Plasma Physics

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Module No. # 01
Lecture No. # 19
Rayleigh Taylor Instability

Today I would like to talk about another instability which is very extensively studied in plasmas as well as in fluids is called Rayleigh Taylor instability.

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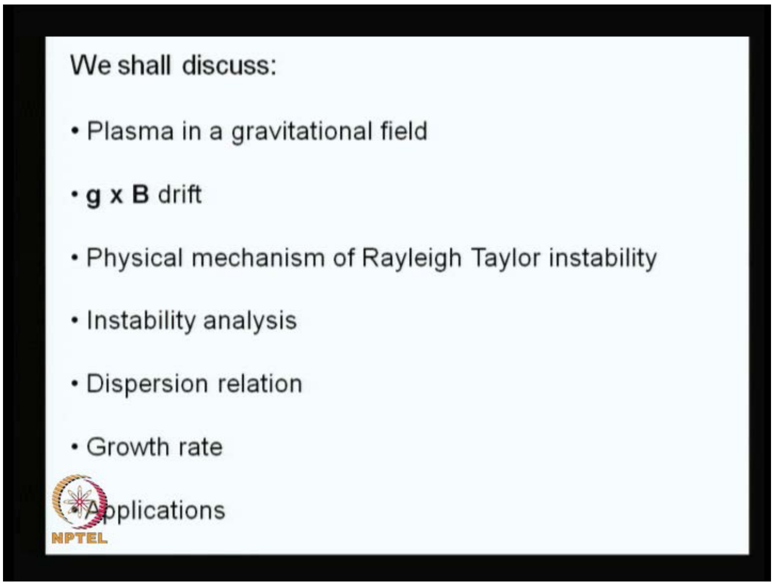

We shall discuss plasma in a gravitational magnetic field, how can you sustain a plasma in a gravitational magnetic field. The plasma electrons and ions will experience a drift called G cross B drift. Then we will discuss, the physical mechanism of Rayleigh Taylor instability, we will carry out a instability analysis using fluid theory obtain a dispersant relation and the growth rate.

Then we will discuss an applications, this instability has been found to be important in ionosphere f region of the ionosphere. And also in a different form, it has been found to be relevant important in mirror machine in tokomak.

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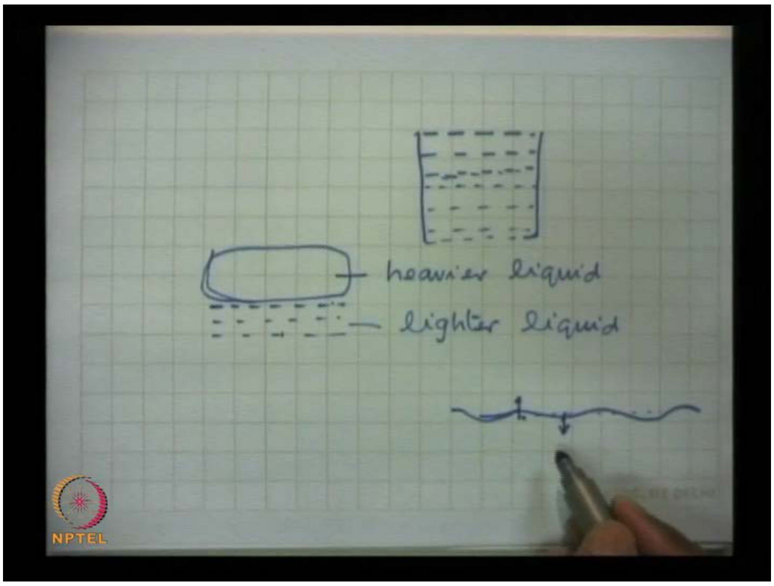

Well, let us consider, a liquid this is a lighter liquid and on top of this there is a heavier liquid. For instance, if I put a stone on water and if in a column there is no point, no region for the water to get up. And the stone exactly fits the channel then the stone will compress the water.

Stone density is larger than the water density and if the stone is very hard, it does not allow the penetration of the water through it, then you can have a stone swimming over water. Because, if I have a container, exactly tide container, in which water is filled there, but, a stone is just exactly fitting in here, then there is a possibility that stone can be there.

However, if there are no walls here, then water can go up from the sides and stone will drown in water. Now, consider a situation, suppose I have a lighter fluid somewhere and a heavier fluid. So, this is lighter fluid and this is a heavier fluid filling in this region.

In principle, you can have equilibrium when the upward force by the liquid balances, the gravitational pulled downward on the heavier liquid here this is a heavier liquid and the lighter liquid.

What will happen certainly there is equilibrium? Possible the issue, is if suppose there is a small perturbation, what will happen? So, on the interface between a heavier and lighter fluid if this is the interface and suppose there is a perturbation like this.

Then if the heavier fluid comes down somewhere, if there is a ripple in the surface. Then there is no equality of pressure in this region is less pressure, in this region higher and as a consequence.

The gravitational force on this portion will not be balanced by the pressure alone and this liquid will start coming down and it will going up here.

So, the ripple in the surface dividing the two liquids will grow. And the liquid in those smaller, deeper portions or turfs will keep on going down and here it will going up. So, liquid will move up lighter, liquid will move up and heavier, liquid will move down and this situation is called unstable situation. Laterally examine this issue, this problem.

And you cannot have a stable equilibrium with lighter liquid being below and heavier. Liquid being on top and this phenomenon gives this gives rise to the phenomenon of convention, this is a conventional thing in liquids.

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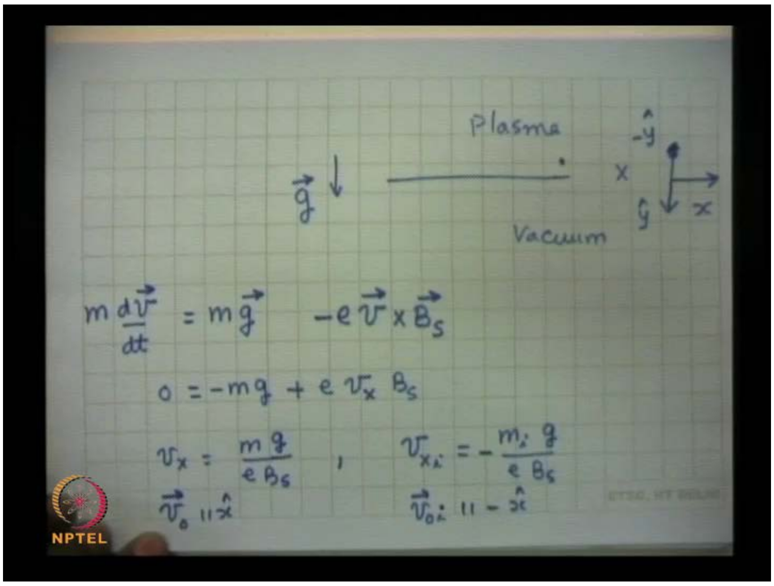

Now, we want to examine, what will happen in a plasma? Is it possible to contain a plasma? Suppose there is a plasma here and there is a weapon here, but, this is placed in a gravity like ionosphere is a region of space plasma, which is have of the surface of the earth. So, earth can pull it. So, if I well there is no vacuum here, the air, but, suppose I have a plasma which is support against gravity, gravity is in downward direction with acceleration due to gravity g.

Well, if there is no magnetic field, then certainly plasma will fall down. So, suppose I create a magnetic field which is perpendicular to the plane of this paper. Then what will happen? Any plasma electron or ion when it sees a gravitational force downward m g and it also sees it is starts moving down.

Then it also sees a magnetic force, which is the product of charge velocity and magnetic field. If minus e is the electron charge, v is the electron velocity, B s is the static magnetic field, then net force on the electron would be this plus this and this will be rate of change of momentum.

One of the possible equilibrium is that velocity becomes constant after a while and electron will acquire a velocity given by this equation, this equal to zero. So, if I put this right hand side is equal to 0, it you get a velocity that is called g cross B drift.

And for instance, if I take g in the downward direction, let me specify my coordinate system this horizontal direction. I will take to be x vertical direction, I will take to be y and well I think in some literature people take y downward direction as the direction of gravity is y. So, this is minus y upward and plus y downwards.

So, if I choose these situations. So, g if I take in the minus y direction, then this is equal to minus m g. If I write down the y component, this term, this will be e v, this is in the z direction. So, this will be y component I want. So, I will this get v x and z, but, plus sign here equal to 0. This is when I equate the y component to this equation to 0, I get v x is equal to m upon e B s and g.

Similarly, if you calculate for ions v x, for the ions would be mass of the ion g upon e B s, but, sign will be opposite, because charge of the ion is opposite to the charge of the electron, this is called g cross B drift. Because, it is perpendicular to gravity which is in y direction and the magnetic field which is in the z direction, g cross B x cross z, oh sorry, y cross z. Did I make a sign error of sign, let me just check.

G is in the y direction. So, y component of this will be z x minus. So, this is plus this is correct, I think this is not wrong here this is fine. I will call this velocity of electrons as v 0. This v x is equal to v 0 and this velocity, I will call as v 0 I the ion velocity. I would like to examine, if I perturbed this equilibrium, what is going to happen? Please note electrons are going in one direction, positive axis direction, which is parallel to x axis and this is parallel to minus x direction.

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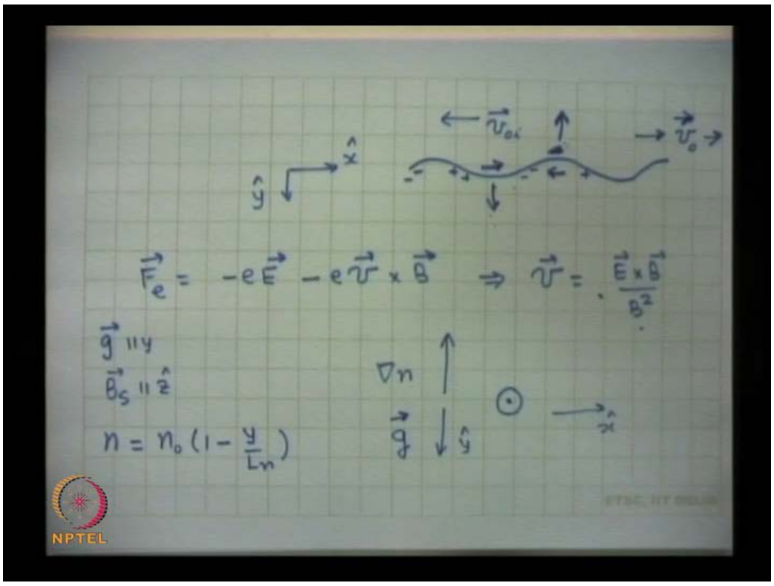

Let me consider a perturbation in the surface, suppose this is the boundary between the lower boundary of the plasma this is vacuum here and plasma there.

Please note, electrons are travelling in this direction, this is direction x-axis. So, this v 0 of the electrons and ions are travelling in the opposite direction v 0 i. sorry arrow is here. So, ions are traveling in this direction and magnetic field is in the z direction, z direction is where let me just understand this.

X direction is here, y direction I am taking downwards. So, x cross y is evolve the paper in the vertically upward direction like this perpendicular to the plane of the board. And this will be upwards x cross y. No, into the plane of the television x cross y, will be right handed screw going to this board.

Now, when the electrons and ions move in opposite directions the look and this region. Here the ions will come somewhere here and electrons will be appearing there. So, when they will produce an electric field in this direction.

Now, this is the electric field in x direction magnetic field is in the z direction. So, x cross z, if you calculate the force, the electric force will be minus e E on the electron and magnetic force would be minus e v cross B. This is the net force on the electrons due to the electric field plus the values that is generated by the v cross B motion.

So, from here, calculate the value of v, this we I call as the electron velocity, that it will acquire because of the electric field. That velocity you will obtain from here and if I take balance the two, then this will give me v which is equal to e cross B. you can just verify this upon B square.

So, what is the consequence? The consequence is that, the force on this will be e cross B upon B square electric field is in the x direction, B is in the z direction. So, this turns out to be minus y, I am bit surprised.

The electric charge here is negative, this charge is positive here, sorry in this region, the electric field will be in this direction, sorry, this will be where the field will be in the minus x direction. So, the force will be probably I made a mistake in the drift, if the charges positive this is this kind of thing and this is this way.

Well it. So, happens that, the this velocity should be downward here and upward here. I might have made some error in calculating the g cross B drift direction. But, essentially is what happens is that the space charge motion the electron and ion motion in opposite directions, when you perturbed a boundary between plasma and free space.

Then you create a space charges on the boundary and that produces an net electric field. And that e cross B drift pulls the electrons and ions together, this is independent of a charge. And that pulls the plasma down in the trough direction and pulls the plasma up in this direction enhancing the perturbation, this is called the relatively instability.

So, a plasma supported against gravity by a d c magnetic field is unstable. Just like a heavier fluid supported by a lighter fluid is unstable here a plasma support a magnetic field is unstable. Now, in order to carry out the mathematical analysis of this process, we will consider a simpler module rather than considering a sharp boundary. We will consider a diffuse boundary a slow boundary.

So, I will consider a situation, that I have a density gradient in the vertically upward direction and gravity in the downward direction and static magnetic field perpendicular plane of the paper.

So, I am considering a geometry in which g is parallel to y. I am taking y as the downward direction and this is my x direction. And my static magnetic field is in the z direction and I will consider a specific variation of density with distance. And I will consider to be increasing function of height.

So, I will consider something like n 0 1 minus y upon L n, because, I am choosing y direction downwards. So, as you go up, you are going to higher and higher values of negative y. So, density will increase because y is negative and consequences increases. So, this is just choose this and if I do this then let me begin with my equilibrium first.

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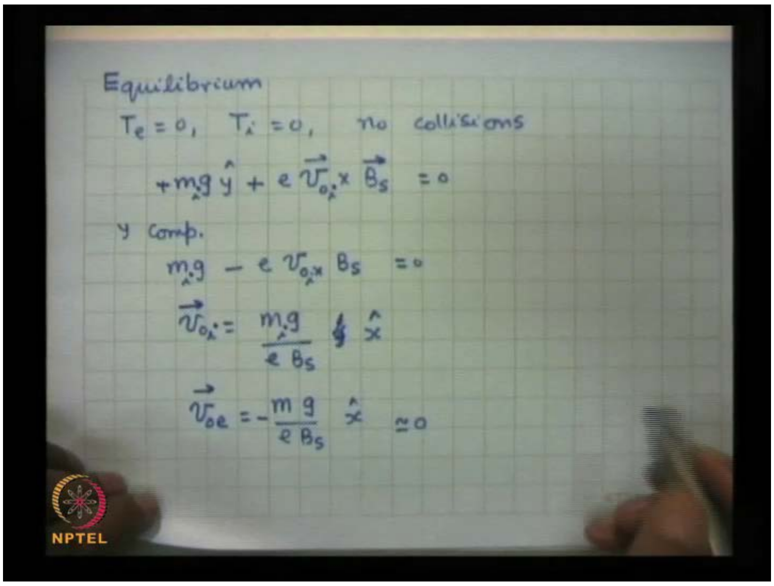

For the sake of simplicity, I will consider the plasma to be having no temperature. So, electron temperature is not there, ion temperature is not there, no collisions. I will not considering any collision effects to be. I am considering a plasma in which the gravitational force which is minus m or the plus m g in the y direction is balanced for ions like that let me write down for ions plus e v 0 cross B s.

Now, let me equate this to 0 in equilibrium. So, the value of v 0 that I get you can obtain by taking y component of this equation. M g this is x this is z. So, minus e v 0 x B s equal to 0, I think that is the mistake I had made earlier.

So, you get v 0 is equal to m g, this is ion motion, ion considering. So, put a ion mass here, ion mass upon e B s this is the equilibrium velocity of ions. And put a subscript i here because, I am correct motion ions. So, put a subscript i to characterize this ion motion.

So, ion drift velocity is in the y direction, no x direction. And similarly, if you calculate the electron drift velocity v 0 e it will be mass of the electron into g upon e B s, but, the sign of charge is opposite.

Please note that the electron drift velocity is very very small as compare to ion drift velocity. Because, electron mass is very small as compare to ion mass and hence, this I can ignore. So, ignore this. So, this is my equilibrium and I would like to perturb this equilibrium by a perturbation. I want the perturbation to have a k vector on the x direction because, this like a ripple in the x direction.

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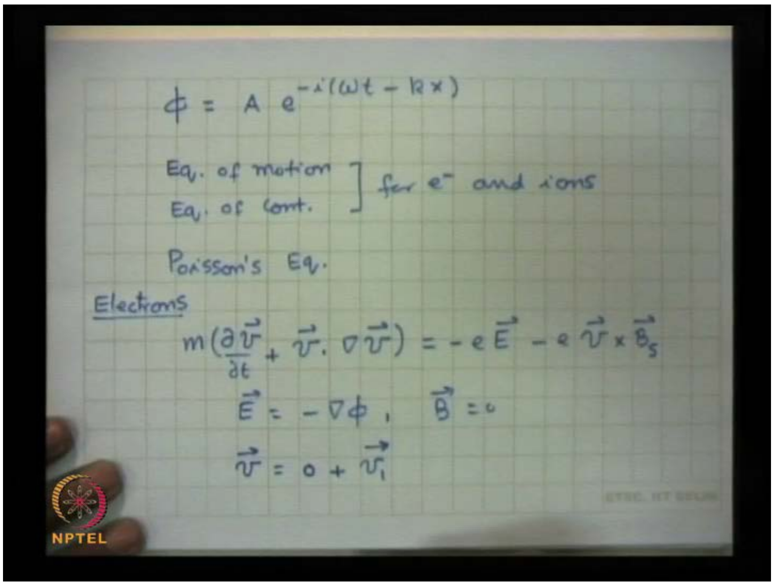

So, consider a perturbation of electro potential phi is equal to A exponential minus i omega t minus k x. I am perturbing my equilibrium by this electrostatic perturbation and like to find out whether this perturbation will grow. Means omega will be complex with a positive imaginary part or not.

To examine that I need to find out, I need to solve the equation of motion and equation of continuity for electrons and ions both, and then I need to solve the Poisson equation, this has to do.

So, let me write down, the equation of motion for electrons this is mass into delta v by delta t plus v dot Del v is equal to minus e E, the electric force minus e v cross B the magnetic force, this I have to consider.

In the system, there is only one magnetic field, there is a static magnetic field which is in the z direction, the perturbation is purely electrostatic. So, electric field is minus grad phi. And there are no magnetic perturbations. So, B field of this wave is 0 because curl of e is 0.

Another thing for electrons this velocity I can write down as a equilibrium velocity which is nearly 0 personally perturbation quantity p v 1. And when I substitute this here, I ignore the product of perturbed quantity. So, this term does not contribute at all and this term survives, this will survive, this will also survive this v 1 cross B s.

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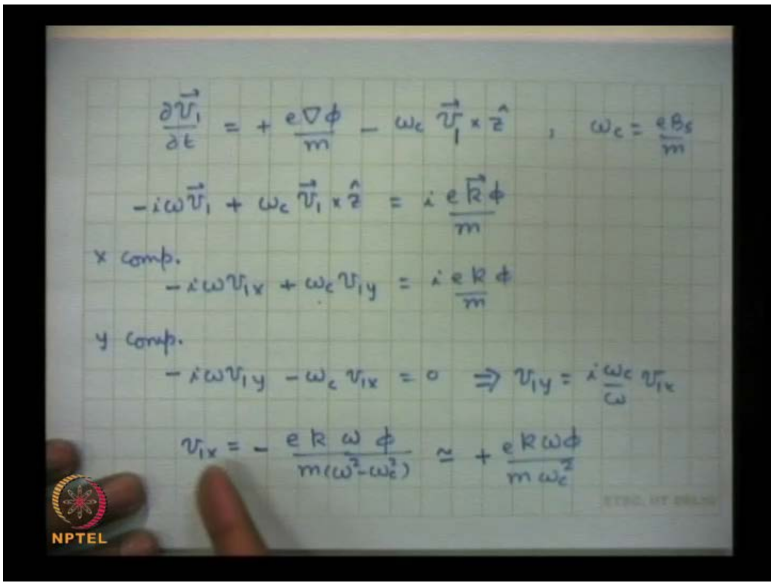

So, let me write this equation for the perturbed velocity as delta v 1 by delta t is equal to minus e grad phi sign reverses upon m minus omega c v cross z cap. Where I have defined omega c as e B s upon m. E is the magnitude of electron charge, m is the electron mass and B s is the magnitude of a static magnetic field. So, I have written that equation in this form, this is the perturbed velocity.

Replace delta delta t by minus omega because, phi varies in that fashion which that divert for this velocity. So, you get minus i omega v 1 bring this term also in the left hand side. So, it becomes plus omega c v 1 cross z cap is equal to right hand side will be i e k phi upon m. Write down it is components x components and z component or y component.

X component would be minus i omega v 1 x, this will give you plus omega c v 1 y is equal to i e k phi upon m, because k is in the x direction. For the y component, you will get y, this equation will be minus i omega v 1 y minus omega c v 1 x is equal to 0. Because, there is no y component of the right hand side.

This equation gives you v 1 y is equal to i omega c upon omega v 1 x take this one to the right hand side divide by minus i omega. And you will get this result and if I use this in this equation I will get v 1 x also.

So, v 1 x is equal to minus, if you just be careful, you will obtain this e k upon m omega square minus omega c square into omega up here, because one omega was there. So, you just obtain this, you can just verify this minus e k phi upon m this expression you will get.

For this wave, if omega is much less than omega c which indeed it is, then this is approximately equal to ignore this. You will get minus e k omega phi upon m omega c square and sign becomes positive. So, electron density perturbation, velocity perturbation is simply this expression and let me calculate the density perturbation also.

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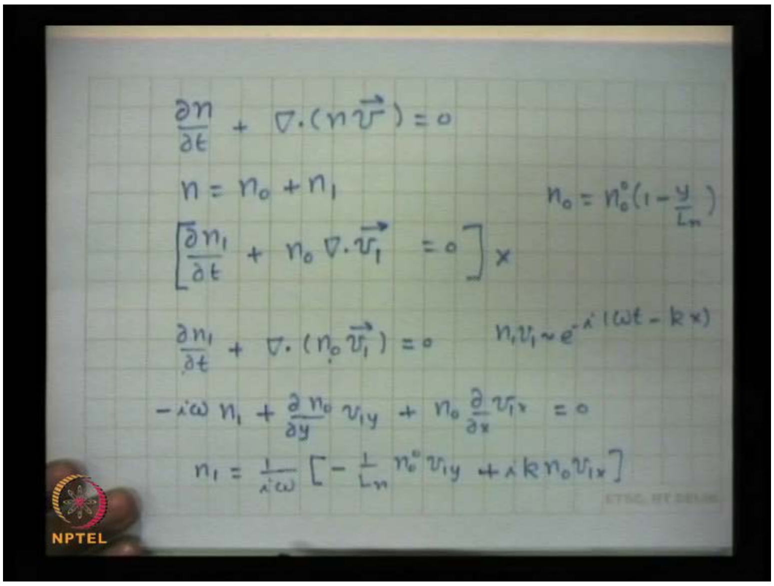

The density perturbation turns out to be, how can be obtained from the equation of continuity delta n by delta t plus divergence of n v is equal to 0. N express as n 0 plus n 1, use this here and linearism, you will get delta n 1 by delta t plus n 0 del dot v 1 equal to 0, replace del by i k. Sorry, I made a mistake here, n 0 is not a constant quantity this is wrong. So, let me delete this, this not write.

Remembering that n 0 depends on y, it is increasing in the vertically upward direction n 0. Please, remember is equal to n 0 0 1 minus y upon L n. Sorry, I made a mistake i n 0 should be in the interior, I will get delta n 1 by delta t plus divergence of n 0 v 1 equal to 0.

This equation please remembers n 0 depends on y and v 1 depends only on x. So, this will have 2 terms and this is I can replace by minus i omega because perturbed density will vary perturbed quantities are all vary as exponential minus i omega t minus k x. But, n 0 is not a perturbed quantity it does not vary in the same fashion.

So, n 1, v 1 they go as this, but, not n 0 that was the error I wanted to I was going to make. So, for perturbed quantities delta delta t can be replaced by minus I omega n 1. And that will give me

2 terms here plus delta delta y of n 0 into v 1 y plus n 0 into delta delta x of v 1 x and this is equal to 0.

Delta n 0 by delta y if I evaluate is like 1 upon l n into n 0 0. So, I will just write this as 1 upon l n into n 0 0 and that gives me how much.

N 1 is equal to 1 upon i omega and here you are going to get minus 1 upon L n into n 0 0 v 1 y this term. And this will give me i k into n 0 v 1 x, when I have taken these terms on right hand side this is the kind of equation I get.

So, density perturbation for electrons I have obtained, now I will put the values of v 1 y and v 1 x and we obtain if I put the value of v 1 y.

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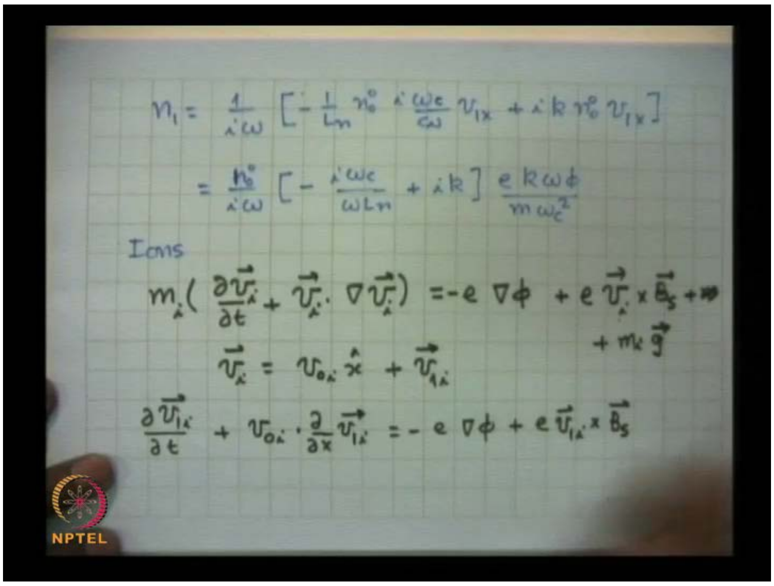

Let me just write this n 1 is equal to 1 upon i omega within this will be minus 1 upon l n n 0 0 and this is i omega by c omega c by omega rather into v 1 x plus i k n 0 n 0. I can write actually as n 0 0 of the order of into v 1 x. And I can take, if I please note here k is bigger than 1 upon l n. But, omega c by omega is additional factor that comes over which is really very huge.

Omega c by omega is may be six out of ten orders of or eight orders of magnitude for some reasonable parameters of ionosphere for instance, there is a huge number. So, usually this term dominates over this term, but, let us retains both the streams and put the value. So, what you get is 1 upon i omega n 0 , I will take common. So, put n 0 0 out and you will get minus i omega c upon omega l n plus i k multiplied by v 1 x whose value turns out to be e k omega phi upon m omega c square.

This is the dominant term actually in this expression, this is my perturbed electron density, then I must calculate the perturbed ion density. So, for the ion response I have to retain the effect of B 0 because the d c drift is there. So, for ions my equation of motion will be difference.

This is m delta v by delta t plus v dot Del v is equal to this ion motion. So, put I subscript everywhere i here i here is equal to e minus e grad phi this is the ion charge plus e and minus grad phi is the value of the electric field minus plus e v cross B the magnetic force. So, when you solve this equation put ion velocity is equal to v 0 ion the equilibrium velocity which was in the x direction plus a perturbed quantity v 1 i and use this in this equation and linearism this equation.

Well I forget to write one more term here, that is the plus m g term, sorry, let me write down this here mass of the ion and gravity. This term should be written there when we substitute this here, the v 0 cross B s term exactly cancels with this term. So, gravity does not really play any role in the perturbed velocity equation. Because, v 0 cross B exactly cancels with this by definition.

And this equation of linearization gives delta v 1 i upon delta t plus v 0 i dot delta delta x of v 1 i is equal to minus e gradient of phi. And this term will give you e plus e v 1 of ion cross B s. This equation we have to solve it is simple replace delta delta t by minus i omega delta delta x by i k this by i k and then this equation take the following form.

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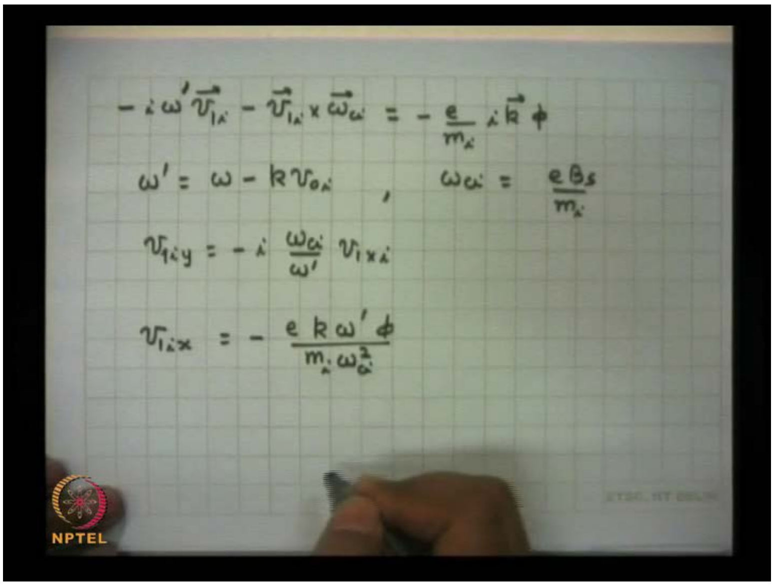

Minus i omega, I have made a mistake, I must put a ion mass in the denominator. Because, this mass I am dividing, this equation becomes minus i omega v 1 i minus v 1 i cross omega c i ion cyclotron frequency. I think, I made a mistake over mass here as well there is mass there also.

So, what you get here is right hand side of the equation of motion becomes minus e upon m i k phi, this is prime here actually and omega prime is equal to omega minus k v 0 i. So, this the only modification, this is the same equation as electron equation of motion with charge of the electron replaced by ion charge.

So, minus sign is there, electron mass is to be ion mass omega c i is the ion cyclotron frequency. Which is defined as e v s upon m i and omega prime is some sort of Doppler shifted frequency of the wave of perturbation, as seen by the drifting ions.

And you can simplify this to obtain v 1 i y which turns out to be equal to minus i omega c i upon omega dash v 1 x of the ion and v 1 i x rather the same thing is equal to x component of v 1 i turns out to be equal to minus e k omega dash phi upon m i omega c i square, this is what you get.

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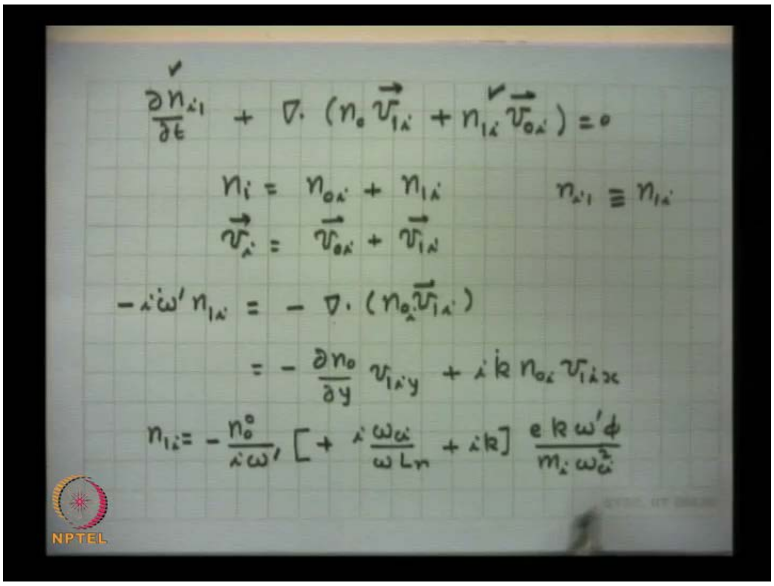

So, the ion velocity perturbation has primarily omega replaced by omega prime which is the Doppler shifted frequency of the perturbation as seen by the ions. Then I go to solve the equation of continuity. The equation of continuity also gets modified for the ions.

The equation of continuity is n i by delta t plus divergence of n 0 v 1 of the ions plus there should be a term here plus n 1 perturbation of ion density into v 0. This is n 1 i please, what I have done here is actually n i have written as n 0 i plus n 1 i or n i 1 whatever you call.

So, when I substitute this in the equation of continuity, delta n 0 by delta t is 0. So, this is only term that survives. And because, I have already written velocity as of the ions is equal to v 0 of ions plus v 1 of ions. So, you get two terms here.

This is the additional term that was missing in the electron equation of motion. And the consequence of this is that Del this is a perturbed quantity. So, when you operate this with Del operator it will be replaced by i k. So, this n 1 and this n 1 they will combine together actually n i 1 is the same thing as n 1 i by mistake. I have written this like this.

So, this term and these two terms combine together to give you minus i omega prime into n 1 i. This is the means replace this by minus i omega this del operator operating over this term by i k. And you will get the simply omega prime and this is equal to minus, this term taken on the right hand side divergence of n 0 v 1 I. Which again you will have 2 terms minus del operating over n 0 first, then this quantity.

So, which is equal to delta n 0 by delta y n 0 of ions the same thing as electrons also into v 1 i y. Because, if I take y component of this, then y as to be there and then you will get a term plus i k this is the x directions. So, n 0 of ions multiplied by v 1 i x.

So, I will substitute the values of v 1 i and v 1 x etcetera. And the result that I will write is this is very similar to the electron result is omega replaced by omega prime. And it turns out to be n 1 I, let me write down.

N 1 i is equal to n 0, 0 upon i omega within the bracket is. So, omega is omega prime and this is plus i omega c i upon omega l n plus i k then e k omega dash phi upon m i omega c i square and sign is opposite.

This expression I have written from the electron expression replacing omega by omega prime and electron parameters by ion parameters charge and mass in similar expression. After I have obtained the perturbations or in density of electrons and ions, it is simple to obtain the dispersion relation by using the Poisson equation. Which turns out to be divergence of d is equal to rho, this is the Poisson equation.

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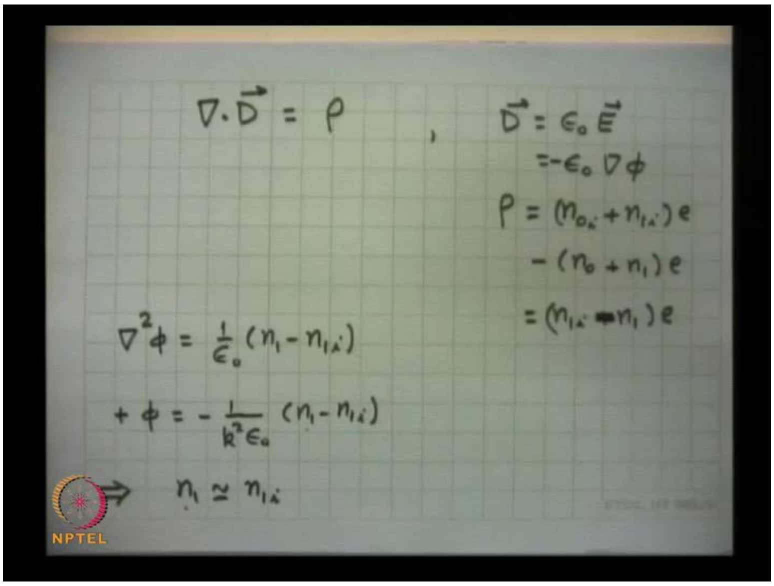

When I substitute d is equal to epsilon 0 e and e as grad phi with a negative sign and rho which is the charge density of electrons and ions together. So, this is equal to n 0 i plus n 1 i this is into e is the ion charge density minus n 0 of the electrons plus n 1 of the electrons into e since n 0 and n 0 i are the equal this is equal to n 1 i plus n 1 into e sign is opposite minus of this.

So, use this in here, this equation takes the following form, del square phi is equal to 1 upon epsilon 0 n 1 minus n 1 i again replace this del square by k square minus k square and you will get minus phi or plus phi is equal to minus 1 upon k square epsilon 0 n 1 minus n1 i.

Just substitute the values of n 1 and n 1 i. You will recognize that they also contain phi and every term that you get in n 1 n 1 i is much bigger than phi. This is coefficient of phi is 1 there will be phi on the other side. Also, but, the coefficient of those terms is much bigger than one.

Hence I can ignore the term on the left hand side. So, this equation gives me that n 1 is nearly equal to n 1 i. Because, the individual terms on the right hand side are too big as compared to unity or phi on the left hand side. So, I can ignore the left hand side term and in order to satisfy this equation n 1 is nearly n 1 i and these perturbations, I have already obtained. So, let me write down the expressions n 1 and n 1 i and what you get is this.

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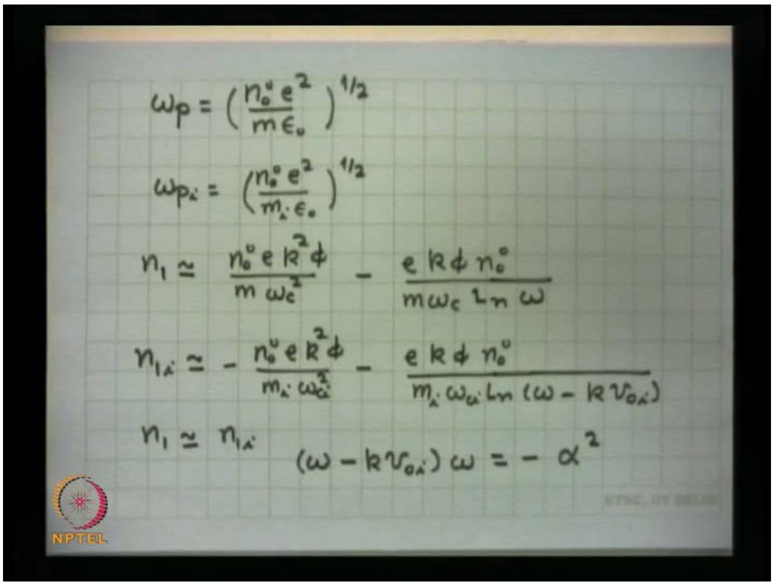

I just write down the expression. I think it will be useful. Please note, I am to divide those expressions by epsilon 0. And I will introduce a quantity called plasma frequency as n 0 0 e square upon m epsilon 0 to the half, Where m is the electron mass similar quantity for ions. I can define as n 0 0 e square upon m i epsilon 0 to the power half. Then what you get when I put n 1 is of the order of n 1 i, you can write down these expressions as follows.

n 1 is approximate is nearly equal to n 0 0 e k square phi upon m omega c square minus e k phi n 0 0 upon m omega c l n l density scale length. And n 1 i is equal to minus n 0 0 e k square phi upon m i omega c i square minus e k phi n 0 0. I think there is 1 omega also here in this equation omega is there and. So, omega prime here m i omega c i l n into omega minus k v 0 of ions what you get.

The expressions are very similar and you have to equate them. Once we equate them, you get a simple dispersion relation because, phi will cancel out from every term. So, n 1 approximately equal to n 1 i lead to every simple dispersion relation. Which says that omega minus k v 0 of ions multiplied by omega is equal to a quantity minus Alpha Square. This is the simple dispersion relation by equating these 2 you get.

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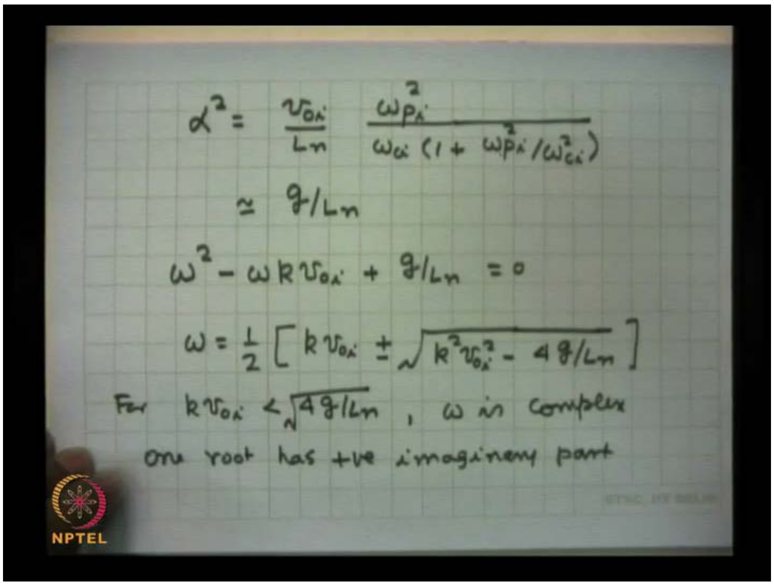

And alpha square turns out to be equal to v 0 ion upon density scale length into omega p i square that I have defined earlier upon omega c i into 1 plus omega p i square upon omega c square c i square.

And there is under root, I do not think this in under root and this turns out to be, if I put the value of v 0 i as g upon omega c i and if I in most plasmas omega p i is much bigger than omega c i. So, 1 can be ignored and this turns out to be simply g upon l n g is the acceleration due to gravity and l n is the density scale length.

So, please note your expression the wave with the dispersion relation becomes omega square minus omega k v 0 i plus g upon l n equal to 0 a very simple dispersion relation you recover. And I found, if I can find the roots, this will give you omega is equal to half k v 0 i plus minus under root k square v 0 i square minus four g upon l n.

Well, this quantity could be bigger than one positive or negative. When this is positive omega is purely real and there is no instability. So, for large values of k this quantity is positive. And there is no instability means, if you are repel on the, of the perturbation in the plasma has a small k, large k, then there is no instability.

However, for k v 0 i less than 4 g upon l n under root, whenever this quantity is less than this omega is complex. And one of the roots, will have a positive imaginary part, one root has positive imaginary part and that gives the instability.

So, especially when k tends to 0 means when this quantity is negligible as compared to this the growth rate is simple. Because, you can ignore this term, you can ignore this term and the growth rate turns out to be.

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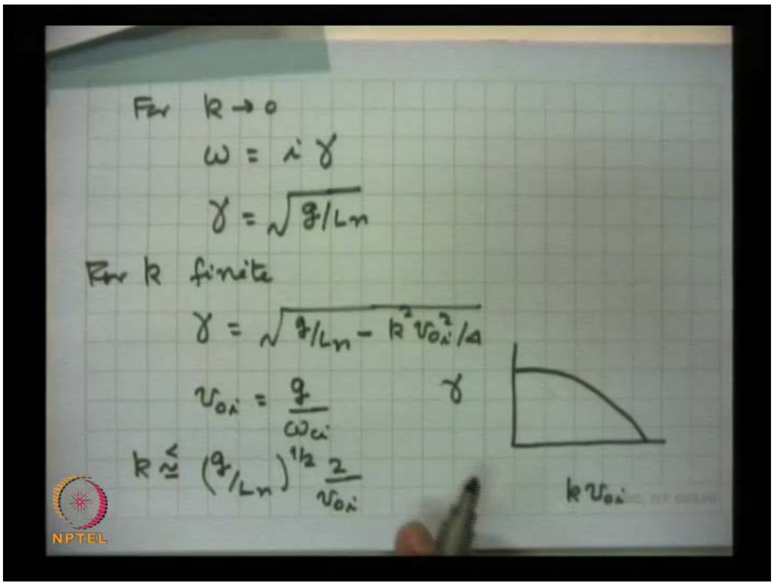

So, for k tending to 0 omegas is simply equal to i times gamma and growth rate is equal to under root of g by l n or time period of growth is root l by g just like a simple pendulum.

This is the interesting part of it, that situation is very complex. It is a plasma with electrons and ions moving. And magnetic field stopping the plasma to fall down against gravity is still the expressions very simple, very similar to what we get in a simple pendulum.

And if k is not 0 for finite k, what you get the growth rate is as I mentioned there. The growth rate is equal to under root of 4 rather g upon l n minus k square v 0 i square by 4. And please remember v 0 i is the ion drift velocity, which is equal to g upon omega c i.

So, this also depends on g, but, k is primary think here it will be useful to plot growth rate as a function of k v 0 i. Normally people plot this upon this growth rate resolve some number, you will get this kind of behavior.

Now, this instability is important in f region of the ionosphere. And it gives rise to fluctuations in density perturbations of the order of with wave length k of the order of from here g upon l n into 4 upon rather under root of this quantity into 2 upon v 0 i.

And that turns out to be typically of the order of kilometer. So, in the ionosphere people have observed density fluctuations with a scale length of the order of eight kilometer may be half kilometer to three kilometers or. So, in that range and they are attributed to this Rayleigh Taylor instability. People also give this name as spread of instability.

Well here I have ignored the effect of collisions, if you include the collisions of electrons and ions then this growth rate is slightly modified. But, primarily the physics remains the same, mathematical treatment remains the same. And this growth rate, this instability has been observed always observed in ionosphere.

At times, people have observed very great depression and densities during especially during the sunset. people have observed order of magnitude reduction electron density because of this density so. But, that is, that requires little more complicated physics is not simply, this I have discussed the linear stage of this instability. That this instability will grow and it will cause a perturbation.

And however, what happens that you may ask a question that if the ionosphere is unstable to this instability, the plasma should fall down. Obviously, plasma will fall down, but, then the air neutral air will go up and again this will get ionize.

So, this is a dynamic equilibrium in the presence of the sun, that is why there is not a really fall down. In that sense plasma is coming down, the gas is going up and some sort of a equilibrium electron density is maintained in the ionosphere. But, these fluctuations are certainly there and they are responsible for causing scattering of radio waves.

And lot of work on this has been done in last several decades, and it is continuous to be important. I may also mention that in the equatorial ionosphere, there is a current called electro jet current. There is a electric field just like g cross B drift can cause instability e cross B drift also causes an instability. Which is similar to Rayleigh Taylor instability and that is also been observed that gives rise to shorter wave length fluctuations.

And I think with these two instabilities, we can understand lot of phenomenon in the ionosphere, I would like to also to mention that Rayleigh Taylor instability of late has been found to be very relevant in laser driven proton acceleration.

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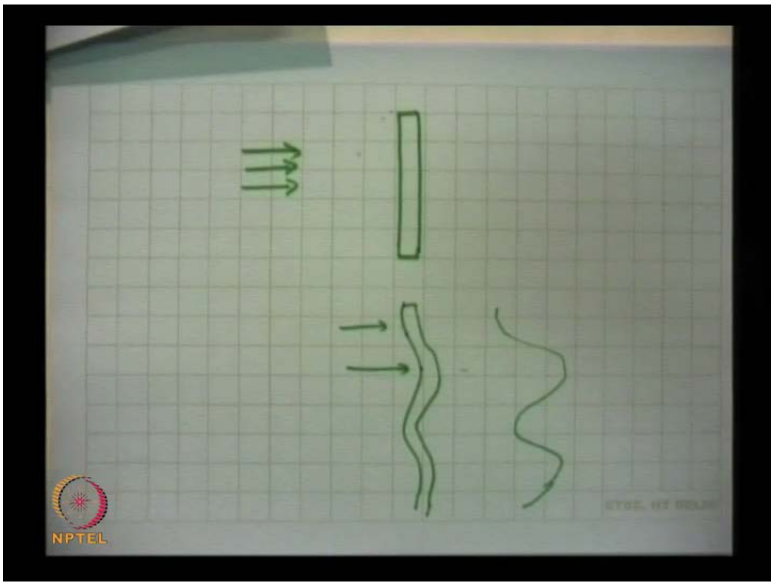

People employ lasers to accelerate ions. For that, they take a very thin foil, very thin foil of sub micron width of a metal and shine laser. On this, the lasers pushes the electrons via the ponderomotive force or radiation pressure force. And when the electrons are pushed, they pull the ions also along with them.

But, it has been found that, if there is a ripple in the surface of this foil, then if the foil takes this form. Then the radiation pressure which is falling in here is different than here. The reason is that, this is curved when the laser foil, this aluminum foil or material foil is curved. The radiation pressure force exert in different, different positions.

The positions like these, they have not acquire larger radiation pressure force and these ranges less and consequently, this foil acquire the shape. So, the perturbation grows and this is also known as Rayleigh Taylor instability. And I think, it is one of the major concerns in laser driven proton acceleration at the moment. And I think, if time permits during our course of lectures, we will have some discussions on laser driven proton acceleration and the relevance of Rayleigh Taylor instability in there. I think I close at this point.

Thank you very much.