathode or cathode is something which generates negative ions; which means I put another say some thermionic emitter over here and I generate negative charges. Put it into this such that it will hit this and what comes out is neutral charges, not positive charges, but, neutral. Therefore, the second problem in which is common not only for gridded thruster, but, any thruster is we need to neutralize. That is neutralization must be done.

Therefore, an ion thruster should have neutralization of the charges otherwise when negative charge is build up it will not be able to push this aside. Well, there is a third problem. The third problem let let us see on this figure how how we can visualize this problem.

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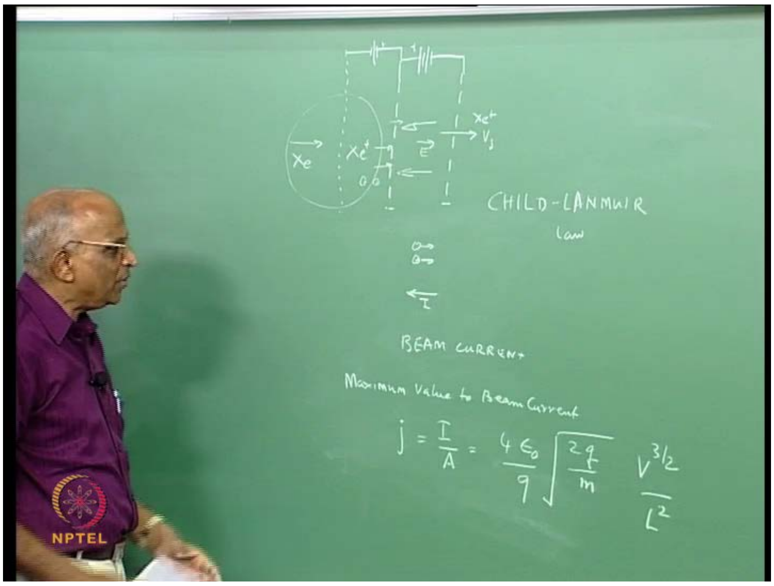

You know what is it that we are doing? We are pushing the charges, positive charges, accelerating it over here. When I positive charges move like this I have something like a current which travels in this direction. What is current? Current is a motion of electrons. Therefore, I have something like a beam current. What is the beam? I have a, this as a beam a beam current as it were. Let us put it down properly I have a beam current as the positive charges are moving, I have a beam current in this particular direction and what will this beam current do? Between the accelerator grid and this particular acceleration grid and this extractor grid even though this is negative; this beam current will reduce the effective voltage with which it is getting attracted. Maybe for a critical value of beam current no more extraction is possible and the thruster will fail. That means, there is tech maximum value to the beam current.

And we will not go into too much details of this. But, we recognize yes there is a maximum amount by which I can push it out because as I go more and more of the positive charges are moving out, I get a current in the opposite direction. That current will ensure that I do not have sufficient negative voltage to suck in or extract the positive charges here.

And therefore, there is a threshold value of this and this maximum beam current is given by the current density J which is equal to beam current divided by the area of cross section and this is given by a law known as Child's low; child Langmuir. Very easy to derive this law Child Langmuir law which says that the maximum value of current density which stops further getting all these things here is given by 4. You remember we talk in terms of permittivity of free space divided by 4 e 0 by 9 into 2 cube by m into the voltage to the power 3 by 2 divided by L square. In other words, all what I am saying is there is a limiting value of beam current beyond which it is difficult to extract the ions over here and the thruster will fail. Therefore, the maximum value of current which is possible in ion rocket is now given by I is equal to J a or J is the critical value let us say.

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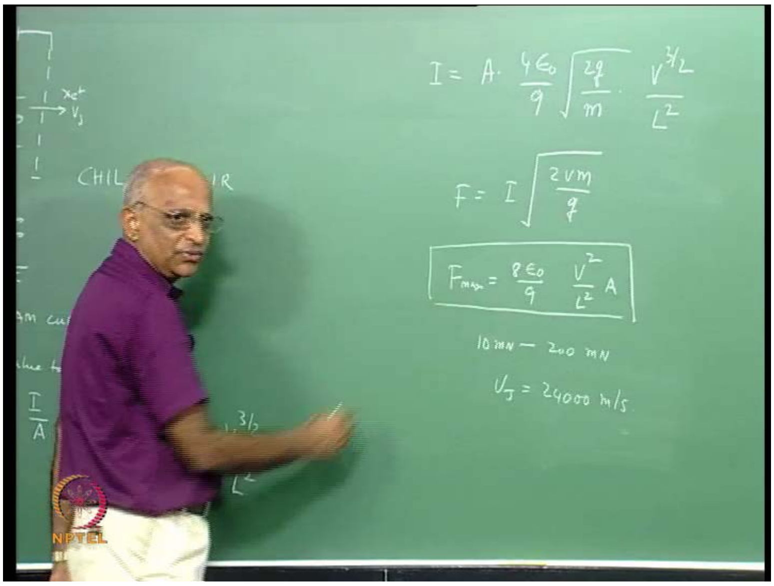

Therefore, the maximum current what I can get in an ion rocket is equal to a into 4 times the value of permittivity of free space divided by nine. Unit of permittivity we saw saw farads per meter into 2 q divided by mass of the charge into voltage to the power 3 by 2 divided by L square. But, I already know the force equation and the force equation or the thrust developed by a particular ion rocket we derived as a I into under root. What was it? 2 v m divided by q.

And therefore the maximum thrust which an ion rocket can develop I substitute the value of a here; I get 4 permittivity divided by 9 2 q by m. And therefore, this becomes 8 over here. Because I have two coming two coming here 8 e 0 by 9 and q by m and q by m cancels off, voltage to the power 3 by 2 is equal to v; v v to the power square divided by L square into the value of a which is the maximum thrust which is possible. How did I get it? A comes over here two and two gives me 8 here, 8 permittivity of free space epsilon not nine over here and I get v the balance v which is left here v square by L square and in practice and this is the equation to the maximum thrust which can be developed by a ion thruster and we find that normally the thrust is around let us say 10 Newton to something like I am sorry 10 milli Newton, very low thrust are generally derived, 10 milli Newton to something like 200 milli Newton. The maximum specific impulse or rather we put in terms of V J is around 24,000 meters per second.

You know when we talked of chemical rockets; we found that the V J is around 3,000 or something. The ion rockets gives around 10 times the performance, but, at the reduced thrust level and what is the maximum thrust level given by this particular equation? Well this is all about ion thrusters. Maybe the, we what we call as, maybe radio frequency ion thrusters and these are what is being used for it has been flown in several missions and it is a strong contender and in India also we are developing the ion thrusters.

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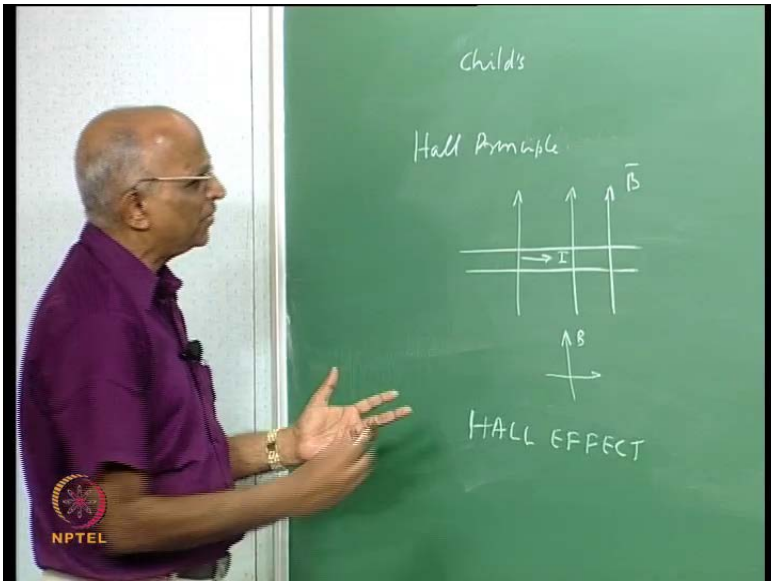

But, something which took the community by storm or something which is totally different was looking at the problem in a slightly different way by the Russians. I think let let us we must try to appreciate some points see all what we are saying is we have the child's law which I just now wrote saying that there is a limitation on the amount of charges which can be emitted and the thrust which can be generated by the ion rocket. Now, there is a principle in electrical engineering or in physics known as Hall principle. What does this principle tell?

Supposing I have a conductor. In the conductor I pass a particular current I and this conduction is placed in a magnetic field which is perpendicular to it. That means, I have so much Tesla normal to the current flow in amperes. Then the Hall principle stays states that when a conductor carrying a current is place normal to a magnetic field a voltage is generated normal to both the current and the field. In other words if I pass a current like this which is in a field B, I generate a voltage normal to both and this is known as Hall principle or something known as Hall effect. In other words what is it I am telling?

Let us, can we make use of this? In other words I am I am always passing current. You know I am having charges, I am passing current over here. If I were to put another magnetic field, I could have something like a voltage generated and this was used by as I said by the Russians in the following way. Let let us try to see whether I can use this principle in improving the performance of my ion thruster because as I said an ion thruster, the thrust is small, V J is excellent and I need a good field.

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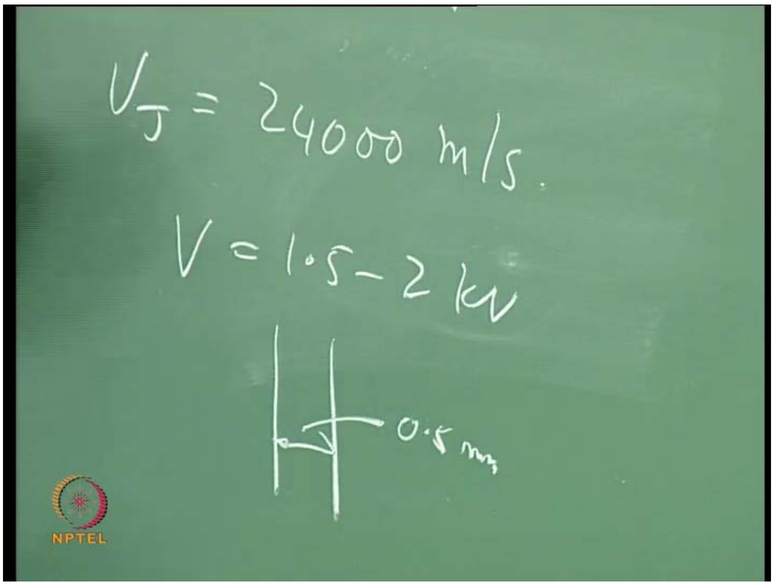

And therefore, I use a voltage of around 1.5 to 2 k v to be able to attracted and since my distance, length has to be small; my distance between the accelerate in between the extracting grid and the acceleration grid is something like 0.5 mm. Therefore, without sparking, without doing this it is not it is not easy business; that means, I am talking in terms of dimensions.

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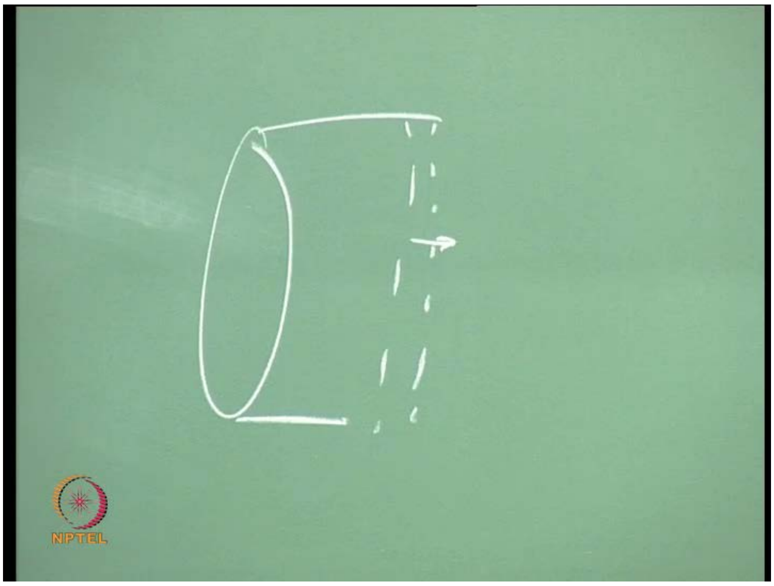

Let let us try to take a gri[d]- thing like this and I have an extractor grade and I have an acceleration grid. This is around 0.5mm, the voltage across something like 1.5 kilo volts and therefore, construction is quite difficult.

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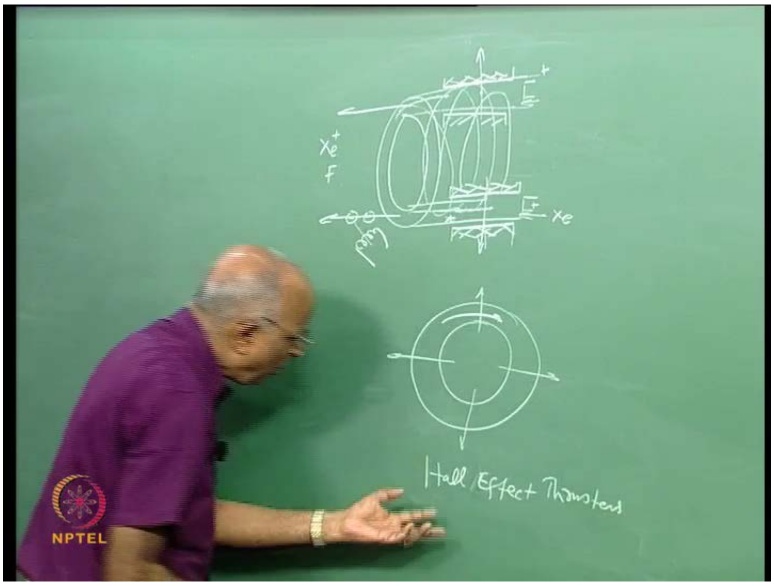

Therefore what is done over here? What what they thought is; if I were to have something like this over here, maybe I put something like a annulus here and lets let us just consider what is it I am talking of? I am talking of something like a cylinder over here and I am talking of annular gap between the inner and outer and supposing I were to put a magnetic field in this annulus; I just put a magnetic field some test liner. That means, in the annulus between the inner and outer I have a magnetic field. That means, the magnetic fields could be let us say in this direction over here. In other words let me take a section over here, a section over here. In this I put a magnet here, I put a magnet here.

Therefore, I have a magnetic field in the radial direction. And now I put let us say an anode here. That means, I sort of put something which which is positive positive voltage here and here I put a cathode over here and the cathode when I heat, it generates electrons. Because I heat the cathode work function is small it generates electrons. The positive one is going to attract it in this direction through the annulus it will go and therefore, electrons are moving in this particular direction and the magnetic field is in this direction. Therefore, now I get tangential; that means, normal to it I get a voltage and therefore, the electron instead of moving normal will now move in a path which is spiraling here.

When the electrons are spiraling here what I do is through this I admit the xenon gas over here and the xenon gas when it comes into this spiraling electrons is going to collide and generate positive charges and these positive charges will be pushed by this positive and I get a net flow of xenon positive ions being pushed by positive and this gives me the thrust. Therefore, I use Hall effect effectively to improve my performance of the ion thruster and this is known as Hall effect thruster. These thrusters have been flown by the Russians in several machines, molennium machines they say cosmos rocket and all that for their satellites and this has been widely used and in India also we are working on these satellites. It was supposed to be flown in the last GSLV, but, as you know the last GSLV did not really flied because it had some problems in the earlier part of its machines, but, people are working on it.

Therefore, all what we will say is Hall effect thrusters make use of these spiraling effect of the electrons which essentially collide and since the spiraling effect is used; you do not have things like Child's law saying that beam current is that. This is the essentially essentially plasma consisting a lot of neutral gases. You do not have the problem of any sputtering here and it is easy thing in which I can use it.

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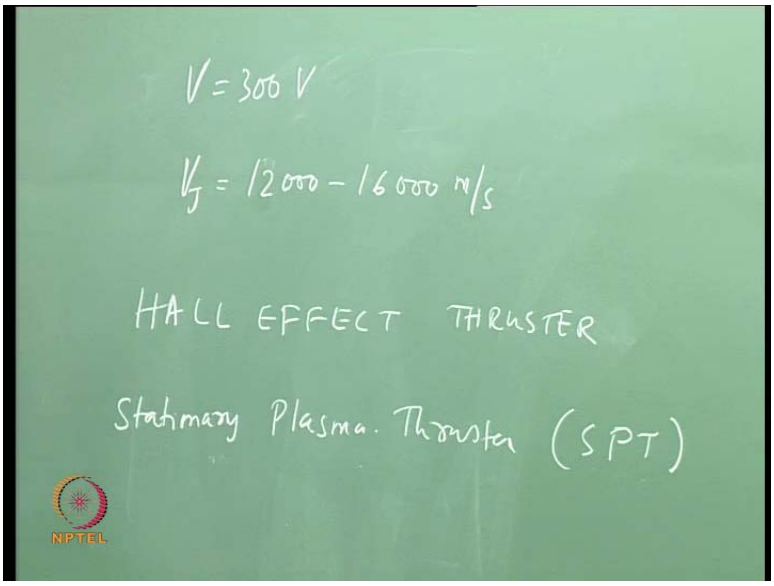

And I use a low voltage of around 300 kV, 300 volts I am sorry and there is no question of gap and the thrust the V J what I get is somewhat lower of the order of let us say 16,000 compared to 24000 what I get. Maybe let us say 12,000 to 16,000 meters per second, but, even though I get a smaller value I use much lower voltages and this is what is known as a Hall effect thruster.

It is also spoken of as you you are creating a plasma which is in the annular passage stationary. Therefore, you have stationary plasma thruster and most more often than not it is referred to as stationary plasma thruster and this is what we make use of the Hall effect in this. Therefore, we have talked in terms of the electrostatic principle and in the electrostatic principle we talked of ion rockets, maybe radio frequency ion rockets, stationary plasma thruster, maybe we could have a colloidal thruster and these are all what comes out of this principle.

Let us go back to the next part of it namely the electromagnetic principle. In the electromagnetic principle things were small and whenever we are studying all this we are not looking at the description of a thruster, but, we are looking at the operation mechanism.

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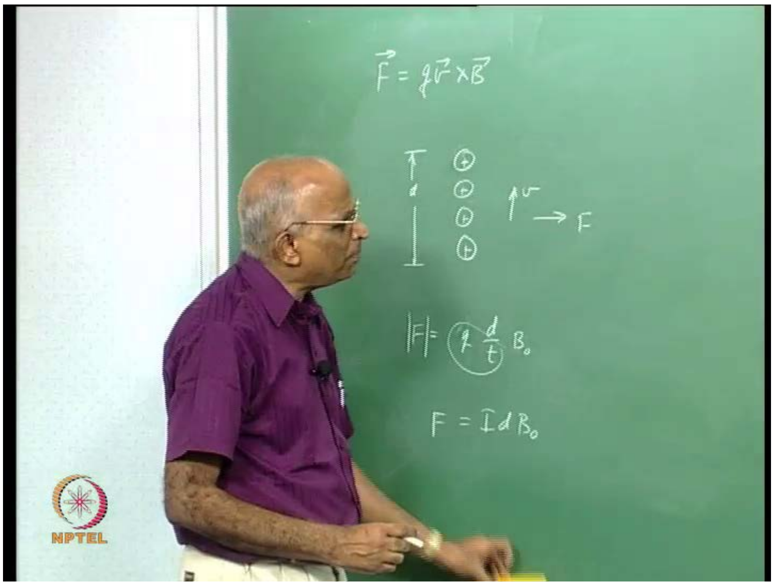

So, that we can go ahead and work out some numbers and also design one and therefore, we said well a force can also be generated in a magnetic field when a charge moves at a value of velocity. This is the force which is generated which we called as a Lawrence equation. Therefore, now I say yes I have maybe an electrical field let us say which goes into the board over here and in this maybe I pass a charge q. We still say yes a positive charge is better because electrons do not have much of mass and much of the force which is coming. I have a charge which is going with a velocity v.

And therefore, if this is going in this, this is going in this well maybe I should get a force in this particular direction. Let us calculate the magnitude of the force from the particular equation. We have force is equal to q into the velocity. Well, let us say I have a distance d over the field over here and let us say I am I am interested in velocity. Therefore, velocity I can write as d by time taken for the body to experience a force in this particular direction or rather let me say I move it in this particular direction such that I get a force in this particular direction.

Therefore, I say d by t is my velocity and force I say the magnitude of the force. I say the value of the flux in Tesla is let us say B not I just use a word because I want to differentiate the vector from the scalar quantity Tesla over here. Therefore, I have q which is the charge and this is the time over which it moves in the electrical field d by t in B naught and therefore, q by t is current. I can also write it as current into d into B naught and this is my force. Therefore, I find in a magnetic field if I have a current I and the depth of the magnetic field is d; I get a force F over here and to be able to complete this scenario, if were to write may be the force as equal to mass into acceleration where m is the mass of the charge.

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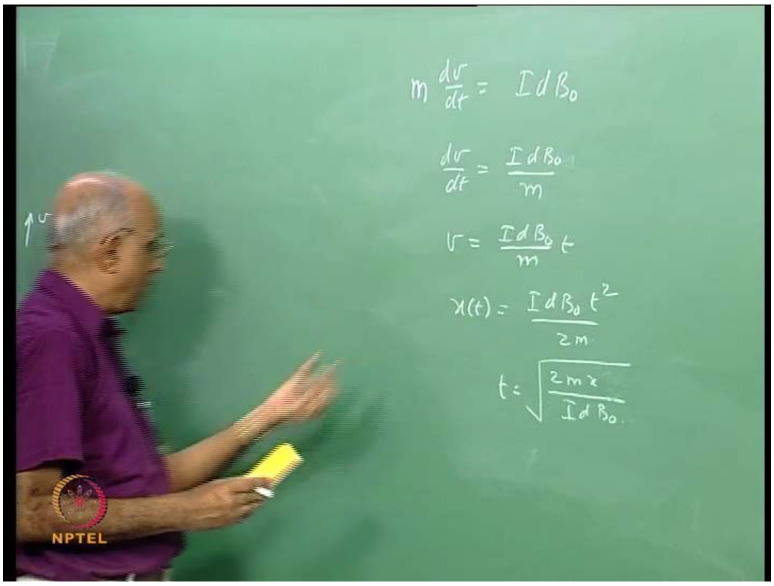

I get m into dv by dt is equal to Id B 0. B 0 is the magnetic field or rather I get dv dt is equal to Id B 0 by m or since at the initial state v is equal to v 0 at time t is equal to 0; I can straight away integrate V is equal to Id the into t or rather the value of x at t. Again x is 0 when I have no at t is equal to 0 I get I get Id B 0 t square by 2 m.

I can go ahead and then simplify the, if I want the velocity here, I can substitute t square I can take the value of t from this. T is equal to therefore, under root of 2 m into x at the time t divided by or just I say x at time t divided by Id B 0 and therefore, I can get the value of velocity which is required over here to give me the particular force and these are the only set of equations which are applicable for let us say a thruster which will make use of a magnetic principle. But, in case of a magnetic principle what happens? You must have the charge must be given a velocity.

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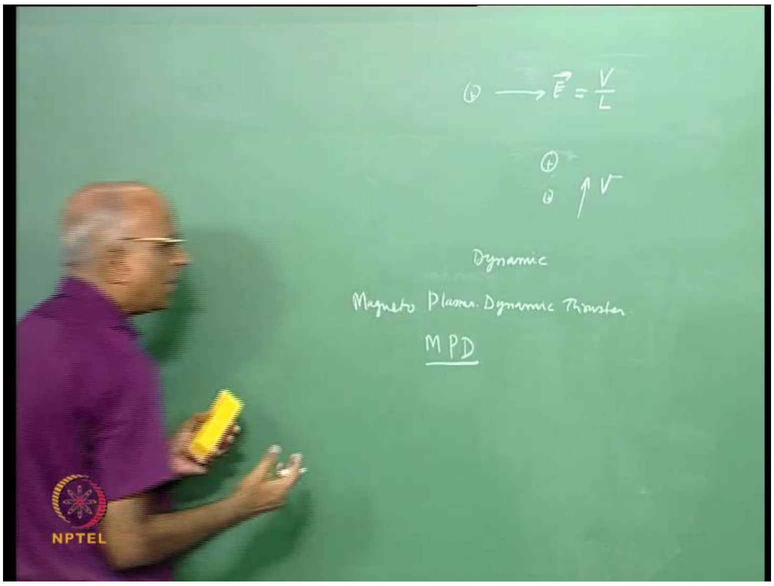

What’s the difference between electrostatic and electromagnetic? In the other case I just have a charge which is accelerated by the field e and what was the acceleration? V is the voltage between the acceleration grid and the extractor grid. The distance between them is this, the value of the field is divided by L whereas, in the case of a magnetic or electromagnetic thruster I have a field which is available and into this field I have to move the charge with a given velocity. In other words I am talking of a dynamic situation and therefore, electromagnetic thrusters or magnetic thrusters or magnetic rockets are known as dynamic thrusters because they you need to have a velocity to begin with. And therefore, if I have plasma; it is known as plasma dynamic thruster. But, most of the plasma is in a magnetic field it is known as magneto plasma dynamic thruster or MPD. These are all about the magnetic rockets.

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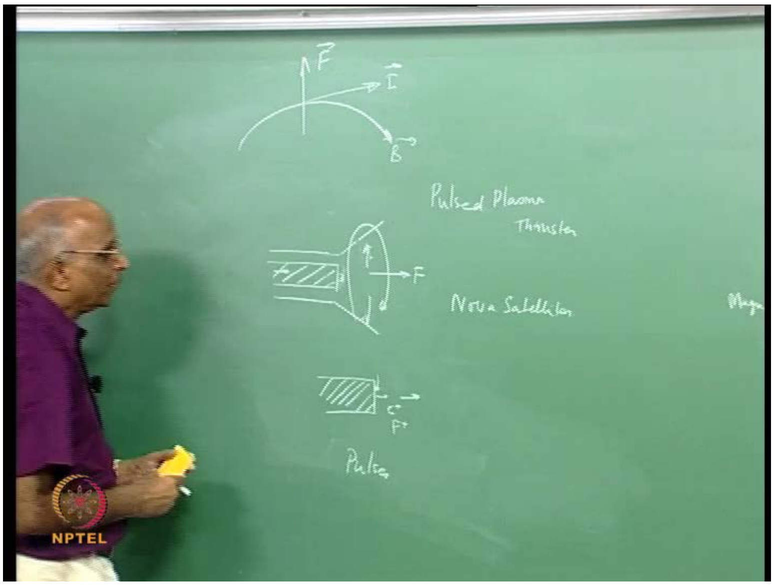

And let let us take a sketch of it. We now know the principle let us take a sketch of how it must be. Well I could have a magnetic field in a tangential direction, maybe I could have in the orthogonal direction a current I and therefore, I will have a thrust normal to it this is my force. Let us see the construction of it. Well I have a chamber which comes like this, may be I pass my gas or my charge into this. I have a construction like this may be I put a material over here may be I have an magnetic field in this particular direction. I charge the flow over here. This is my body over here. Let us say I put let us say a voltage here, I put a voltage here such that I make the charge go in this particular direction or the current flow in this particular direction and now I get a force in this particular direction and this is how a magnetic a electromagnetic thruster operates which we say is a dynamic thruster or we say magneto plasma dynamic because you have a plasma of current which is there. Current goes in the radial direction and therefore, the force you get in this particular direction.

Well, these are about this. You know one one development which may be Kanpur people IIT Kanpur is working on is something known as instead of having the thruster in this particular direction; why not you have something like a material like Teflon and I put an electrical spark here and therefore, generate a plasma when I have some material like let us say Teflon which is essentially carbon, fluorine and all that. I generate carbon charges, I generate fluorine charges and these fluorine charges in a field I whenever I put a spark I generate little bit of this and this gets gets into the magnetic field here and it generates a thruster. That means, I generate thruster in pulses. Whenever I put a spark, I generate this ions and I generate pulses these are known as pulsed plasma thruster. See you can keep on evolving and that is the beauty of propulsion and in propulsion what all we want is some field to generate a force. You use different types in pulses, you generate as a steady flow you generate and these are the different possibilities.

These things have been done elsewhere and it has also been flown by the by the French people in one of their Nova satellites. Well, I think there's it is time to take stock of whatever we have learnt so far in electrical propulsion. We tell yes it could be either electrostatic or it could be electromagnetic and in electrostatic we had the ion rockets we had hall thrusters, stationary plasma thruster we had the dynamic.

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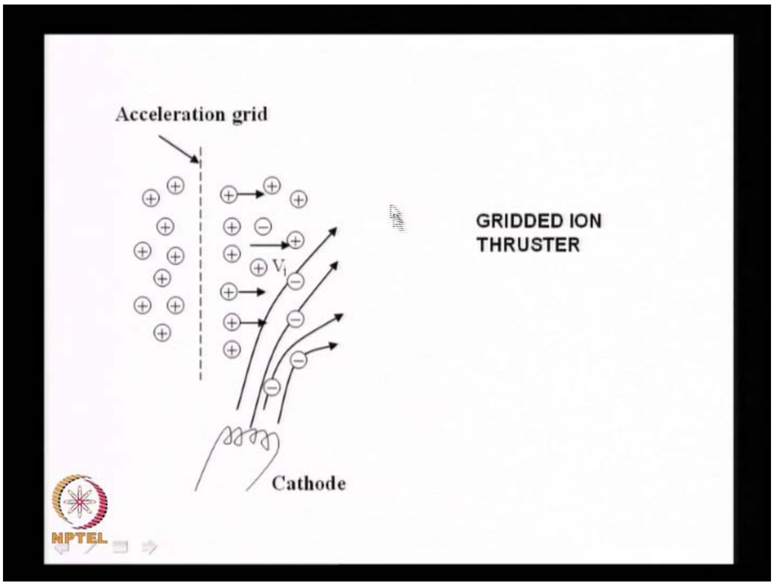

Therefore, let us quickly go through it and see how how we conclude the question on thrusters. Well this is what I said. You need an acceleration grid, you need a neutralizer in which I put the electrons into it such that what comes out is neutral these things are not taken back over here; One.

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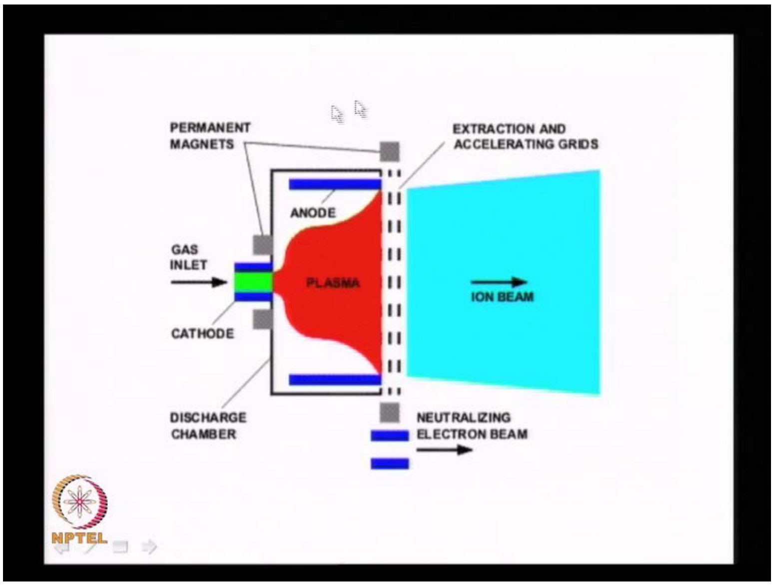

You know this is how an ion rocket looks like I admit this xenon gas over here. This is the chamber in which I make the positive ion and this is something like an extractor grid, this is something like an acceleration grid, the spacing between them is around half a m m and the voltage is around 1.5 k B a. That means, I have an intense field the whole thing is accelerated and I put something here in which I inject the electrons into it for neutralization. Therefore, I have magnets and why do I put magnets in this case? To make sure that I have a controlled plasma here. Mind you it is not a it is not something like a electromagnetic thruster.

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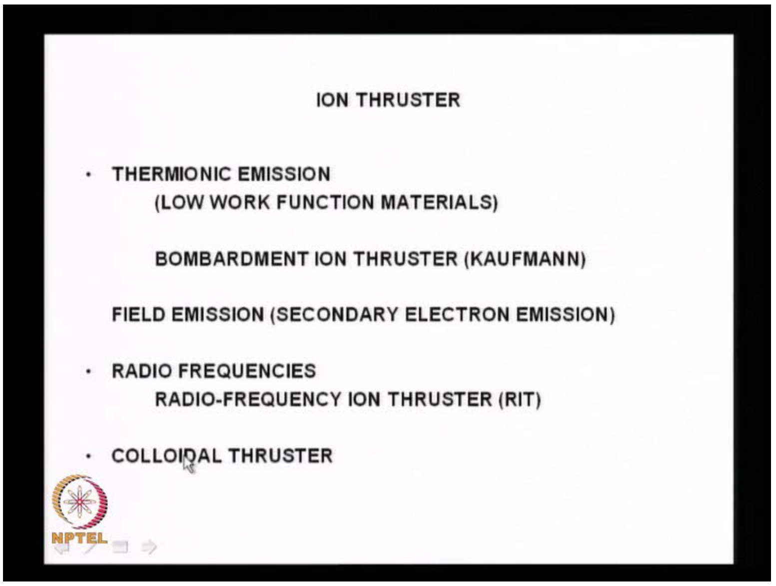

Therefore this is the, these are the constituents of a ion ion rocket or ion thruster. Well, we talked in terms of thermionic emission or bombardment of ion thruster because I bombard the neutrons on to the or I am sorry the electrons on to the charges and by bombardment I get ions over here and this is what we had the gridded ion thruster also known as Kaufmann thruster. I could have field emission where in bombardment takes place and secondary electron emission also constitutes to generate more current or more more charges, positive charges. We talked in terms of radio frequency thruster. I talked in terms of some substances which could be which could be charged like a water droplets or some collides which could be charged and I could generate a thrust.

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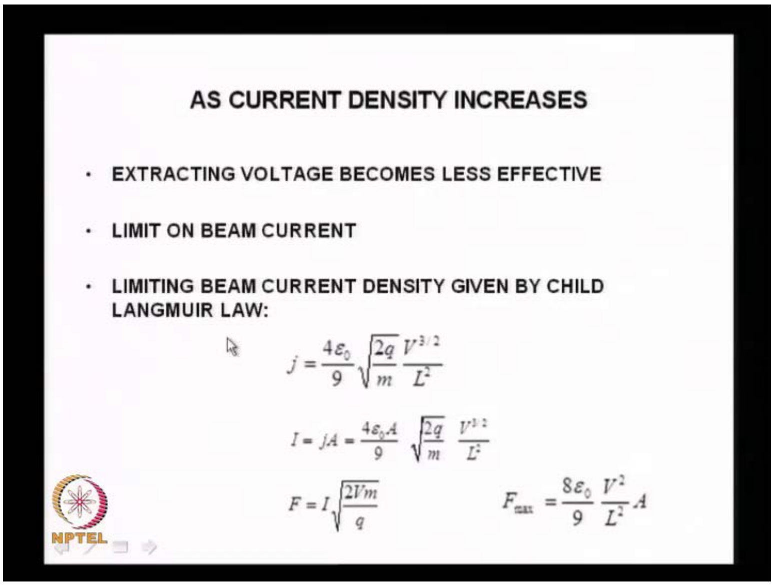

Well, this is all what we say is as current density increases we had the three problems; may be the extracting voltage becomes less. Therefore, the Child's law came into the picture. We have limitation on beam current and we found out how to get the maximum value of thrust.

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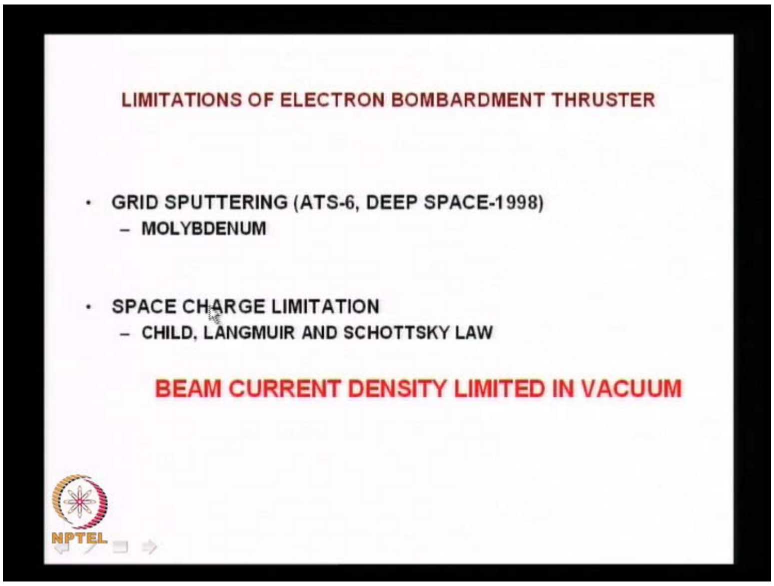

And as I said these grid thrusters even though there are limitations; it was used for the Indian INSAT which we had used satellite known as application technology satellite. It has been used in some missions like deep space which leaves our solar system and gets into distinct space and the thing is that to prevent sputtering we use molybdenum in ion rockets. But, considering the space charge limitations;

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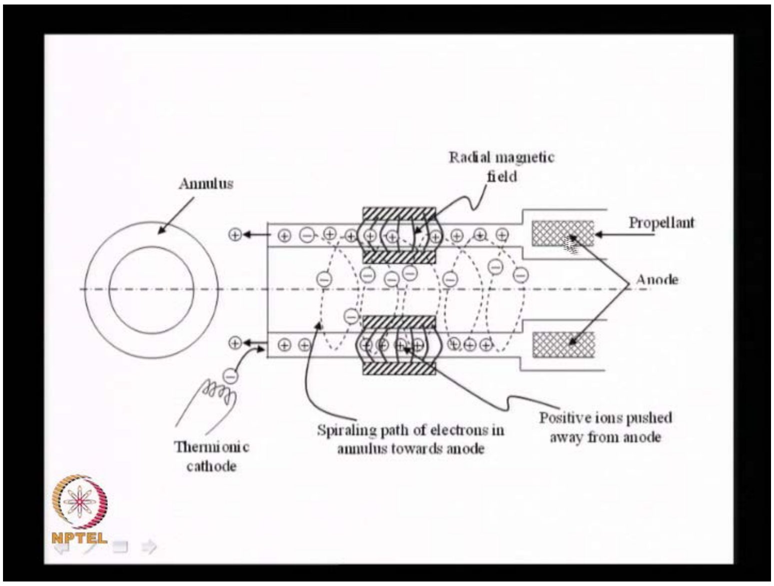

The tendency is to make use of the Hall effect wherein you allow the electrons to be attracted over here. The electrons spiral generate the positive charges rippled by the positive charges and out it goes over here.

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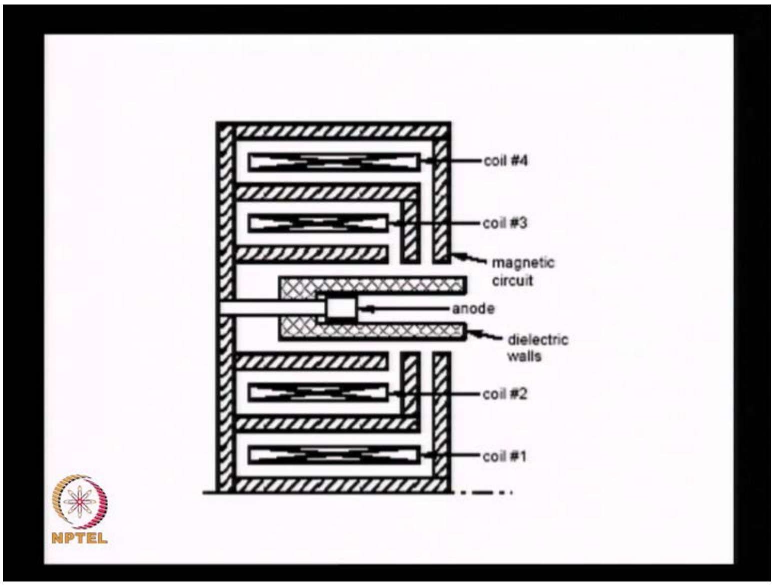

But I did not really specifically tell about disadvantages of the Hall thruster, but, let us look at the construction. This is the center line, I put magnet here this is the annulus. I put a set of magnets here. I have a strong magnetic field. The strength of the magnetic field in the hall thruster since we talk of numbers; I think we should have some numbers for the field. We told that the earth magnetic field is around 0.4 into 10 to the power minus 4 Tesla.

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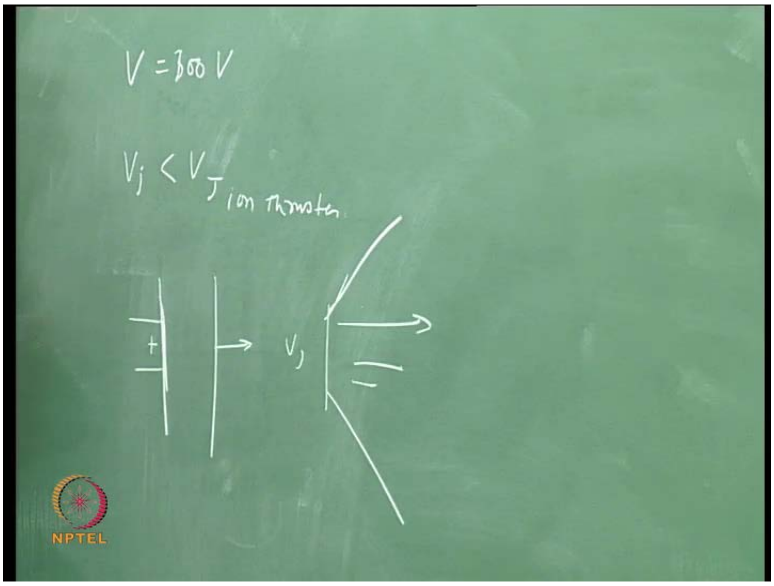

Compared to that it is around 0.1 to 0.3 Tesla is what is the strength of the magnetic field which is used in the Hall effect thrusters. As I said voltage is around 300 volts and you can generate slightly higher thrust compared to the ion rocket. But, as we said the V J is less than what you get in the ion rocket, ion thruster.

But there is one problem which we can immediately foresee. You have the anode, you are this is positive it is pushing out the charges with some velocity and therefore, the velocity being lower, you know it does not really go as a free stream. It tends to diverge a little bit and when it diverges you know it goes and contaminates the other bodies space craft around it and to be able to prevent it, people talk in terms of something. Can I reduce the length over here such that the positive charge is more effective? And that is what I also show here after a couple of slides over here.

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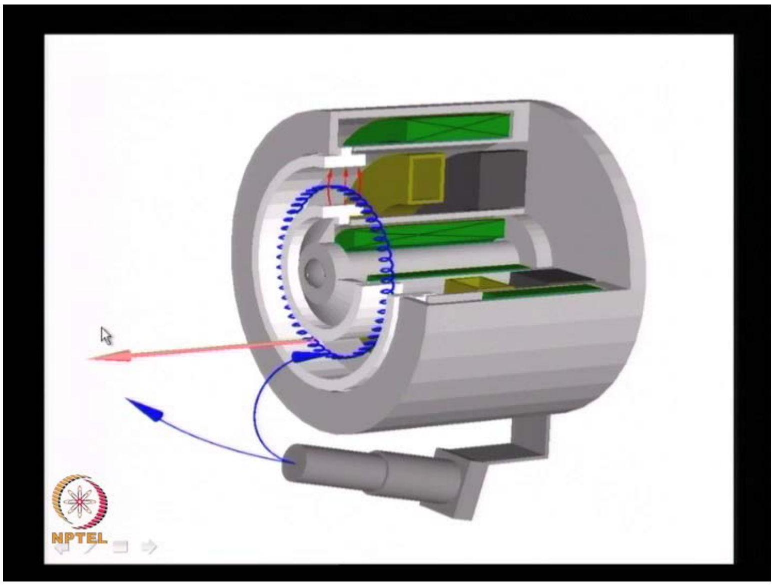

Let let us take a look at it. Well this is a picture of a of a Hall effect thruster this is where the electrons are generated using a cathode. It enters the annular gap over here. There is a strong magnetic field in this particular gap over here and therefore, the electron spiral you have an anode here which pushes the thing out and you get the thrust over here.

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This is the face view in the annular gap through this the xenon comes out and you get the thrust. This is the sort of the cathode which generates the electrons.

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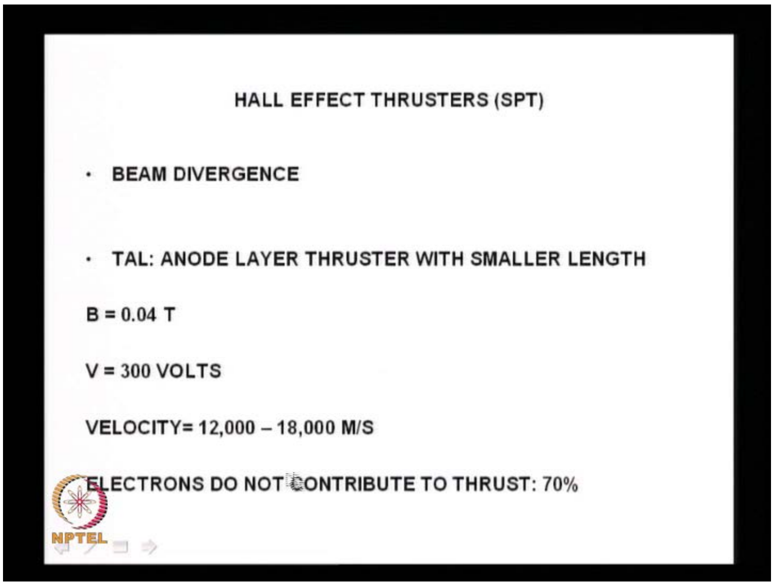

To prevent the divergence which leads to contamination; a small length is to be preferred and this small length thruster is known as the anode layer thruster or rather TAL. Well we have considered this I said 0.1; the field is around point 0 4 Tesla voltage around 300 volts. We get around 15,000 meters per second and we said since the electrons are just spiraling they do not contribute to thrust. The efficiency is low around seventy percent.

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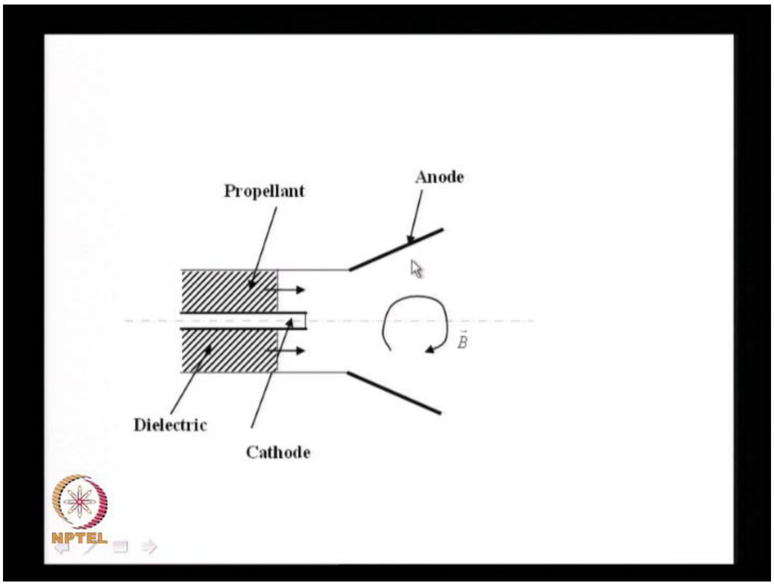

Well, we considered the electromagnetic thrusters and this is an electromagnetic thruster well you have a tangential field into which charge is charge comes over here. I have a voltage difference between this and this. Therefore the charge is goes in travels in the radial direction and I get a thrust coming out in this particular direction.

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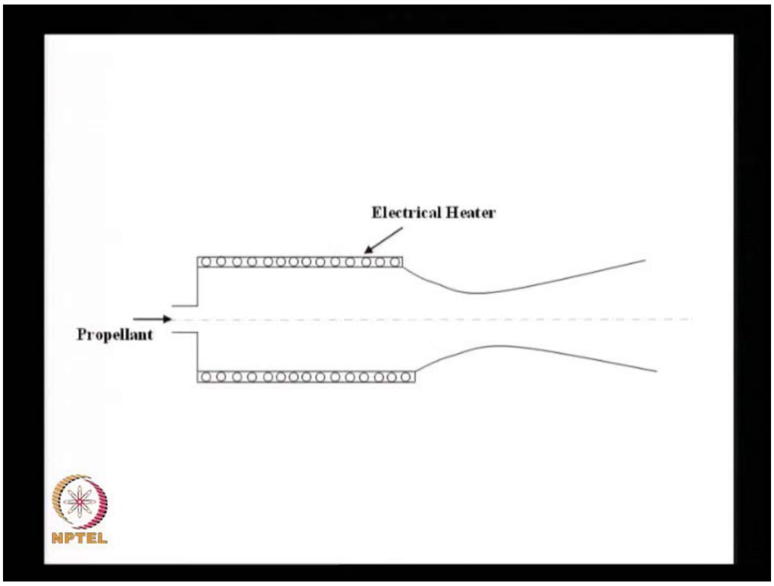

Well this is all about thrusters. But, something you know which we missed out and I missed it out very intentionally we talked in terms of electrical rockets.

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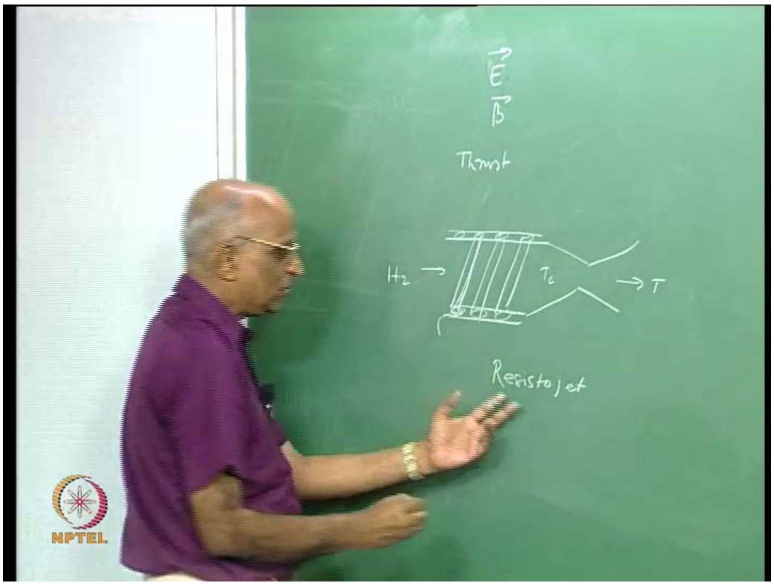

And electrical rockets we essentially went into the principle of electrostatics, E bar; electromagnetics B bar how to generate thrust? But, something which was very apparent which we did not do was supposing I have a gas flow and I use may be a series of resistances here; I put a resistance coil on the wall and I pass current through this; Well I can always heat this chamber and I could have a regular nozzle.

That means I heat the gas using resistance wire and these are known as Resisto jets. But, not very practical though. You know see all what I do is I heat the gas either by putting the resistance wire in the gas or I heat the wall using some resistance wire. That is just the same way as we have a geyser at home where in we heat the water. I heat the gas and the hot gas at t c and if I were to admit hydrogen which has a low molecular mass. Well, I can get a thrust. This is known as a resisto jet and why a resisto jet?

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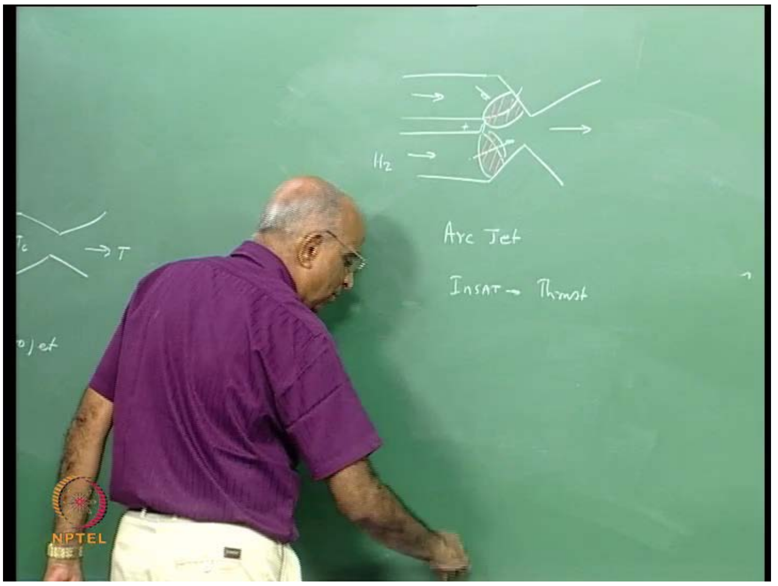

I can also use the a similar principle after all I can create an arc and what is an arc in the same chamber may be I put something like I pass a gas into it a low low molecular mass gas let us say hydrogen and I now generate an arc over here.

I strike an arc. I have a high voltage here may be a neutral here, I strike an arc over here and when the gas flows through the arc; it becomes highly ionized. The arc itself dissociates also and I have very high temperature and I could expand this out as a as a high temperature gas and this is known as an arc jet. In other words, instead of using resistance for for heating, I use electrical arc for heating and the zone of the arc I show like this, highly non equilibrium. I have dissociation taking place, I have lot of excited species being formed and these excited species will create, will reduce the efficiency, but, I can get high temperature and therefore, I can get a good thrust also. Therefore,, these are arc jet thrusters, but, you know they have some problems because of dissociation and the arc which tends to create electrical disturbances, it is been a problem to use them in space, but, it can be used.

In fact, when we made the first prototype or a discussion on Indian national satellite INSAT satellite; we thought we will use ammonia as a gas with an arc and use it to generate thrust. Therefore, to conclude the present or the discussions on electrical rockets;

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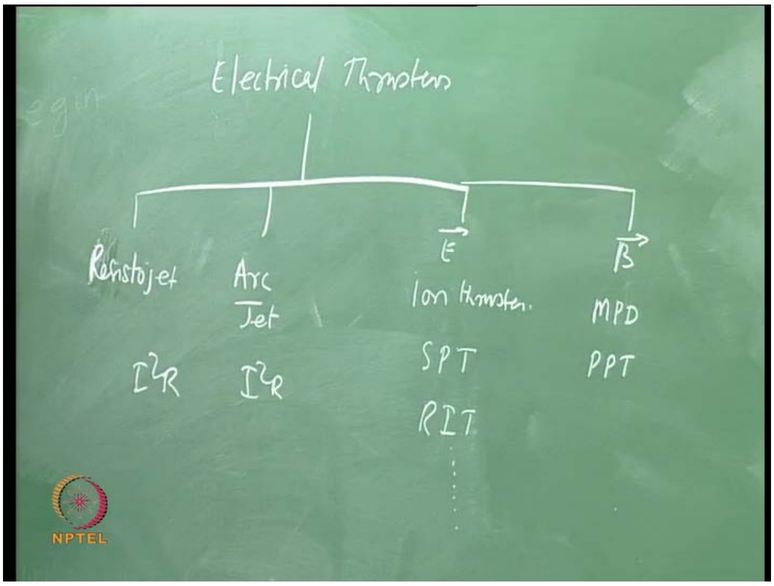

We can say well electrical rockets are essentially we could call them as electrical thrusters since they generally can be used only for low thrust. It could be something like an resisto jet using electrical resistance. It could be an arc jet. Then it could also be use the electrostatic principle in which case it could be an ion thruster. It could also be a derivative of let us say, I correct the ion thruster I guess stationary plasma thruster or Hall effect thruster. I could have a radio radio frequency ion thruster and may be collider thruster and so on. I could also use the magnetic principle namely the Tesla what I have magnetic field to create may be the MPD, magneto plasma dynamic thruster or I could also have pulsed plasma thruster and the you could keep on deriving this. Well, this is all about the electrical thruster we have looked at the principle of this. In this case it is I square r which is the heat source, in this arc jet again it is I square R.

Though the resisto jet is easy to visualize; Arc jet is little more complicated. How does How do you get the arc going? May be the thruster operates in vacuum. In vacuum, I have a gap d between the electrode and the neutral over here and therefore, what is going to happen to me? When it is vacuum I cannot strike an arc. When I keep on, when I start supplying the gas the vacuum level comes down and if the vacuum level drops to a level where in I get the product of pressure into the distance is a critical value; I get something like a discharge coming I can heat the gas and I can get the thruster.

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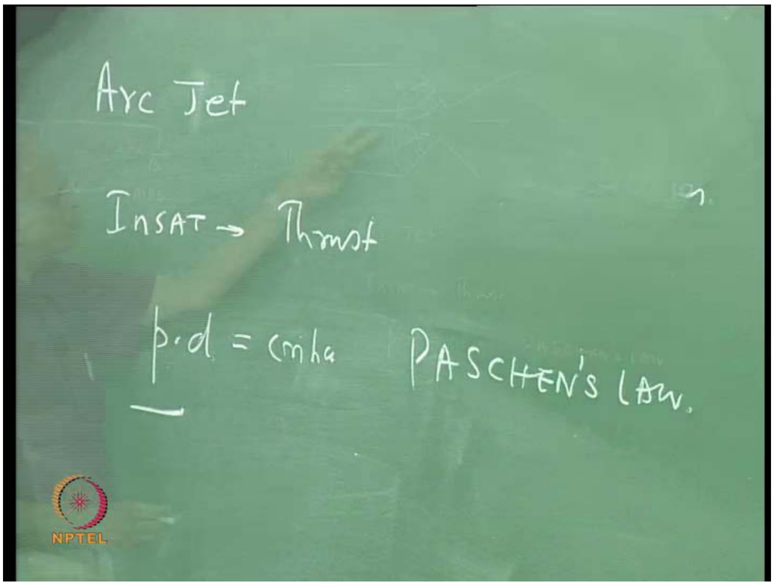

The product of pressure and distance defines when an electrical arc can be found out and this is what is known as PASCHEN'S law. Now, there are some people make use of this for starting a thruster, others make use of maybe I put it, I mount this in a gear train and I can advance this up and down. I strike an arc at a low distance and then I bring it to equilibrium and still maintain an arc. And therefore, this is how an arc jet works. Therefore, for us we say well electrical thrusters are classified into the following and we have gone into the mechanisms by which these thrusters function.

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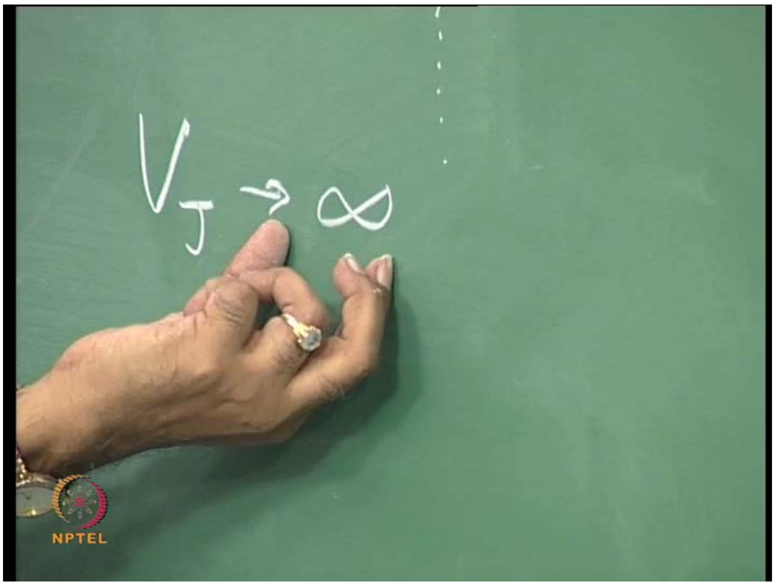

In the next class; what I do is we will wrap through whatever we have learnt in this course, but, we will also see, you know we tell ourselves is it possible to get V J to be infinite? In fact, one of the goals which Robert Goddard set was he said why not have V J the speed of light such that I get an extremely large value of V J? But, is it really possible or is there some limitation on V J which effects the performance? And this is what we will see in the next class, in the next hour. Thank you.