Welding Processes
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Part 03
Physics of welding arc

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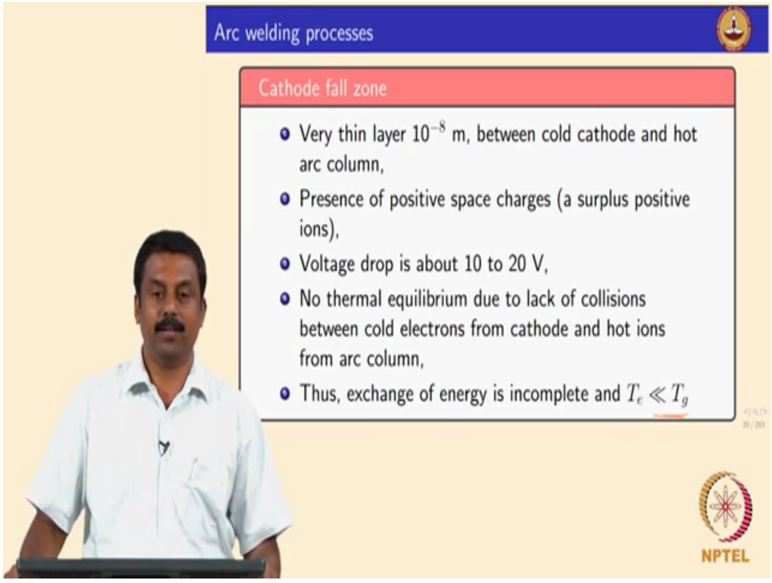

So now we looked at three regions, right Anode fall zone, cathode fall zone and third one.

Student is answering: arc column.

Arc column, seen that the anode fall zone and cathode fall zone which are there just above both anode and cathode, very tiny, extremely tiny if you make that bigger these zones if they expand then you have a serious problem of arc stability because obviously if a voltage changes dramatically then you have a problem of energy gain, right. So generally in a stable arc condition the anode fall zone is very thin 10 power minus 7 meters, extremely few microns, ok so between the cold anode and hot arc column, ok.

And this region is characterized by the presence of electrons the negative space carriers, energy carriers and because these anode is positive, right. So there you will not expect the positive ions taking to the positive terminal because of recursion, so the anode fall zone is always characterized by the accumulation of negatives space charges, the lack of positive ions, ok. The voltage drop is somewhere between 1 to 10 volts, again if it goes more than that then it is not sustained, right and you have problem again.

And there is no thermal equilibrium because we want to have a thermal equilibrium, ok. So you need to have a collision is between the electrons and ions which should be giving an equivalent energy transfer, ok. Suppose if you do not have adequate number of in this case ions, so there will not be collision, adequate collision to make both ion temperature and electron temperature equal, is not it because you have a large number of negative space carriers charges electrons.

So then electrons, electrons will be collide you will not get an equilibrium because the ion temperature in this case will be much lower than the electron temperature because there is no real equilibrium transfer, it is clear. So there is no thermal equilibrium at these in regions, so where because the accumulation of electrons, the electron temperature will be much higher than the ion temperature, in anode fall zone, ok so that is what I written here.

The exchange of energy is incomplete, ok because you are accumulating the electrons here and due to that the electron temperature will be much higher if any ion present into the density the ionic temperature will be much lower because there is no energy exchange between the electron because you have only electrons, yes it is clear, Anode fall zone. The next fall zone is extremely important the cathode fall zone because the cathode act is as an electron emitter, ok if you do not emit electrons there is no discharge, is not it.

So similar to the anode fall zone, cathode fall zone also is very tiny 10 power minus 8 between the arc column and the cold cathode whereas in here you have a positive accumulation of (elect) the accumulation of positive ions which is a negative terminal, right. So you have a surplus positive ions, the voltage drop is slightly higher than the anode fall zone but it is about 10 to 15, again here also no thermal equilibrium is not it because we have a only accumulation of ions that mean is that the energy exchange is not complete but whereas in this case the electron temperature will be much lower than the gas temperature, ok.

So the gas temperature will be higher than gas mean is here the ions, gas ions, the gas ion temperature well be higher than the electron temperature because the energy exchange is not possible because you only have a accumulation of ions is no it. The function of cathode is extremely important welding case because cathode emits electrons, so if you do not emit electrons how do you discharge? How do you discharge an a gas item? Because the electron first interact knocks the other electron out from the gas atom and you have a generation of positive ion and that avalanche happens, so the discharge is sustained, ok.

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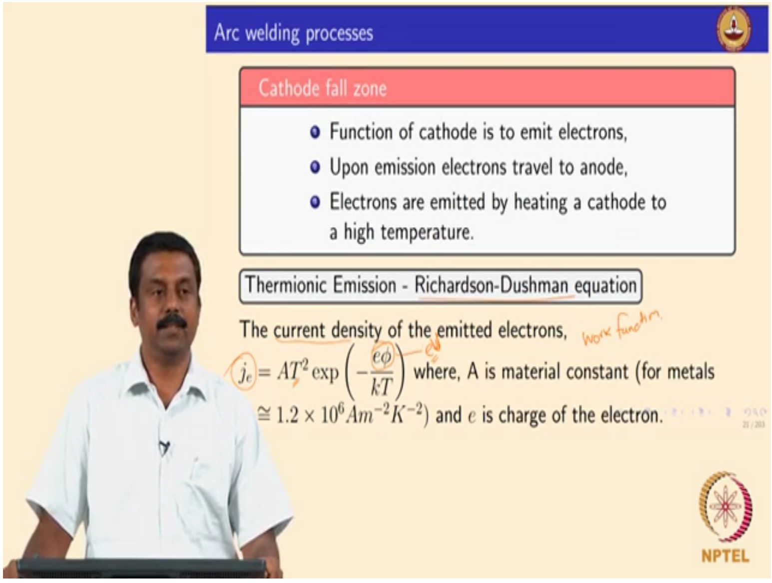

So the main function of cathode is to emit electrons, ok it is very important. So the function of cathode is extremely important because that is where you emit electrons, so once you emit obviously it will travel to the electron will travel to the anode but during this process it will also interact with the medium gas causing some more emissions, the avalanche, the discharge, ok.

So how do you emit? What are the mechanism begin the electron emission?

Student is answering: thermionic

Thermionic emissions, ok so that is one type of emissions where you can emit electron from a material, thermionic emission, ok that is good. So how do you how does thermionic emission work? You heat up, if you heat electrode at high temperature, ok so then the electrons emitted and that is determined by the work you need to emit or a knock an electron out from a material, ok that is nothing but work function, ok.

So the main mechanism begin the electron emission is thermionic emission but thermionic emission alone will not give you the electrons there is another emission.

Student is answering: field emission.

Field emission, ok. The field emission can also give the sustained electron emission but both combined would generate electrons needed for discharge, ok. So in thermionic emission we heat up the cathode give you heat up the cathode to a higher temperature based on the work function whether you will emit an electron or suppose if a work function is very high, so you need to increase the temperature much further that is determined by these beautifully equation which is Richardson dushman equation it is not dusman, it is Dushman, ok so Richardson Dushman equation.

So where you see the current density or electron density emitted from a cathode is determined by there are two important factors here, right. t what is that?

Student is answering: temperature.

Temperature and this guy, ok. e times phi, so that is work function, ok. So this e is charge of electron or potential difference it is electron volt e v, ok so that is work function. So if you multiplied by electron which is nothing but the ampere, right the electron density the charge multiplied by volt what will what does that mean? V I

Student is answering: (())(09:11)

V I mean is the energy, is not it electron volt that is basic. So that mean is that the work you do to emit an electron, ok that is work function is not it. So these define by e v electron volt, ok so that mean is that the work you should do to emit an electron from the material, ok that is work function. And if you look at this equation and you have T square that is temperature that mean is that a temperature increases so obviously he emit more electrons reading to increasing in current density, that mean is that the electron density increases, ok.

And this guy e the phi or e phi electron volt, it is a material parameter, ok how good electrons are all bonded or in the thermionic configuration. So generally material which has higher melting point would also have a high work function, ok. And if you want to have a thermionic emission you need to increase a temperature to higher temperatures, generally you would have a thermionic emission, right but now you have a problem because if you want to keep an electrode for example if you want to make a non-consumable electrode that electrode should have a high melting point, so that you can increase a temperature and then you can emit electrons, is not it.

So now it is difficult, so to emit an electron by thermionic emission, right. So what we do we add some oxide, ok so when we use a non-consumable electrode in welding a material the alloy should be having high melting point but then if you have a high melting point you will also have a high work function. So if you add if you dope the material with high melting point with oxides, ok so then we can promote thermionic emission, yes.

So if use a high melting alloy most commonly used a non-consumable electrode is tungsten, so it is not pure tungsten when you do a welding, weld is dope with oxides, ok. So most commonly used the oxide opened when I was doing my PhD was thorium, thorium oxide but thorium oxide is ready radioactive, ok. So nowadays you (())(12:08) econ by thoriated, tungsten electrode because it is banned but that is fantastic, the electrode stability of thoriated electrode is very nice unfortunately thorium oxide is radioactive, so that is replace with cerium oxide, ok.

So these are all rareth oxides which have extremely low electron the work function. So we dope the high melting alloys with these oxides so that we can emit the electrons by thermionic emission, ok. So the equation defines the amount of electrons emitted as a function or temperature run the work function we can use Richardson dushman equation to calculate for example if you give you a work function of a material a material constant A you can always calculate what will be the amount of electrons a density of electrons emitted by the material at a given temperature, yes we can calculate right.

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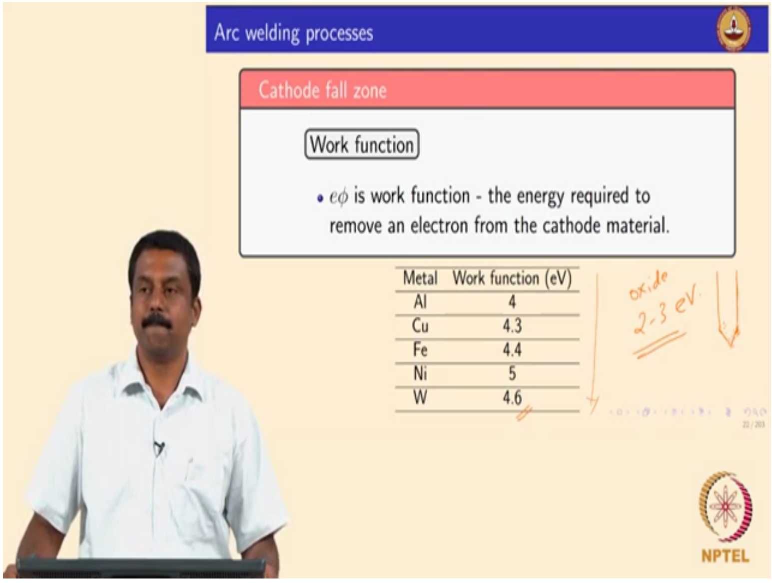

So if we dope it with oxides, the oxides are very low work function which is beneficial, so what we do generally so if you look at the electron volts so nickel has slightly higher electron volts than a tungsten but melting point is lower than tungsten, so we cannot use a nickel as an non-consumable electrode because it will melt by the time you induce a thermionic emission. So if you use tungsten the work function is reasonably ok and you can reach up to high temperature, so that you can induces thermionic emission that is why tungsten electrodes are commonly used as an electron source, ok ne c m or cathode or a tubes, c r t s when you have an electron gun tungsten is commonly used, right because of these fact that high melting and electron volts the work function is reasonably ok, so you can work with tungsten to emit electrons.

To in order to increase the efficiency of thermionic emission we also dope tungsten with oxides, so oxides electrons volts somewhere between 2 to 3 electron volts. Suppose if you have a tungsten electrode and you dope it with oxide so obviously whenever there is an oxides and if a temperature is increased these oxides would start emitting electrons by thermionic emission and because of that there will be electron emission locally when the oxides and they cannot travel to the tungsten obviously then locally and they would knock out further electrons from the tungsten orbitals and then you will have a sustained emission of electrons from the cathode, right.

So the most commonly used the oxide opened for tungsten is thorium oxide and nowadays we also use cerium oxide dopends and we look at in detail when we look at the gas tungsten arc welding in chapter 2, what are the oxides? What are the functions of the oxides? Right now you can assume that the work function is extremely important, so thermionic emission is happens because of the high temperature when heated up obviously electrons go out when you supply energy equal to the work function the electron can be knocked out, right it is clear and we need reasonably high temperature therefore we use high melting high temperature melting alloys where we have a doping of oxides leading to and efficient thermionic emission because of the oxides have a low work function, it is clear ok.

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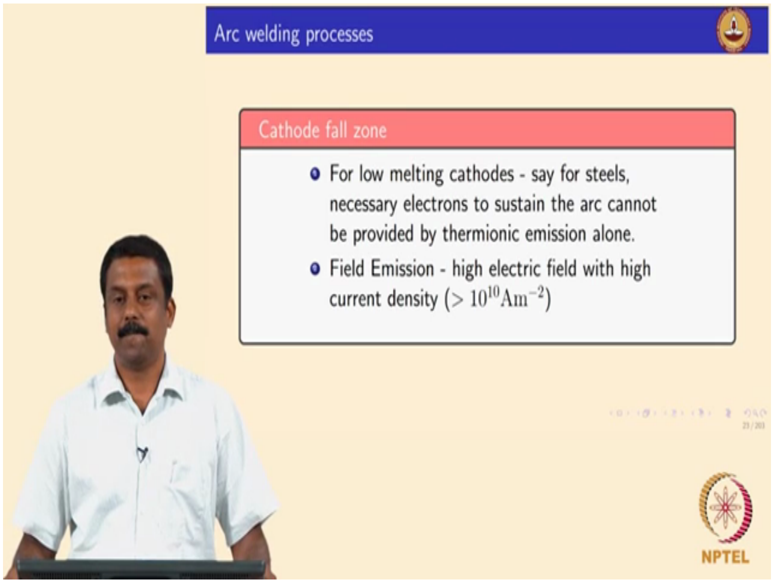

So the thermionic emission alone cannot give sustained electron emission needed for the arc discharge, ok. For example if use a consumable welding process not tungsten you use an steel filler, now you want to strike an arc you cannot expect thermionic emission from a steel wire is not it but how we do sustained the electron emission, so then so you need to use a field emission as your main source, for example low melting alloys for steels and you want do an g m a w gas metal arc welding.

So then if you make one of them cathode either your steel wire or steel surface, so obviously you need to generate electron, right from the cathode otherwise you cannot strike an arc, you cannot make a discharge, so in that case thermionic emission may not be sufficient so the main the electron generation mechanism in that case is field emission, ok but the field emission if you want to have you need to have a very high current density amperage, ok.

So we ignite the arc by the high density current density so that we can also cause a field emission, yes you have question yeah. So the field emission is helpful when you want to use a low melting cathodes because thermionic emission is not providing enough electrons needed for the discharge, ok. The phenomena of field emission is extremely complex that only happens because of the electron tunnelling, ok but the principles behind it is the electrons are tunnelled and then it comes out of the surface because of the high energy density, ok so you maintain by the field emission, so you do not need an a high melting alloy but you need to have very high electric field to promote the field emission, yes it is clear.

So the function of cathode is to emit electrons, the cathode emits electrons by two ways one is thermionic emission the other one is field emission, ok. The thermionic emission happens when you heat up a material to higher temperature and if the energy the heat is sufficient to knock an electrons based on it is work function then electron will be emitted from the material, ok.

The amount of electrons emitted by thermionic emission you can be calculated using Richardson Dushman equation as a function of temperature because all of the things are constant in that equation, right ok. The work function is constant material constant only variable there is a temperature, with a temperature you can calculate so what will be the density of your electrons, right.

So second phenomena which also enhances the electron emission is field emission. It is a field emission is widely used are field emission is a rate controlling when you have a low melting cathodes, ok. So low melting cathodes are also needs high electric field to emit electrons by field emission, right. So the field emission governs the electron emissions in the low melting cathodes, it is clear.

So the two fall zones we have seen now anode fall zone, anode is mostly darment, ok. So anode function is to have a cause of potential difference to charge carriers, so that charge carriers can travel but cathode determines the density of charge carriers, ok the cathode emits electrons so if you want to sustained the arc that means that you need to supply the charge carrier, right.

If you switch of the power source what happens you also stop the charge carriers, right so there will not be any more thermionic emissions, so when you pass an electrons obviously the electron the electrode is also heats up by resistance heating the temperature increases, yes it is clear, so two emissions, ok. So now will go to the important zone, ok arc column, right so whatever happens arc column determines the heat generation, right it is clear.

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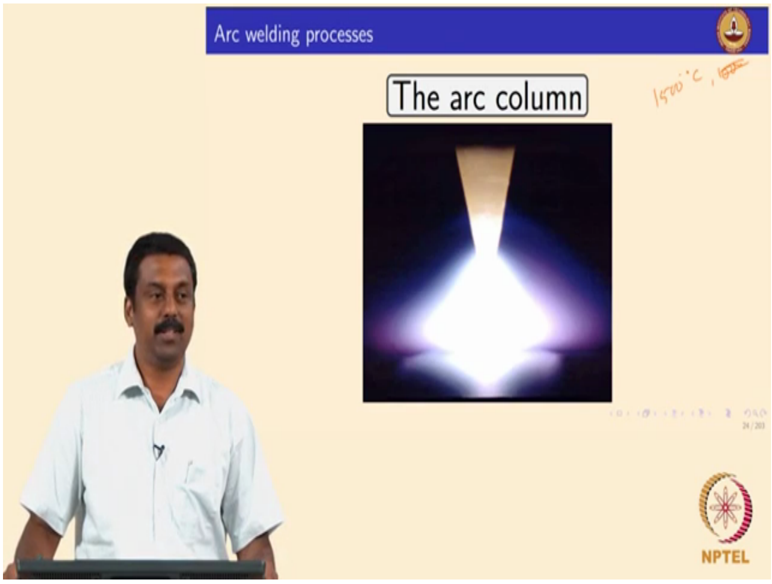

So it is beautiful the arc column, right it is very bright. So what will be temperature of this guy? The bright region.

Student is answering: more than 10000.

More than 10000, how more than 10000, yeah how much more than 10000, 5000 more than 10000, yeah you there about yes.

Student is answering: 16000

Yeah the temperature is there about 20000 kelvin, so the temperature of the arc if I will show you in subsequent slides at the central arc column will be close to 20000 kelvin, ok but unfortunately we do not transfer the heat efficiently because the conduction convection radiation is not that efficient, so therefore the process is not that efficient if you can transfer the entire heat of the arc towards the work piece, so that is nothing like that I mean you will love a fantastic you can penetrate 30, 40 mm plate even with 100 amperes current, right.

So efficiency is not there but arc is a fantastic we look at in what is happening inside? How does the temperature increase as is 20000 kelvin inside the arc, ok before that we will see again so if you look at in inside the arc obviously there are two particles, fundamentals particles what are they? Electrons and ions that is it, ok so you will have electrons and ions of course you will also have unionised gas items or if you use diatomic gas, what are diatomic gasses?

Student is answering: (())(23:44)

N 2, h 2, c o 2 diatomic gas you will also have molecules, ok. So that is what the fundamentals particles are electrons and ions and with that we can generate temperature as is 20000 kelvin, ok.

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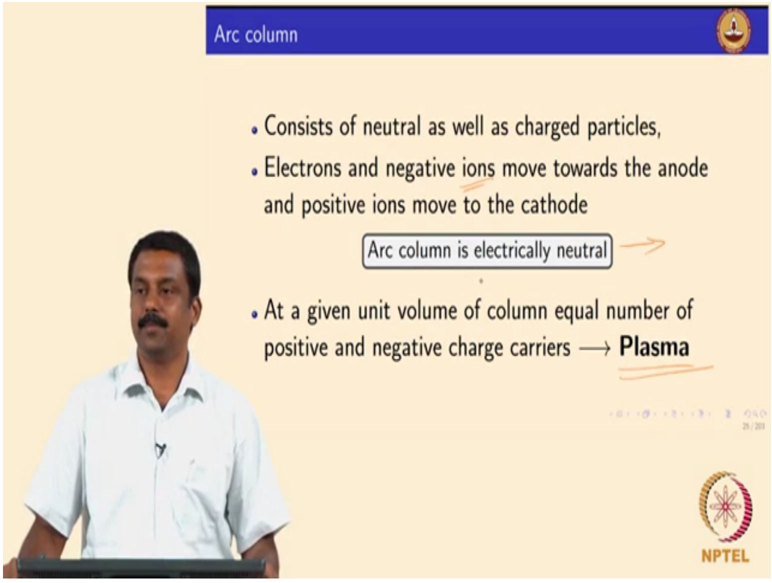

So if you look at arc column is mainly consist of as I said neutral particles, neutral atoms which are not where it to be ionised are neutral molecules it to be dissociated, ok. So if you have n 2 he will have n 2 but n 2 will become n and then n becomes n plus, n plus further becomes n two plus, n three plus until you strip of all the electrons, ok and if you have organ, organ becomes organ plus and you generate electrons, ok.

So the arc consist of two fundamentals particles, ok of course if you consider the light is also fundamental particle he also photons but in our case we can assume the two fundamentals particles electrons and ions, ok. So obviously the electrons are negative ions, ok so generally it is negative particles sometimes in also negative ions, ok. So all the negatively charge particles would move towards anode which is positive terminal.

The positive ions would move to cathode, a during this process they will not go just like that, ok so when you rocking on the corridor you do not collide with someone else then you transfer energy, the other person is fall or you fall because other person can also transfer energy to you, ok so then you dissipate energy by falling down, ok so that can be pain as well, ok but in this case so when the electrons and ions travels from cathode and anode they also collide, ok so the collision obviously then discharge energy, right.

So this collision can be the elastically collision, inelastically collision and we can look at lovely mechanism begin this collisions but we are not going to that detail because it is too much high temperature physics. We will assume now that the ions and electrons in the arc column when they travel towards anode and cathode they collide each other and they transfer energy the dissipate energy that energy is released as a heat radiation on various other mechanisms.

So the heat is generated because of the collision when they travel from one end to other end, ok and if you have (())(26:38) of electrons and ions so then (elec) arc column becomes electrically neutral, right. So then the charge is neutralize in most of the cases in if you have just have arc, ok arc is selectory electro negative because he always have more numbers of electrons than ions, ok always electro negative but when the number density or the charge density of electrons and ions equal then your arc columns becomes electrically neutral that state is known as plasma, ok.

So plasma is state of metal, right when we call arc plasma?

Student is answering: equal (())(27:32).

So when arc column becomes electrically neutral then you call that plasma, plasma is metal is not it, so plasma is a metal because is electrically neutral, ok. So eight given unit of volume, ok if you have equal number of positive or negative charges then it becomes electrically neutral when you have arc column electrically neutral then you attain a state plasma, so if you wanna do that then you have to do a lot of things, in a conventional arc generally it is not electrically neutral I would tell arc column is electrically neutral, so when you have a given unit of volume you have equal number density of electrons and ions then you will reach electrically neutrality and system becomes electrically neutral and you reach plasma state, ok.

So generation of plasma is extremely difficult given if you can strike an arc, ok to create a plasma you need to do lot of things will see when you look at plasma welding how arc changes into plasma, so as if now we assume that when arc column becomes electrically neutral when you have equal number of electrons and ions but generally arc column is electro negative you have more amount of electrons, right.

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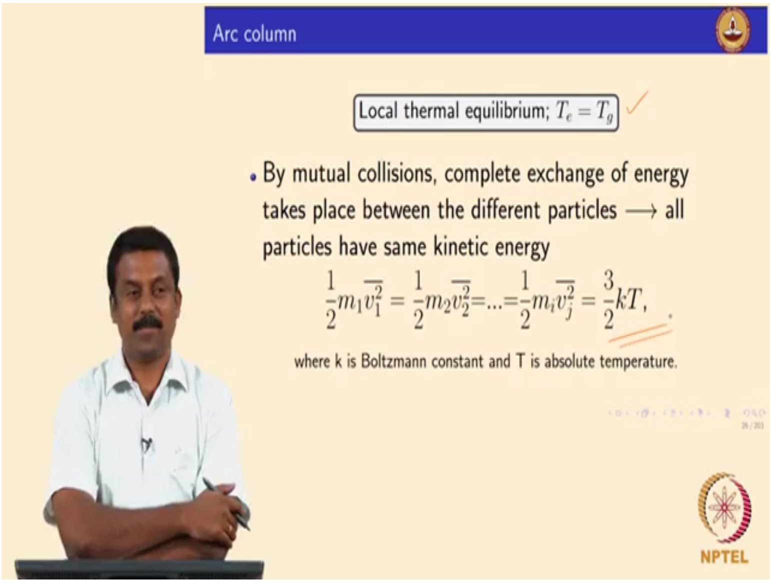

So if you look at temperature in anode fall zone what happens you have accumulation of.

Student is answering: electrons.

Electrons then the electron temperature much higher in cathode fall zone.

Student is answering: ions temperature higher

Ion temperature will be higher whereas an arc column you have thermal equilibrium because the number density is more or less equal, so the temperature of electrons and the gas ions would be more or less the same, ok and apart from electrically neutrality he will also have a thermal equilibrium, ok. In arc column because of the equal number density they will be mutual collisions and then they will be complete exchange of energy between different particles ultimately all the particles inside the arc column will have a same kinetic energy, is not it.

So if you look at of m v square kinetic energy equation and if you calculate all the particles kinetic energy will be equal because there will be absolute mutual collision resulting in complete exchange of energy, right and that is equal to 3 by 2 k T, what is k here?

Student is answering: (())(30:44) constant.

Good, we will end up here, thank you.