Welding Processes

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Physics of welding arc Part 04

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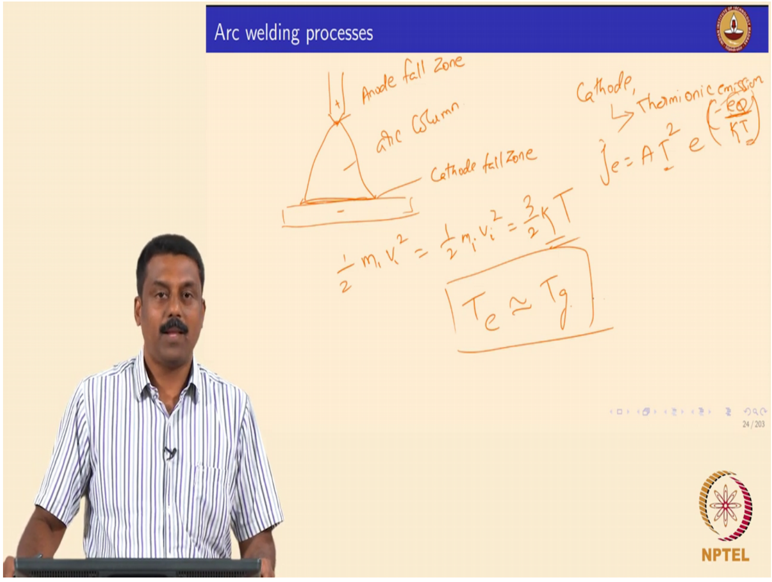

Okay so last class we were looking at the distinction area in arc, so we saw 3 regions, so what are the 3 regions we saw in arc. Okay so suppose if we have a an arc you form in a beautiful so I am not a good artist but still you can imagine, so suppose if this is our anode and this is cathode so we see just below the anode tip we have anode fall zone, right? And then just above the cathode region we have cathode fall zone, is not it? And we looked at the distinctive characteristics of these zones, so we looked at in the anode fall zone because of the positive polarity it attracts electrons.

So electrons then accumulate at the tip of the anode and form anode fall zone and due to that we have accumulation of electrons leading to improper collision, the collision is not complete. So mutually energy extend is not complete therefore the electron temperatures are much higher at the anode fall zone than elsewhere okay because there is not (())(1:37) of exchange because number density of electrons are much higher than the ions okay so that also leads to a voltage gradient, right?

So voltage gradient in anode fall zone similarly our voltage gradient in cathode fall zone because of the accumulation of electrons on the surface of the cathode which we call it a cathode fall zone. Okay again in cathode fall zone the gas temperatures are much higher or gas ions temperature are much higher than the electron temperature because again there is not enough energy exchange between the electrons and ions, right? And because of that gas temperature is always higher than electron temperature, much higher, right?

And we looked at the function of cathode, so the main function of cathode is to emit electrons, right? So we looked at the cathode functions, so subsequently will see the detail of word emission but we have seen cathode emissions like thermionic process and thermionic emission, right? And we looked the de-creation which governs the thermionic emission, right? The electronic density is without referring your notebook, can anyone tell?

Student:(())(2:54)

Prof: e square e power minus work function yes by

Student:(())(3:02)

Prof: Yes again Boltzmann okay so the work function we define as the work we do to emit an electron from a material in this case for example cathode, right? So e is nothing but the charge and then 5 is just like an electron volt, so electron volt is again so what is one electron volt? How many joules is one electron volt? Or 1 joule is how many electron volts? 1st lesson…okay so one joule is how many electron volts? So when did you say 1 joule when one column of electrons travel over 1 volt, right? Then the energy gain, so obviously one joule is 6.242 times 10 power 18 electron volts okay so that is one column, right? Number density, number of electrons in one column, is not it? So is all related, so if you say 1 joule is 6.242 time 10 power 18 electron volts.

Okay so that is what one column we define, number of electrons in one column okay if you say one electron volt obviously if it is one joule it is obviously 6.242 into 10 to power 18 electron volt, right? So that is what the work function defines the energy joules, in terms of joules, right? So that is the joules you need to give for creating one column of charge travelling to 1 joule of energy, so this all simple later, so the work function e5 defines the energy, so work function is again is a material parameter, so for some material it can be very high and for some material it can be very low and we have to have compromise between the melting point or the thermal stability of the cathode with respect to work function because not the thermionic emission in electrons by thermionic emission you need to heat it up to high temperature because T determines the emission, right?

So we dope it will some oxide of an high melting point material or material which have high thermal stability so that we can emits the electrons at low temperature or reasonably lower temperature by doping these materials with oxide because oxides are generally they have very low work function and then we looked at the field emission because not always it is possible to emit electrons by thermionic emission because sometimes we use say consumable cathode, so in that case so we need to emit electrons by some other way, so we use field emissions high frequency, so it has to be done with very high electric energy, so we go up to 10 power 10 ampere per square metre to emit the electrons by field emission, right?

So we looked at the emission mechanism between the thermionic emission and the field emission and we will see in subsequent chapters how these emissions are used to ignite an arc. Okay arc emission is done by these 2 emissions okay so we will see when you want to ignite an arc, how we can promote these 2 processes that will come in subsequent chapters when you look at the process itself. So now before even going to that we have to study about the 3rd region in this figure which has arc column.

So we just touched upon arc column, so the arc column is electrically neutral in general, so therefore the voltage gradient is not steeper as compared to the anode and cathode fall zone, so why do you say electrically neutral because the number density of the electrons and ions is more or less equal okay, so when the arc column becomes electrically neutral we call that state as plasma okay, so plasma is defined as a neutral state of matter okay, so the arc when it becomes electrically neutral then it becomes plasma but then the number density must be equal, so we need to create as much electrons and ions in such a way that we maintain electrical neutrality but it is very difficult to have attain that state in a welding case.

So we have to do some modification to the arc itself to make arc into plasma, so most of the arc welding processes, the arc is electrically negative because contains more electron than ions, right? But in a way you can assume that in arc column of all the arc welding processes, the kinetic energy of these charge carriers, the electron ions are the same because there is a mutual collision. The number density is close to equal means slight negativity but you can say that the amount of the density of electrons and ions are so high okay so there will be mutual collision between them leading to an exchange of complex change of energy between the electrons and ions, so therefore if you look at kinetic energy of these space carriers, the charge carriers it is equal, so if you say that…

So we were looking at one electron okay it must be equal to say for example ion as well anywhere, so must be equal to a kinetic energy of a particle as function picture can be determining buy 3 by 2 Boltzmann again, right? It is clear? So now we will go in even deeper, so when you say that that is equal energy that means said that it is a mutual collision okay. So the mutual collision ensures that the complete energy exchange like in a snooker ball that means that when electron heats an ion, the electron stops if there is a complete exchange of energy okay and then ion is carrying the energy of electrons and travel further, so that is the complete mutual collision and exchange of energy okay but it is not always the case, right?

So because the electrons carry very low mass compared to ion, so ion is nothing but as a gas atom okay where it has 1 or 2 electrons lesser than the complete shell it used to have. So the mass of ion is much higher than the electrons okay so technically if (())(10:27) is maintained if a mutual collision happens then the electron temperature must be equal to gas temperature, is not it? Right? So that is completely energy exchange system, it is an equilibrium, it is electrically neutral and thermal equilibrium.

System is under thermal equilibrium as well okay so this is the ideal state we can have, so when you define or when you say it is plasma that means all these subatomic particles and the charge carriers should have a same temperature and the number density should be such a way that you maintain electrical neutrality, so that is the state of plasma, right? So that means that it is like any other matter, so it does not have any electrical charge, neutrality charge and all the microscopic entities have same temperature, so that is plasma but in our case because again the electrons are slightly higher in number density okay and that drift velocity of electrons are much higher than the ions.

What is drift velocity? For example after the collision in between 2 collisions because of the low mass they can travel much further than the ions, is not it? Yes, the electrons carry low mass compared to ions, so the average drift velocity between 2 collisions will be much higher for electron, right? See if the electron drift velocity is higher obviously it is also exposed to in the system for more time, is not it? So they can travel far between 2 collisions because of the high drift velocity given by the low mass therefore the electrons can heat up slightly more, right? So the electron temperature is slightly always higher than the ion temperature in the system at atmospheric pressure okay.

So if you look at the curves… not one atmospheric pressure is more or less equally as you can look at the sign I drew okay I was so careful not to make a mistake but it is not equal, it is more or less equal okay so the electron temperature is more or less equal to gas temperature. At one atmospheric pressure it is the case okay so you can assume so between 18,000 Kelvin to 18,500 Kelvin you would say it is equal, right? Is not it? We want to even distinguish 500 Kelvin when the temperature is already close to 20,000 Kelvin.

So that is the case at atmospheric pressure, the electron temperature is slightly higher than ion and gas temperature but when the pressure is changed when system is under different pressure then the situation is not going to hold because then your drift velocity will change, if you change the pressure your drift velocity will change, suppose if you are going to low-pressure, so obviously the effect of pressure on the mass is so high electrons would drift even much faster at low-pressure situation then the electron temperature will increase even further compared to ions, right? Is it clear?

So atmospheric pressure more or less equal you can say but when the pressure is increased for the pressure is decreased then drift velocity will also change dramatically okay, so if you doing welding at one atmosphere you can assume that the temperature of the electron are more or less equal to gas electrons. These are important… Why these concepts are important? Because I am going to teach you when you look at the heat generation, so then you need to understand all these phenomena. When you are deriving the equation for electrical conductivity of an arc which is needed because conductivity determines our heat generation, resistivity one by conductivity, reciprocal of conductivity, I think it? So when you are deriving equations for that you need to understand these concepts. Okay so we will move on for this class.

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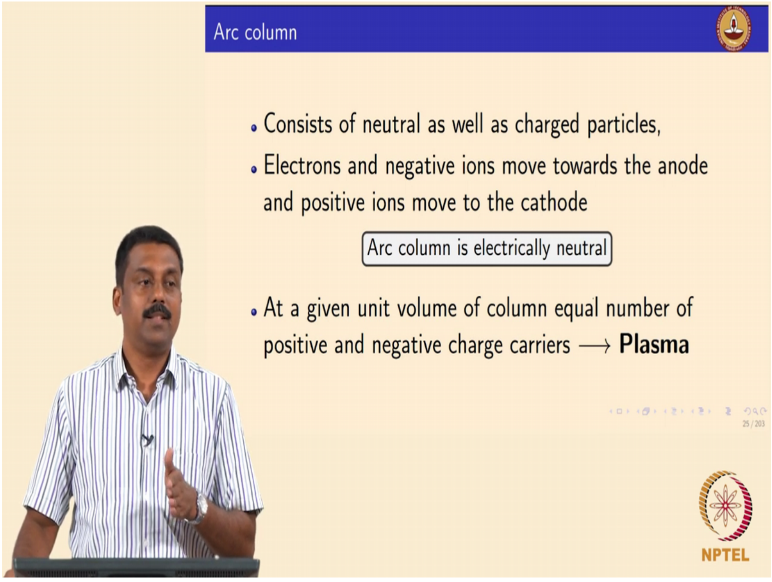

See arc column again to recall they consist of neutral as well as charge particles. Obviously the electrons and ions will move irrespective of the polarity to either to anode or cathode based on the charges. Electrons travel towards anode and ions will travel towards cathode and because of the number density, equal number of positive and negative charge carriers you maintain electrical neutrality. Once you achieve that electrical neutrality you can climb that you created a plasma, right? And because of the mutual collision within the electrons and ions it ensures the local thermal equilibrium okay.

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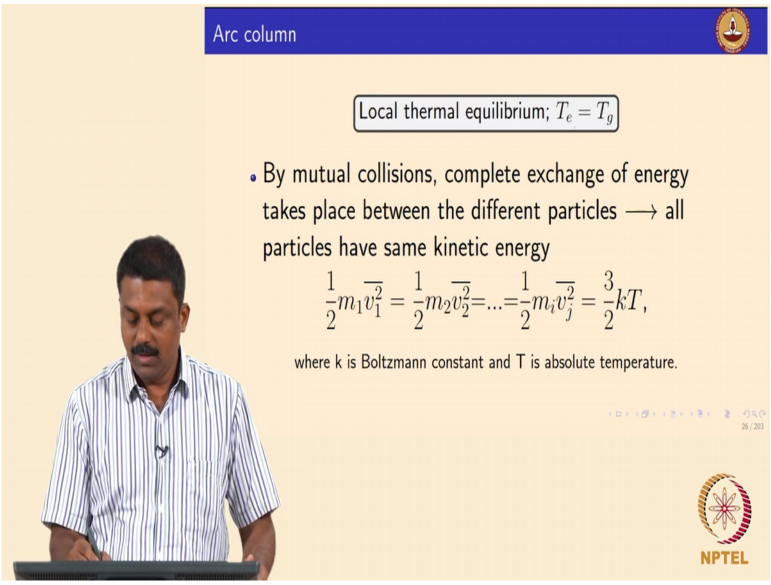

So the temperature of electrons and gas temperature are all equal and if you achieve such state it is clear equilibrium state of plasma where your plasma reached the electrically neutral and thermal equilibrium system okay. In that system the kinetic energy of all the particles are the same which is equal to 3 by 2 kT, is it clear? Good.

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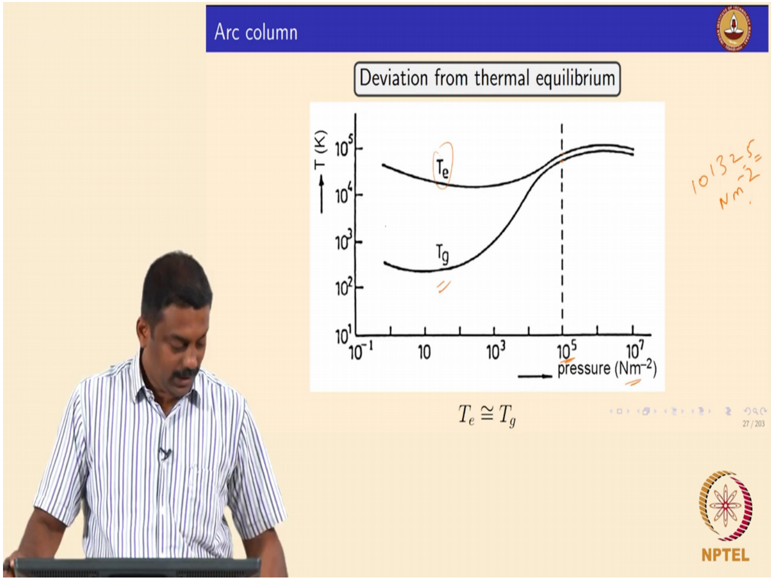

But it is not always the case, right? So you have because of difference in mass the electrons drift more or they travel more because of the mass the drift velocity is also higher leading to the electrons are heated slightly more than the gas in the system, so at one atmosphere pressure the electron temperature are slightly higher than the gas temperature, okay. So what is atmospheric pressure in the Newton per square metre? If you change the pressure of the system, what happens?

The drift velocity of the electrons also change okay, so obviously at lower pressures if you look at it, the electron drift velocity will be much higher at low pressures obviously the difference will increase because the gas… Because of the mass the effect of pressures will be significant when the mass is changed for example lighter mass material would have a high velocity at lower pressure than the heavier mass and that can lead to the change in drift velocity at lower pressures and because of that… So you will have electrons gaining more temperature than the gas ions, so the difference will be significant at lower pressures. Yes, is it clear, any questions?

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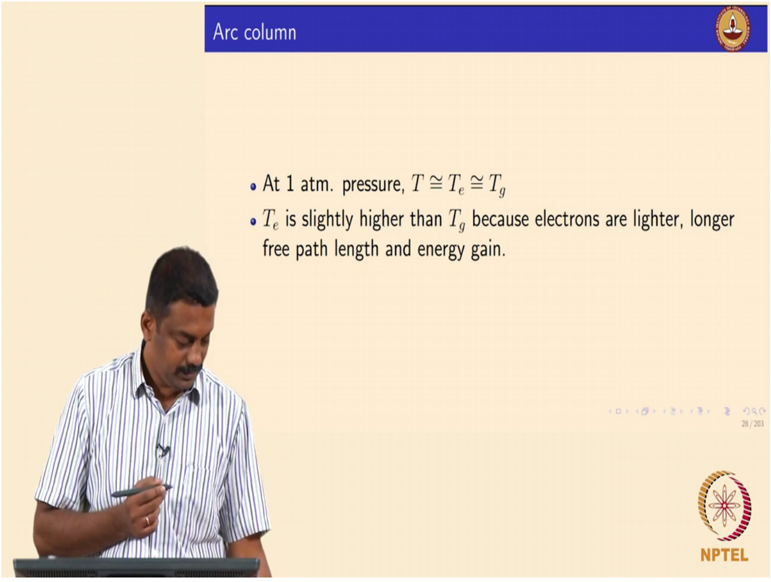

Okay so we will move on further in the arc column? Okay so this is what I explained so at 1 atmospheric pressure temperature is more or less equal but always the electron temperature you should be careful, it is slightly higher than the gas temperatures because electrons are lighter and they have a longer free path because of the high drift velocity, so that they can spend more time and before the energy exchange which is the collision okay so that they are heated up higher, right, is it clear?

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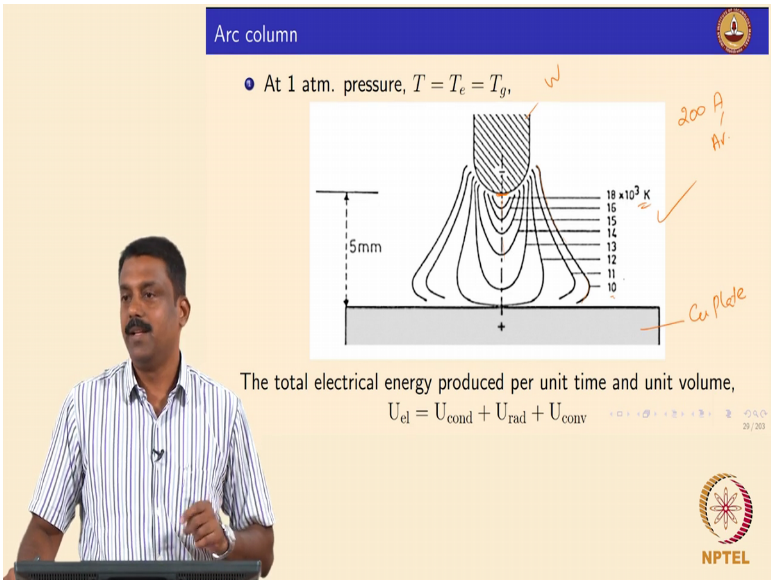

So when you say that there is energy created in the system by the collision of the ions and electrons, so obviously that energy has to be consumed, is not it? So suppose if you want to calculate how much energy is generated? We can calculate that by looking at how the energy spent? Okay so if you know how you spend that energy then we know how much energy is already there before begin with okay. Suppose if you spend all your pocket money in a day, if you know that how much money is spent if you sum up (())(18:59) and you get it how much money you had to begin with, right?

So the same thing when you want to calculate how much energy is generated in arc we can calculate it by knowing how much energy is transferred to the system, so when energy is there obviously the energy is transferred in this case by 3 ways, right? By conduction, convection and radiation, right? So that is how the energy is spent, so by looking at how the heat is conducted from the arc and how it is actually transferred by convection and radiation and we can also know how much energy is created in the system but it is not that straightforward, okay. So this experiment be carried out to look at how much temperature is… What would be the temperature distribution of an arc?

So this is the real experimental data, so it is done using 200 amperes current of a tungsten thoriated electrode okay in argon atmosphere and this anode is copper plate which is water cooled copper plate, so it is fully cooled, so when you look at the temperature distribution typical at one atmosphere okay, so again so at the Centre of the arc the temperature and can go up to 18,000 Kelvin. Someone asked the question in the last class, suppose if you are having a metal electrode here and cathode here is in tungsten and system is exposed to a temperature of 18,000 Kelvin, what it melts? It will not, right you see in real life in gas tungsten arc welding, the electrode tip is stable, right? Why it is not molten?

Student: (())(20:54)

Prof: Yes it is obviously melting point okay, so the temperature we see that the Centre it can go up to (())(21:04) but still you have the tip not molten, right? Because of the formation of the cathode fall zone, so when you say that the arc column starts from in this case cathode fall zone, cathode fall zone is very tiny area 10 power minus 8, 10 power minus 7 that is what you are exposing okay and this tungsten is conducting heat very effectively as well as the exposure is towards very tiny area okay and similarly when you are doing non-consumable electrodes welding you make sure that electrons are moved away that means that electrons carried more heat than ions.

So the heat is carried away by electrons very effectively from the tip which is very tiny already 10 power minus 8, so you do not melt because of the effective conduction as well as he electrons are not reaching the electrodes, the heat is effectively transferred by the electrons okay towards anode in this case, so anode is molten, right? Because the electrons are reaching the anodes which carry the heat, right, is it clear? Okay now if you look at the temperature distribution obviously at the Centre of the arc column the temperature can go up to 18,000 Kelvin. The arc envelope what you call it is the outer periphery is known as arc envelope okay and can go up to 10,000 Kelvin.

So the temperature of the arc is entirely determining by the nature of gas what you have which is forming the arc, why is that? Because the gas determines the ionisation okay, so if you want to understand what is a happening inside the arc and how we generate these temperatures then we need to understand the 1st basic principle of the generation of the charge carriers. Of course the thermionic emission, the field emission they just ignite the arc okay, so they supply enough electrons to the system so that these electrons which are generated from the cathode can trigger now the subsequent sustained discharge which is ionisation, yes is it clear?

So before going to look at the heat balance 1st we need to understand how these charge carriers are created, right? Is it clear? Because that is going to determining the temperature distribution, the temperature is rising from the collision, the heat which is generated in the arc. Yes, okay so first you will understand the basic principle, the basic fundamental process that is happening which is ionisation, right?

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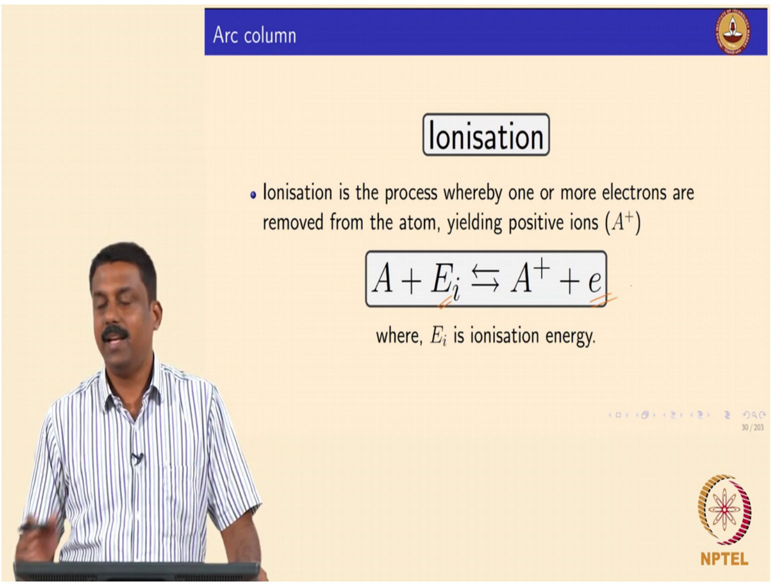

So when you say the ionisation, so what is ionisation? We need to define again, right? It is simple when you say ionisation it is nothing but… It is a process of removing one electron okay from an atom.

In this process you generate an electron right? And the atom becomes a positive ion right? So that does not happen by itself, okay you need to always supply an energy to an atom so that you knock out an electron, same as thermionic emission, in thermionic emission you have work function whereas in here you have ionisation energy, right? You supply an energy which is ionisation energy because you are creating an ion okay so that you knock out electron from an atom okay, so this is the very basic reaction helps in sustaining the discharge.

So you pump up of electrons by thermionic emissions, okay so those electrons subsequently once they attain the energy equal to the ionisation energy then obviously that electron can trigger the ionisation in subsequent reactions okay so if once the electrons which is emitted by thermionic emission they attain the energy equal to ionisation energy then the subsequently knockout subsequent electrons from the shell of gas atom okay, so this election is endothermic or exothermic?

Student: Endothermic.

Prof: Endothermic because you supply energy, right? So this energy is consumed by the atom to release an electron. Yes, is it clear? So Ei again it is a function of the material. In this case a function of gas because Ei can be changed in the composition of the gas or nature of the gas, right, is it clear?

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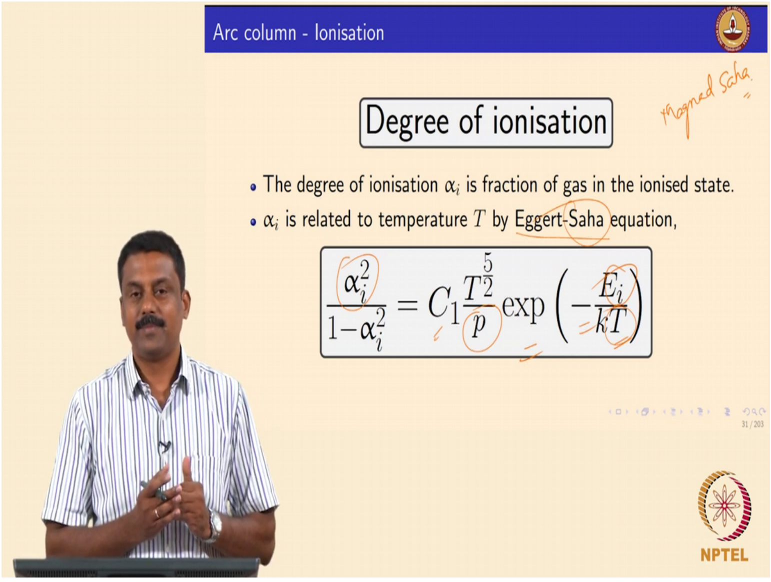

So degree of ionisation, suppose if you want to calculate that much amount of ion you generate at a given temperature you can use this equation it is a very famous equation. An arc is a beautiful star okay, so if you know that what gas you are using it and you know ionisation energy, right? And you get the spectrum, spectrum is not constant, it changes okay from the middle of the arc column to the envelope if you accurately predict the spectrum you can calculate the temperature, is not it? Right, is it clear? So for…

Student: What is p in this equation?

Prof: What could be p here? It is pressure okay so (())(27:42) pressure p goes away, right? So if you change the p the pressure obviously you also change the fraction ionised okay, so it is negligible at one atmosphere pressure but it is not the case, right in arc we can neglect p, arc pressure is based on the curve I showed you already. So if you keep the pressure constant the only thing is going to affect your ionisation fraction, so again Alpha is defraction ionised a degree of ionisation. This is nothing but degree of ionisation over the unionised gas atoms there is a fraction okay, so total or the unionised with the ionised fraction is again this is constant and Ei is the ionisation energy right? So your pressure is constant the only thing it is dependent upon is the temperature or in other words if a gas has high ionisation energy than the temperature should be increased in order to ionised okay, is it clear?

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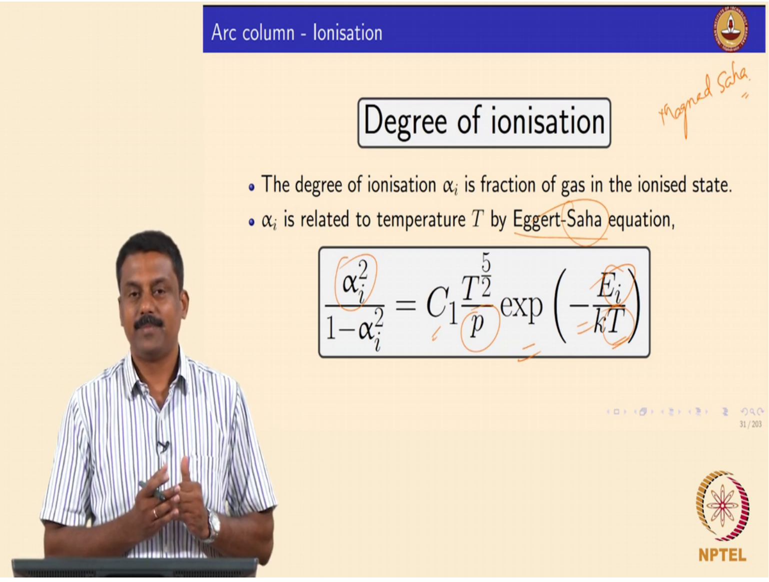

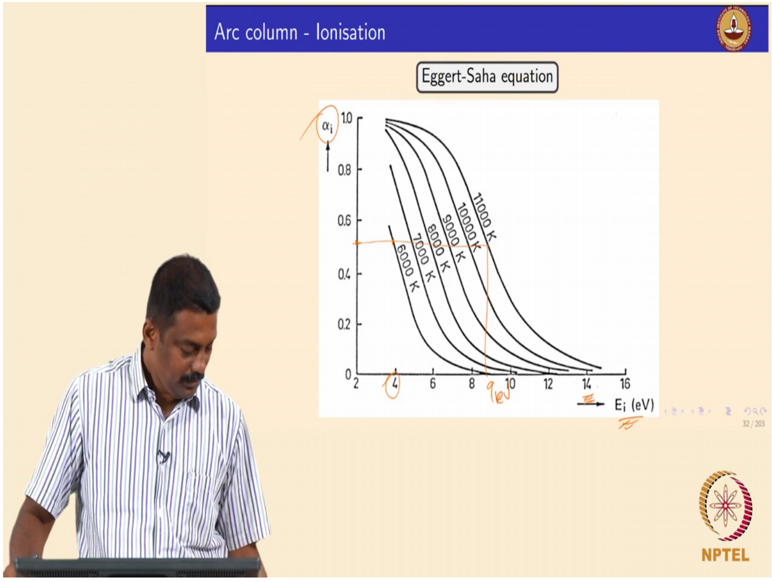

So if you look at the function of ionisation energy as a fraction ionised obviously if you have a very high ionised energy you need to increase the temperature is too much higher than only you can create ions, Sara equations. Sara equation defines the shape of this curve increase the exponential decay okay so that is the exponent here is doing a negative sign here okay so the equation determining the shape of this curve, right, is it clear? If you look at thermionic emission is similar equation, is not it? A T square E power minus work function divided by kT that is also you are emitting an electron, here also you are emitting an electron there it is work function and here is ionisation energy okay.

So the nature of the curve with these exponential decay, the similar is the function of the temperature, is not it? So these curve when you fit it you will get Sara equation okay so this curve when you fit so you will get Sara equation and what this curve says for example if you have very high ionisation energy, if you want to create… for example of the gas atom would be ionised 50 percent ionisation in this case, so you need to increase some around 11,000 Kelvin the gas temperature should be increased 11,000 Kelvin if your ionisation energy is somewhere 9 electron volt okay.

See the gas has a very low ionisation energy obviously you can ionise the half of gas atom at much lower temperature 6000 Kelvin okay. In other words if you say that the heat is emitted in terms of heat generation okay that means that suppose if you are giving an energy to the system obviously when the gas has a very low ionisation energy it also creates low temperature, is not it? Whereas if you ionise the gases with high ionisation energy you also create more heat, more temperature, is not it? It is the same you are, right? So gas is low ionisation energy, can ionise with low temperatures okay. In other words if a gas is with low ionisation energy when they get ionised, the temperatural systems is also low, is not it?

So when you use… For example helium as a (())(32:15) gas helium has the highest ionisation energy okay, so when you use helium as a shielding gas when you ionise helium obviously the system temperature should also be very high, obviously all temperature will also be very high, right? Suppose if you are ionising a metal vapour okay and metal vapour has generally very low ionisation energy, so than the arc temperature would also decrease or it will be very low compared to when you have a system where you have helium or argon for that matter, is it clear? Good so now this curve is clear right, so this is nothing but Sara equation.