# Plasma Physics

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## Lecture No. #01
## Introduction to Plasmas

Today, we begin a series of lectures on plasma physics. My first lecture will be on introduction to plasmas, it is a part of a course forty two lectures course that will be given by myself, and professor Vijayshri. My name is V. K. Tripathi, I teach physics at IIT Delhi.

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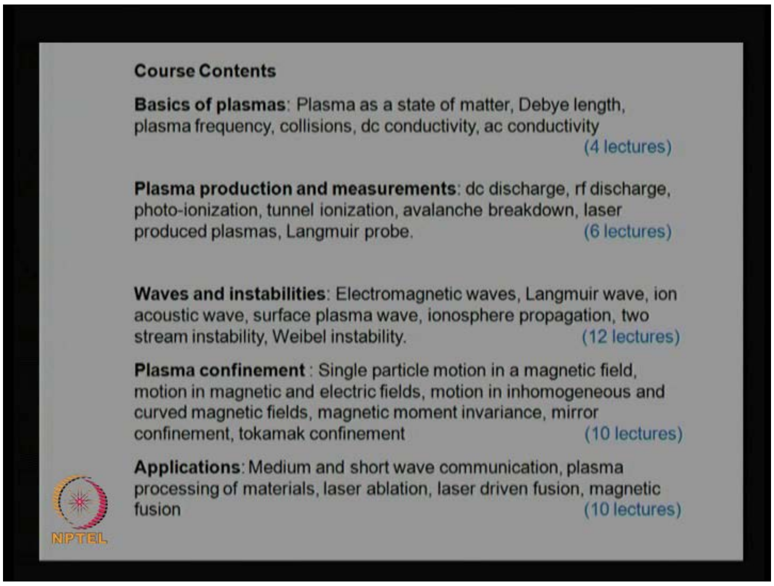


First, I would like to give you broad outline of the course. The course will contain following topics; four lectures will be given on basics of plasmas that will include plasma as a state of matter Debye length, plasma frequency, collisions, DC conductivity, and AC conductivity, and in magnetized as well as un-magnetized plasmas. Second topic would be plasma production and measurements, it will include DC discharge, rf discharge, photo- ionization, tunnel ionization, avalanche breakdown, laser produced plasmas, and Langmuir probe measurements.

Next, topic would be waves and instabilities; that will include electromagnetic waves, Langmuir wave, ion acoustic wave, surface plasma wave, ionosphere propagation, two stream instability, and Weibel instability. Next, would be plasma confinement; we will begin with single particle motion in a magnetic field, then motion in magnetic and electric fields, motion in inhomogeneous and curved magnetic fields, magnetic moment invariance, mirror confinement, tokomak confinement.

And then finally, we will include discuss applications to medium and short wave communication, plasma processing of materials laser ablation, laser driven fusion and magnetic fusion.

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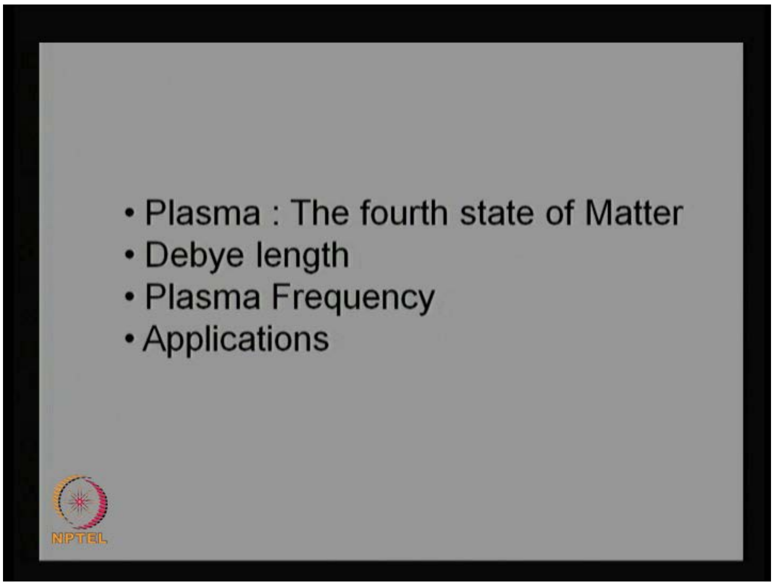


So, now I would begin my first lecture. Well the basic things that I would like to discuss today would be plasma as a state of matter, and in that category I will discuss Debye length and plasma frequency and finally, I will outline some of the applications.

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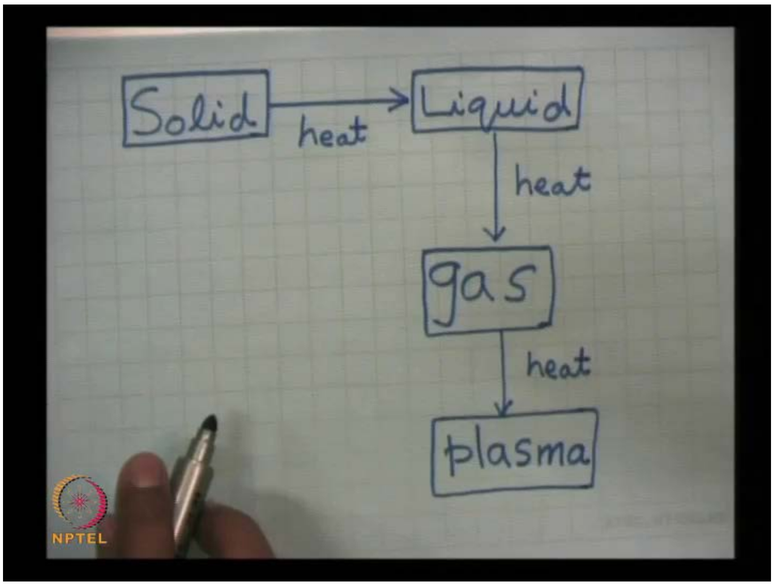


So, let me begin with plasma as the fourth state of matter. Well, we are aware of three states of matter, they are namely solid then you are aware of liquid; then you are aware of gas and then there is another state of matter which we call as plasma. Well solid is a state of matter, where the atoms are arranged in a in the specific positions and they cannot move freely inside the bulk of the material, though they can oscillate above their mean positions. Liquid is a state in which atoms or molecules can wander inside the bulk of the material because they have substantial kinetic energies that can overcome the potential energies due to mutual interactions and in a gas; however, in a liquid the molecules cannot leave the surface of the material because at the surface they experience a surface barrier or a large potential energy which they cannot overcome.

And then, there is a gaseous state where the molecules have enough kinetic energies they are free to move and as a consequence you require some vessel or container to contain a gas; well you can go from one phase of material to another phase like from solid to liquid if you heat the material. So, just by heating this up to a point a temperature called melting point, if you heat a solid then it will convert into a liquid. Similarly, if you heat a liquid to a temperature called boiling point, then the liquid will convert itself into a gas. The question arises, what will happen if you heat a gas? Well if you heat a gas to high temperature of the order of 10,000 degrees Kelvin or higher than the gas can get ionized gas atoms can get ionized producing ions and free electrons and they can that state of matter is called plasma.

So, just by heat treatment a solid can be converted into a liquid, liquid can be converted into a gas and gas can be converted into a plasma well the requirement is that if you want to ionize a gas the atoms must possess enough kinetic energies. So, a gas can be converted into plasma only when the electrons are released from the atom.

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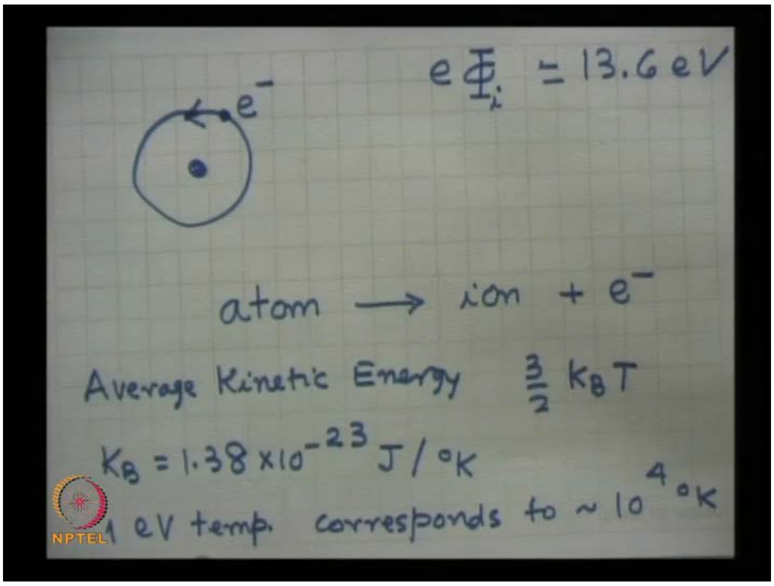


Now, a gas atom has a nucleus in the center and electrons may be in hydrogen there is one electron in helium there are two and in other gases in other atoms there are many electrons. So, electrons go around the nucleus at least one of the electrons of these orbits have to be rendered free should be removed from this atom then the atom is called ionized. For the case of hydrogen, if you want to render this electron which is rotating like this to be free you require an energy which we call as ionization potential 5 multiply by electron charge.

This should be about for hydrogen this is 13.6 electron volts. So, you require colliding atoms to have energies of the order of 13.6 electron volt then, they will be ionized they can ionize each other or one of them will be ionized in collision. So, when an atom gets ionized, then atom gets converted into an ion plus an electron the energy required for this is of the order of ionization potential or more. So, typically I would say that energies for most of the atoms to be ionized are about 10 electron volts or higher.

Now, when you require 10 electron volt of energy in terms of temperature? Let me mention a quantity called average kinetic energy of atoms in a gas the molecules have maxwellian distribution function as a consequence if the temperature of a gas is t then, average kinetic energy of the atom is average kinetic energy of an atom is 3 divided by 2 K B into T. Where, T is the temperature of the gas K, B is the Boltzmann constant and if you put this usually in plasmas we talk of K B T as temperature rather than t is the actual temperature is T, but we multiply this K B the Boltzmann constant whose value is K B is equal to 1.38 into 10 to the power minus 23.

This is joule per degree Kelvin. So, in plasmas K B T is normally called the temperature of plasma, but if you put T is equal to 10 to the power 4 degree Kelvin K B T is around 1 electron volt. So, we say that 1 electron volt temperature corresponds to about 10 to the power 4 degree Kelvin. So, in plasma there is a practice to call temperature in electron volt. So, typically 10,000 degrees Kelvin is equal to about 1electron volt. A 1, 00,000 degrees temperature will be like 10 electron volts.

So, to ionize a gas you require enough kinetic energy of particles if the temperatures of plasma is about 10,000 degrees Kelvin then average kinetic energy is 1 electron volt, but there are substantial number of atoms with kinetic energies of the order of 10 electron volt or more and then, they can; when they collide they can ionize each other. So, the issue is that at least you require a temperature of 10,000 degrees Kelvin to ionize a gas. Well, this is a difficult thing to do and confinement of plasma is another issue which is important. So, people found another via medium to produce plasmas and a simple scheme by which nature produces plasmas in our atmosphere and the process is called photo ionization.

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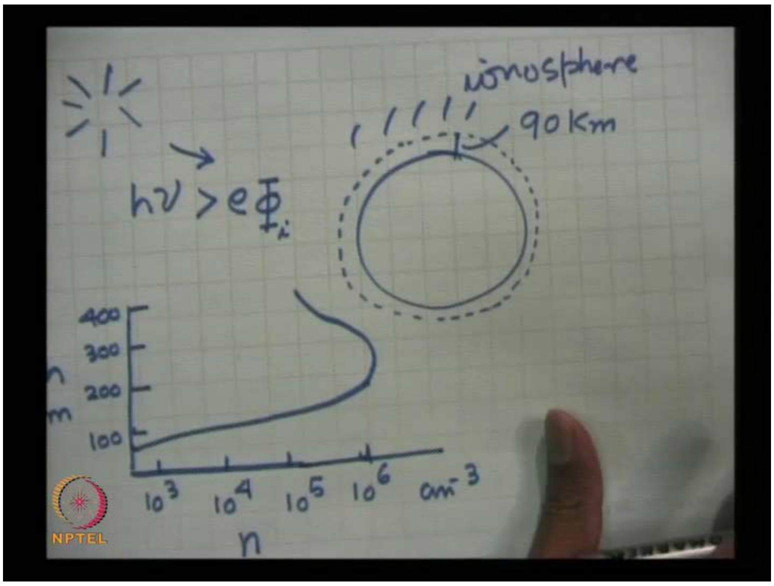


Like we have earth and on the outside on the surface of the earth, we have atmosphere, but there is a sun that is sending solar radiations to us and some solar radiations called ultraviolet light they have photon energy h nu. nu, is the frequency of light, h is the Plancks constant. So, this is the quantum of energy of each photon. Whenever this is more than the ionization potential of the atoms of the air they will ionize it. So, what happens that due to these photons coming from the sun there is a layer around the surface of the earth which is ionized.

Well, the air starts from a height above the surface of the earth this height is about 90 kilometers. So, outside this layer; here in this region this is ionized is called ionosphere. So, the region of the atmosphere at a height of 90 kilometers or higher is called ionosphere and if you plot the density as a function of height normally, the plot is like this people plot height in kilometer this height is measured from the surface of the earth and this is logarithmic scale the density. So, the density is 10 to the power 3 here 10 to the power 4 here 10 to the power 5 here 10 to the power 6 here this is in this electron density in per centimeter cube and the plot is something like this is height here, but I will call as like this is 100 kilometer; this is 200 kilometer; this is 300 kilometer; this is 400 kilometer.

This is logarithmic scale on x axis and linear scale on y axis; height here and it is about 90 kilometers that you get and the peak comes at ten to at 300 kilometers. So, this goes like this and it goes like this typically parallel, I think; I am not very accurate on this something like this. So, this is a region of ionosphere which is ionized due to photons this process is called photo ionization.

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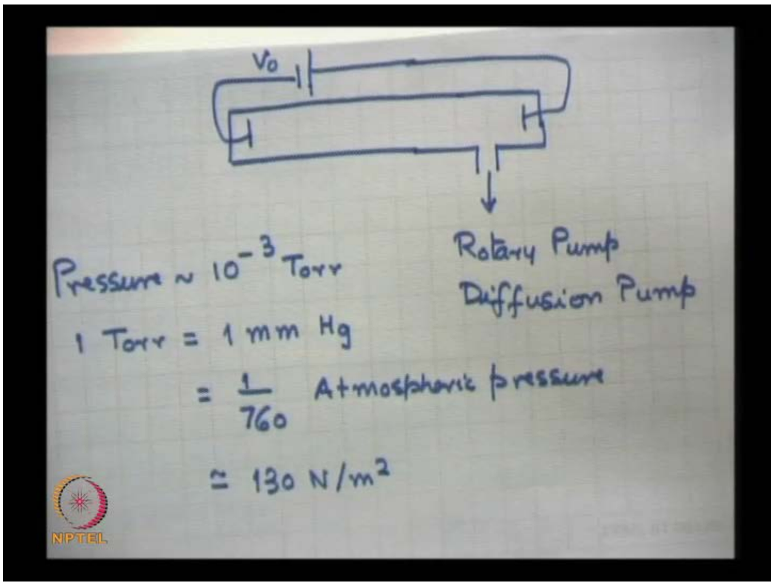


A even simpler scheme, one can employ in the laboratory to produce a plasma and that is called by discharge either by DC discharge or a RF discharge and the scheme is simple you consider a tube which is typically of length of the order of a meter and then you have a vacuum pump to create a vacuum in the interior for this you use a combination of a rotary pump and this is backed by a diffusion pump and these two can give you a pressure of the order of 10 to the power minus 3 torr, torr is a typical unit one torr is equal to 1 millimeter of mercury.

Which means, if I put this in terms of atmospheric pressure, this is equal to 1 upon 760 atmospheric pressure? So, you may see here that rotary and diffusion pumps can create a pressure inside a tube of the order of 10 to the power minus 6 atmospheric pressure; In terms of Newton per centimeter per meter square. If I want to put one torr turns out to be about 130 Newton per meter square that is the kind of pressure that a the gas will have inside this container you have to achieve this pressure. Then, put two electrodes here one here one there and apply a DC voltage between them which is typically like 220 volts the potential difference is suppose v 0 here length of the tube is L.

So, the electric field that you will produce here will be electric field will be equal to v 0 upon L, L as I mentioned 1meter 220 volts is the potential difference. The electric filed will be like 220 volt per meter is the electric field that you produce here now what happens in this space though you are filling a gas, but the temperature is like room temperature and some every gases a few electrons are ionized atoms those electrons are then pulled towards the anode by the electric filed and they move until they collide with a neutral atom.

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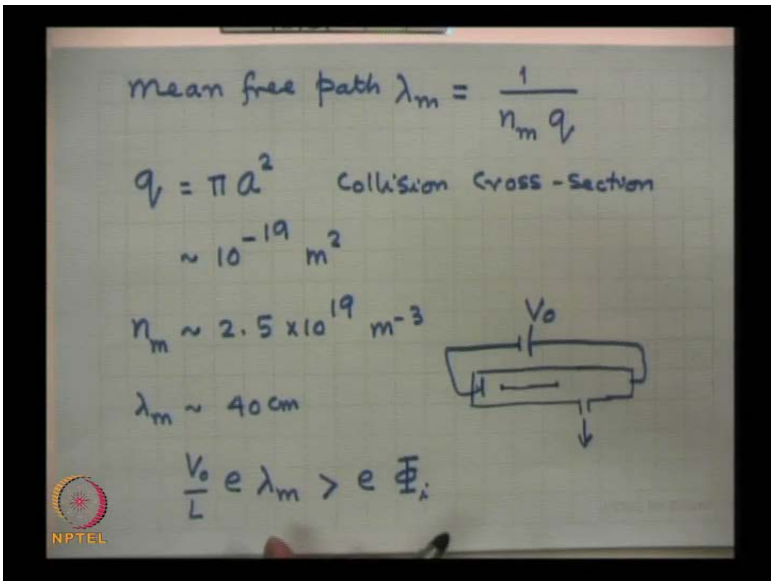


So, the distance an electron covers between two collisions is called mean free path .Well mean free path is typically expressed; as mean free path lambda m is equal to 1 upon n m. The density of neutral atoms per meter cube into q the collision cross section. Collision cross section q is expressed as pi a square, where a is the radius of an atom this is called collision cross section. Typically for atoms q is of the order of 10 to the power minus 19 meter square and the density of atoms is typically at 1 milli torr is about 2.5 into 10 to the power 19 per meter cube. As a result, lambda mean free path is of the order of 40 centimeter means, in that tube the electrons will have a time to travel a distance of the order of 40 centimeters before it hits another atom.

In this process, if it can acquire enough kinetic energy. The kinetic energies will gain in this process, will be of this order. If the potential difference between the two electrodes that you have applied is V 0 and L is the length of the tube then V 0 by L is the electric field in the region multiply it by e charge of the electron, this is the force on the electron and the distance it will travel is one mean free path between two collisions. So, whenever this quantity exceeds the ionization potential e phi I, it will cause brisk ionization one electron will produce ionize one atom. So, that number of electrons will be doubled after one collision and then those two electrons will be accelerated by the electric field and they will produce ionized more atoms and So, on.

One can have multiple ionizations and even the gas can get ionized doubly or triply and this is the process of DC breakdown of a gas the DC field can be replaced by a RF field, radio frequency electric field and that can be applied with great ease by using a coil. Well, this is a simple technique to produce plasma with temperatures of the order of 10,000 degrees Kelvin or So, and lot of basic experiments can be conducted on this. So, this is a simple technique of producing plasma, there are other techniques also and we shall discuss those techniques when we are talking about the methods of plasma production and measurements.

Well, now the issue is that a ionized gas must satisfy certain conditions. So, that they can qualify as a state of matter normally when you talk of a solid liquid or a gas. We talk of some microscopic quantities that, what is the volume of the gas? What is the pressure of the gas? What is the temperature of the gas? And So on. Similarly, we also talk of quantities like conductivity, a refractive index and So on these are called microscopic properties of a matter. So, in order to qualify a state of matter an ionized gas must certain satisfy certain conditions? The first condition is called the quasi neutrality means the number of electrons should be equal to the number of ions.

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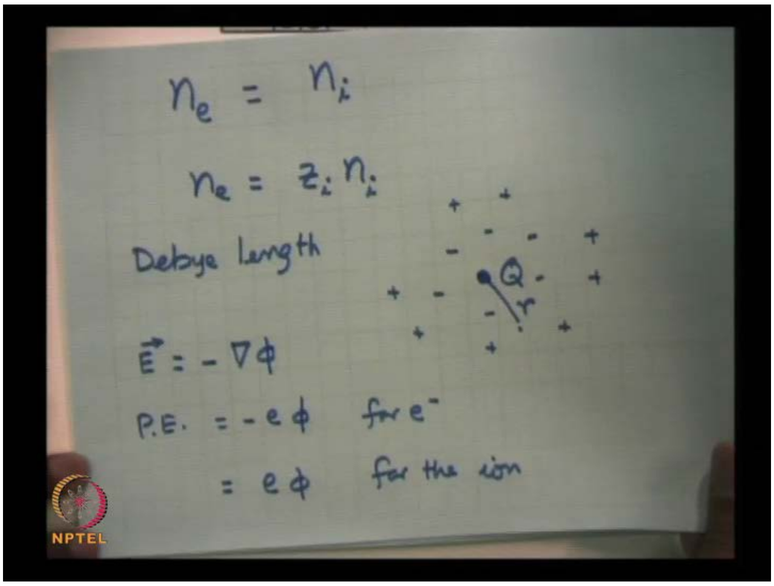


If, the plasma is singly ionized or if the plasma is multiply ionized suppose, the average number of electrons released by an atom is z i. So, this is the average ionization state of an atom of an ion rather then this product should be this is called the quasi neutrality condition. The reason is that, overall plasma should look like electrically neutral otherwise the fields of individual charges will be seen and the dynamics of plasma becomes very complicated. So, in order to qualify to be called a state of matter a plasma must have this condition that n e is equal to or rather the negative charge per unit volume should be equal to positive charge per unit volume.

Now, very important quantity here that can characterize under, what conditions you can have this on what time? On what length scale you can have this? Well to qualify that, we introduce a quantity called Debye length. Let us understand what is Debye length? Consider a charge Q, placed in plasma, suppose there is a plasma a large ionized gas and you are introducing a charge particle Q. It is positively charged for instance. Then, what will it do? It will attract the electrons all around and the ions will be repelled by this. So, in the neighborhood the ion density will be more ion density will be less and the electron density will be more now in equilibrium.

You would expect that, if this charge has produced an electric field e in the region around it, then you may express this as a gradient of a scalar potential phi. Then, what happens at any position at a distance r from this test charge suppose distance r away from here. If there is a charge particle there an electron there the potential energy of the electron would be minus e phi for electrons and if the charge of ion is singly ionized then, the potential energy of the ion will be e phi for the ion. So, potential energies are different for electrons and ions now, Boltzmann law says that electrons will have a tendency to go to regions of a small potential energy.

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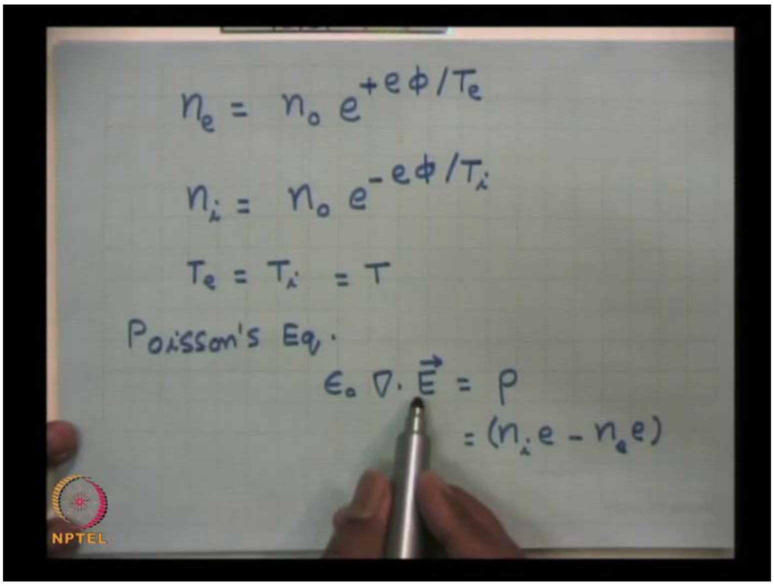


So, what will happen? That the electron density is expected to be something like n 0 exponential of potential energy, which is minus e phi? So, it becomes plus e phi upon T e the electron temperature. Where, n 0 is the density of electrons in the plasma far away from charge q and ion density is expected to be n 0 exponential minus e phi upon T i if T i is the ion temperature for the sake of simplicity, I will consider T e is equal to T i means the electron temperature is equal to ion temperature is equal to T.

So, n 0 is the equilibrium density of the plasma electrons, which is the same as plasma ions? So, this is the modified density due to the charge plus q that you have brought in the system. Now because of this charge, if you go back to the Poisson’s equation in the electro statics the Poisson equation says that epsilon 0 divergence of E is equal to charge density rho. So, which is the same thing as ion charge which is n i into e minus electron charge per unit volume which is n e into e minus e this is the quantity

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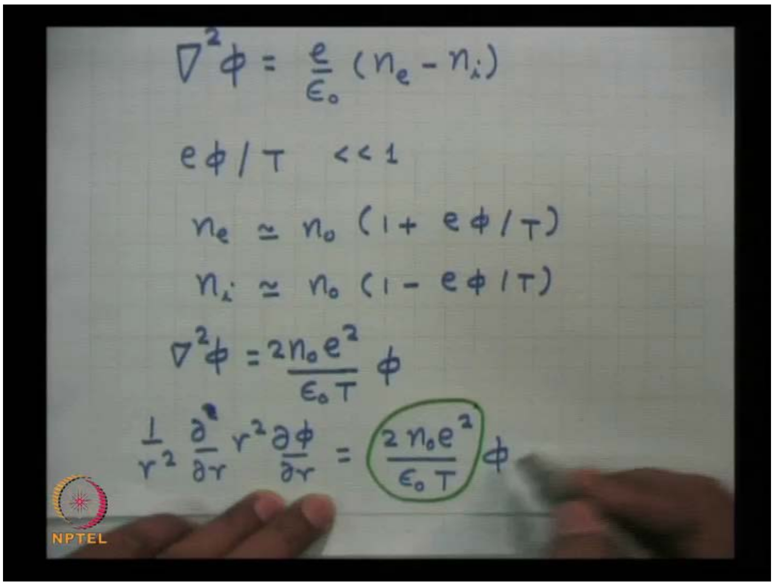


If, I put e is equal to minus grade phi this equation becomes del square phi is equal to e upon epsilon 0 n e minus n i. If, I substitute the expressions for n e and n i in the limit that e phi upon T is much less than one in that case n e becomes of the order of n 0 into 1 plus e phi upon T and n i becomes of the order of n 0 1 minus e phi upon T substitute these expressions in this equation you obtain del square phi is equal to n 0 e square into 2 upon epsilon 0 into T into phi.

Well, this equation has to be solved to obtain phi, the potential due to charge q as a function of distance by symmetry one would expect that the potential will be a function of distance alone not of the direction. So, in that case del square operator can be written as one upon r square d 2 rather del del r of r square delta phi by delta r is equal to twice n 0 e square upon epsilon 0 T into phi. One thing I would like to mention that the coefficient in the right hand side that multiplies by this whole quantity this quantity has the dimension upon upon length square.

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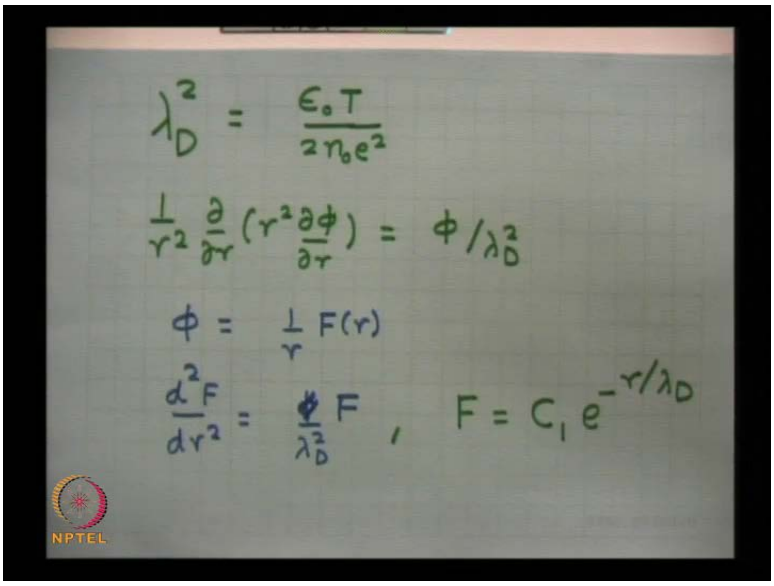


And one would like to write this or rather one would like to define a length like this lambda D square as epsilon 0 T upon 2 n 0 e square. So, lambda D is some parameter which depends on plasma temperature and electron density and as the dimension of length lambda d as the dimension of length. We will see it is physical significance in a minute. So, in terms of this the Poisson equation can be written as one upon r square delta delta r of r square delta phi by delta r is equal to phi upon lambda D square now to solve this equation, we are guided by the fact that in the case of a charge placed in free space your potential goes as one upon r into some constant.

So, we expect that this will be modified by some factor and I will call this F some other function of r. So, if I presume phi of this form use this in here, what you get? You just substitute it here and you will find that this equation gives you d 2 F divided by d r square is equal to phi upon lambda D square a simple equation and this is rather not F phi. This is F, rather I should cut this and this is F upon lambda D square same F here on double differentiation the same F is reproduced with the except of a constant one upon lambda D square and the solution is simple exponential solution.

So, solution is F is equal to some constant exponential of minus r upon lambda D. This is a simple expression and I have written, I have used a physical argument that the potential must decrease as you move away from the charge. So, I have not consider plus r by lambda D otherwise, there is another solution possible for this with plus r by lambda D.

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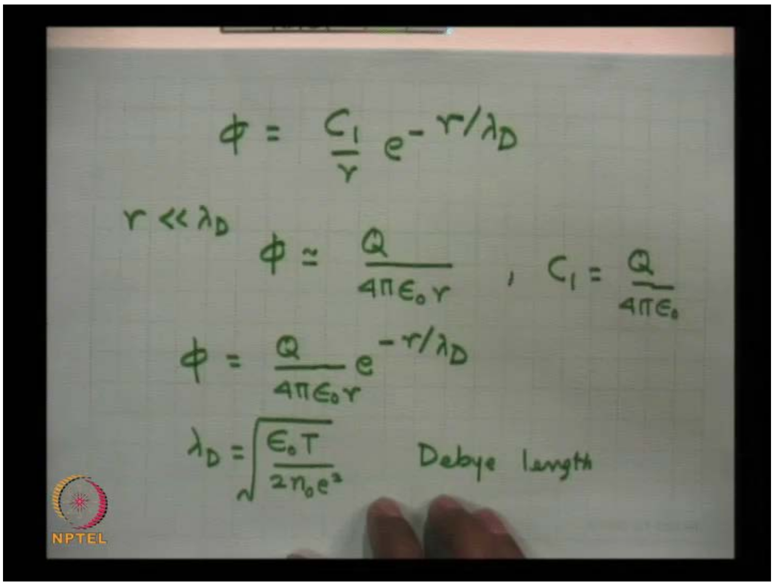


Now, if I put this F in phi my potential becomes phi is equal to C 1 upon r exponential minus r upon lambda D and to evaluate C 1. We believe that, when you are very close to the charge the screening effect of the electrons or ions will not be effective because in any inside any electron cloud or ion cloud. The field is 0 electric field. So, potential So, in the limit when r is less than lambda D phi must tend to the expression that you that Q upon 4 phi epsilon 0 into r the potential in free space as a result you get the value of C 1 which turns out to be equal to Q upon 4 phi epsilon 0 and then the potential can be written as for any value of r as Q upon 4 phi epsilon 0 exponential into r exponential minus r by lambda D.

So, this is an extra screening factor and you would see that the potential will fall off quite rapidly when r is bigger than lambda D exponentially not as 1 upon r. So, Debye this is called screening length or Debye length lambda D which is we defined as epsilon 0 T upon 2 n 0 e square under the root is called Debye length. The significance is that the electrostatic potential of a charge is felt over a distance of the order of lambda D beyond which this is screened out.

So, the dimension of plasma should be bigger than Debye length then you can ignore these effects of mutual charge individual charges rather collective behavior can become important and there is one important requirement on a plasma. So, Debye length is a very important consideration and as we proceed in this course we will see that Debye length naturally comes in many places when we are studying the charge behavior after all why we study plasma physics? We study plasmas because they are media employed for various applications for energy production for communication and they always whenever you pass any signal through plasma the electric field of that wave will influence the charges. So, charges move.

And how charges move not only single charge moves millions of charges move together. So, what is the influence of these charges over each other over the wave and then. So, on those effects require understanding of particle dynamics and hence net force is in particles become important. Dynamics would be very complicated if individual charges effects become dominant. So, the requirement in understanding plasma as a medium a macroscopic state of matter that the size of the plasma should be bigger than Debye length and another issue which is important is plasma frequency.

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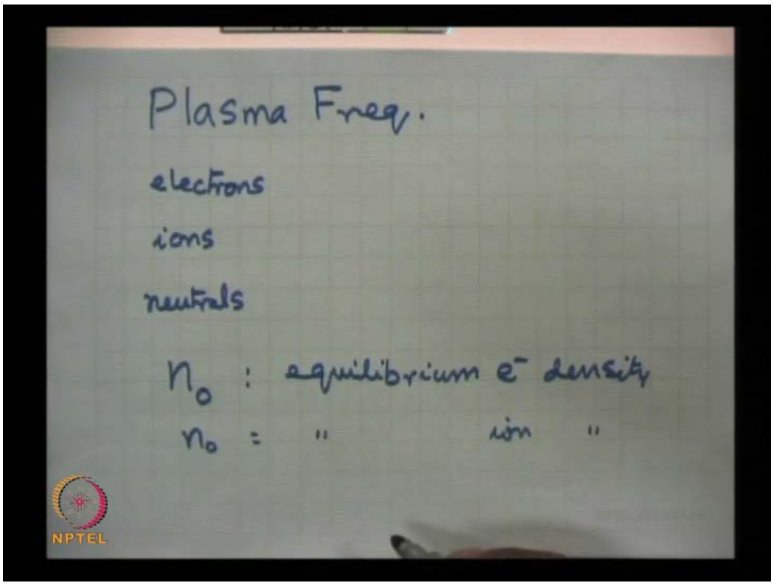


Now, plasma frequency is also a very important characteristic of a plasma let us understand what is this as I mentioned to you plasma is comprised of three kinds of particles electrons, ions and neutral atoms or neutrals electrons are light in mass, ions are heavy in mass and neutrals are heavy in mass and have no charge. So, in all wave phenomena electrons play the dominate role because they can respond quickly to the electric field of a wave.

So, for the moment we will consider the response of a plasma if you produce some electric field in the plasma time independent electric filed in the plasma or if you disturb the density of the plasma. Suppose, I consider a plasma where electron density and equilibrium is n 0 this is called equilibrium electron density and the same; obviously, because I am considering the plasma to be electrically neutral equal to equilibrium ion density. So, n 0 is also equilibrium ion density.

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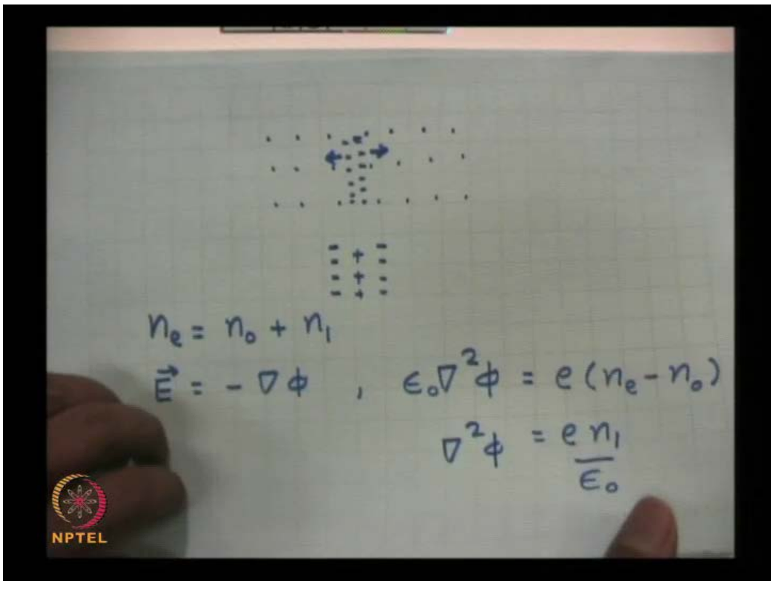


So, now, suppose I have a plasma in which electrons and ions will equally distributed all over they are moving with thermal velocity. So, I am not do not treat them as a lattice. They are moving all over randomly, but on an average the density is n 0, but suppose somewhere these electrons are accumulated suppose instantaneously some electrons come together in some region what will happen? They will produce an electric field and that electric field will cause them to move away from there because the charge of these electrons is negative. So, they will have a tendency to move out and as they move out they do not move out only by the amount extra amount that there were placed here, but they create a deficiency of electrons here. So, electrons move out here ,here, here ,here leaving behind a positive charge there.

And then this positive charge attracts them back and they start oscillating. So, whenever there is a accumulation of electrons in a plasma in some region the electric field is produced in that region and that electric field moves these electrons away from there then creating a deficiency of electrons. So, the reverse this reverses the direction of electric field and pulls the electron back and in this the electrons oscillate. Let us calculate the frequency of oscillation of these electrons what you expect that the density of the electrons would be n 0 plus some modification n one that you have caused and you expect this to be changing with time I would like to find out how how n 1 evolves with time.

Well, whenever there is n one then there is Poisson equation tells that there will be electric field produced because of the space charge and that will be minus grad phi and this is governed phi is governed by the Poisson equation which is del square phi into epsilon 0 is equal to e into electron charge minus ion charge which I take to be n 0. So, it becomes is equal to e n 1. So, del square phi is equal to e n 1 upon epsilon 0. So, as soon as there is a accumulation of charge quickly the potential phi is produced according to this equation, when there is an electric field the electron dynamics is governed by the equation of motion

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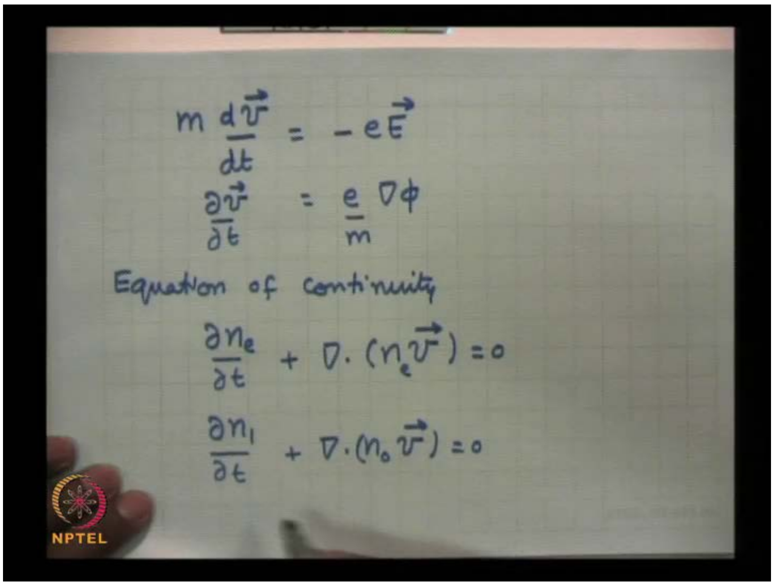


And that motion would be equation of motion is m d v divided by d t rate of change of momentum is equal to the electric force the electric force is minus e E and if I put E is equal to minus grad phi this becomes is equal to e grad phi. Well, I will make an approximation here total time derivative velocity v I will presume is expressible or approximately equal to partial time derivative. I will come back to this effect later then this can be written as delta v divided by delta t is equal to e upon m into grad phi.

So, this is one equation that governs the velocity of electron fluid in terms of the potential and potential is known in terms of density perturbation. So, I would like to write down an equation which connects the density with the velocity, drift velocity and that equation is called equation of continuity. So, let me write down the equation of continuity; which says that delta n e upon delta t rate of change of density with time plus divergence of n into v and e into v is equal to 0 well n e is sum of n 0 and n 1 if n 1 is very small as compared to n 0 I can approximately write this equation as delta n 1 divided by delta t because n 0 does not depend on time.

So, n e simply n 1 here because delta n 0 by delta t is 0 plus divergence of n 0 v is equal to 0. If, I can differentiate this equation with time once I will get delta v by delta t here then I can use this equation the velocity equation and this equation then will become let me write this. So, delta 2 n 1 delta t square plus n 0. I can take out divergence of delta v by delta t and if I use this equation of motion in here

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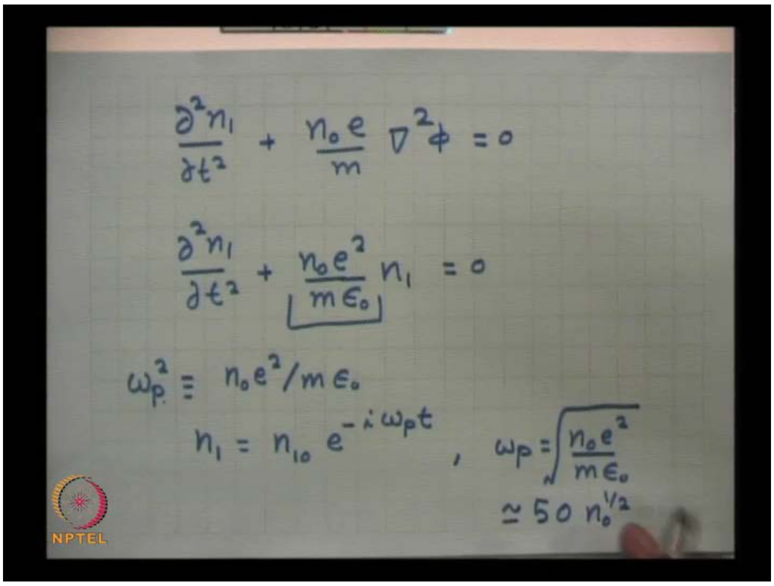


I get this equation as del 2 n 1 upon del t square plus n 0 e upon m del square phi is equal to 0. But del square phi; I had already written in terms of n 1 then this equation becomes del square n 1 upon del t square plus n 0 e square upon m epsilon 0 into n 1 is equal to 0 this is a very simple equation the coefficient of n 1 here this coefficient has the dimension of frequency square. So, we give it a name omega p square is defined as n 0 e square upon m epsilon 0 then this equation has a solution. N 1 will be equal to some constant; I will call this is as n 1 0 exponential minus I omega p into t. So, the electron density oscillates with time and omega p is the frequency of oscillation which is relative to the electron density like this.

So, let me write down omega p is equal to n 0 e square upon m epsilon 0 under the root if you put m as the electron mass the value of m this you know e the value of electron charge and epsilon 0 the free space permittivity this is typically of the order of 50 into n 0 to the power half where n 0 is in m k s units or per meter cube.

So, this is the quantity that depends on density a plasma of higher density will have a space charge oscillation of larger frequency whereas, the plasma flow density will have a space charge oscillation of low frequency and this is a very important phenomena that a plasma supports a space charge oscillations. In this derivation, I ignored the effect of temperature when you include that then these plasma oscillations are called plasma waves they move they carry energy, they carry momentum just like electromagnetic waves; carry energy and momentum plasma waves also carry electron energy and momentum and they are largely responsible for accelerations of electrons to very high energies of the order of g e v energies these days.

So, very high phase velocity in the large amplitude plasma waves in plasmas can be employed for electron acceleration to energies of the order of one thousand m e v which is a very fascinating field of current research. So, today we have learned two important characteristics of a plasma one Debye length that it has a tendency to screen the charges. So, that you do not feel the effect of charges over long distances. And Secondly, the plasma has a natural frequency of oscillation omega p if we launch a wave of frequency close to omega p it can very resonantly interact with the plasma and can do lot of very interesting things.

It can heat the plasma very effectively, it can be scattered by the plasma very strongly and so, on. So, wave phenomena around frequencies of the order of omega p the plasma frequency are very important. Well before I close, I would like to mention a few important macroscopic quantities governing plasma. The derivations, I will give you later just as I mentioned in the beginning that any state of matters characterized by certain macroscopic quantities like temperature volume pressure etcetera.

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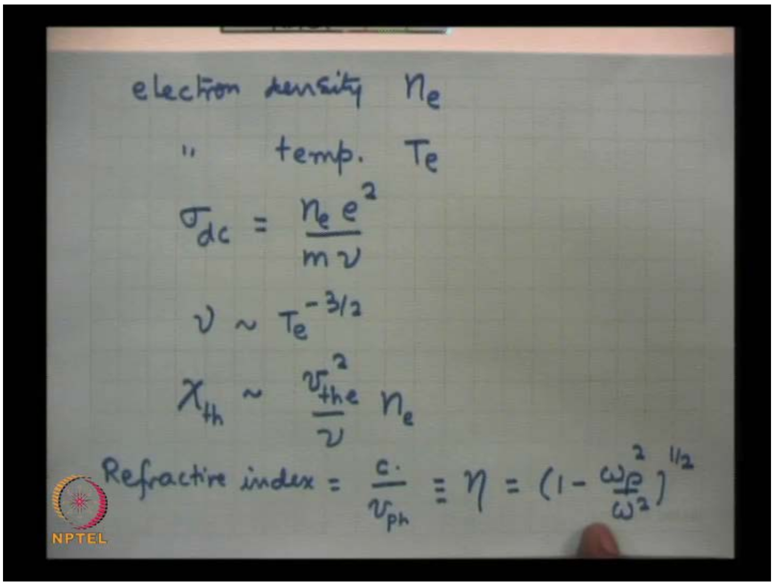


A plasma, is characterized by few macroscopic quantities like electron density n e it is also characterized by electron temperature T e it is also characterized by electrical conductivity sigma d c which is defined which will obtain an expression which depends on electron density into charge electron square mass of the electron and collision frequency nu. Number of collisions an electron suppose per second; we shall write this expression and this is a quantity in a strongly ionized plasma wave there are no neutral atoms only ions and electrons are there this nu decreases with electron temperature.

So, when you have a plasma of higher and higher temperature the collision frequency becomes smaller and smaller and conductivity is very large and this conductivity could be of the order of the conductivity of a metal with even larger a very hot plasma like plasma in the stars or in the sun the collision frequency is very low density is large and the value of this ratio is higher than that in a metal in gold or platinum.

So, plasmas are highly conductive media; very important thing, another important thing is thermal conductivity, thermal conductivity chi thermal is of the order of thermal velocity upon collision frequency square of the electrons v thermal is the thermal velocity of electrons. So, v thermal electron square upon collision frequency into density of electrons at high temperature this also becomes a very large quantity.

So, plasmas are highly thermally conductive another important issue is refractive index. Refractive index we define for an electromagnetic wave which is c upon v phase if the wave travels in a medium in a plasma with a phase velocity v phase then velocity of light in free space c upon v phase is called the refractive index. And we define by a symbol eta for plasma it turns out to be 1 minus omega p square upon omega a square to the power half where omega p is the plasma frequency, that I just mentioned and omega is the wave frequency frequency of the electromagnetic wave this is a very important result important expression because it tells that plasma is a dispersion medium the refractive index depends on frequency.

Secondly, refractive index is less than one means; phase velocity of the wave is bigger than c very unusual characteristic and third a wave of frequency less than omega p will not penetrate in the plasma because eta becomes imaginary. Well, I just forgot to mention that conductors and semiconductors also have free electrons and holes and the lattice atoms because when they release electrons they are ionized. So, this is also like a plasma in which free carriers move all around. So, they are known as solid state plasmas because these materials are in solid state, but the free carriers free electrons and holes in these materials move around hence they are called solid state plasmas.

Now, if you look at this similar expression holds for gold or silver or any metal. So, the plasma frequency of gold and silver is around in the ultra violet. So, whenever you launch an electromagnetic wave or a laser or light of frequency less than the ultraviolet light frequency then eta will be imaginary and this will not penetrate that is why these materials are good reflectors of light. But if you shine ultraviolet light or X-rays on metals this will penetrate because omega is larger than omega p. So, this is a very important omega p is a very important characteristic of a material that characterizes the refractive index.

Well, there are some modification in case of solids instead of factor one here lattice permittivity lattice dielectric constant comes in there, but those are subtle effects and we will discuss them later. So, this is a another important parameter that is important in communication in plasma heating and even in other applications finally, I would like to mention that plasmas well they are they are in nature ever since the creation of the universe, but people learnt about this state in systematic fashion in last 80 years or so. And with the understanding of plasmas especially in last 40 or 50 years, I think several major applications have emerged one of the most important application of plasmas is thermal nuclear fusion .

In this course, we shall learn of those applications. So, I would like to tell very briefly about what are the major applications of plasmas one is fusion

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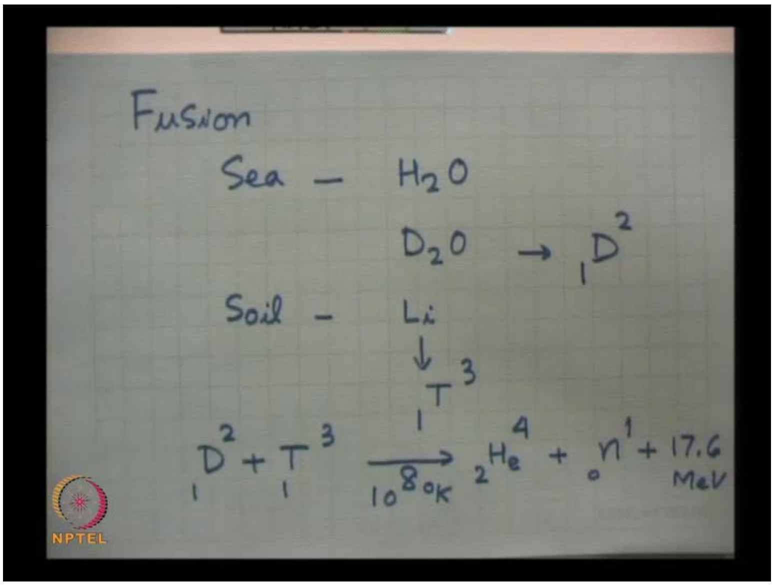


Well, the biggest reservoir of water on the earth is sun is sea in sea well most of the water molecules are H 2 O a very significant of them are deuterium D 2 O and it is not very expensive to recover deuterium from sea water. Similarly, from clay or soil there is lot of lithium and it is not difficult to recover tritium from lithium by bombarding neutrals. So, this can produce tritium and this can produce deuterium. So, we have to measure reservoirs of deuterium and tritium or sources of deuterium, tritium .Deuterium have a atomic number one and atomic weight two tritium has atomic number one and atomic weight 3.

And, if you can heat the mixture of deuterium, tritium D plus T to a temperature of the order of 10 to the power 8 degrees kelvin this will they will fuse that nuclei will fuse and they will produce helium whose atomic number is two and atomic weight is 4 plus neutron and in this process huge amount of energy is released 17.6 M e V energy per reaction is released in the form of kinetic energy of these particles. So, in last 4 decades or 5 decades this has been a major effort world wide it is started with Soviet Union and then it went to with a lot efforts conversed in United States and Japan and European countries and India also joined this effort, and now India is a big partner in this major effort.

So, I think this is a major effort globally to produce energy by using sea water, and I think this has very very lot of promise, and when there are applications of plasmas in the communication, plasma is in material processing, and plasmas as media of electron and ion acceleration to very high energies. So, I think all these interesting phenomena we will discuss in these lectures. This was the first one, and in next 41 lectures I think we are going to uncover lot of fascinating phenomena.