Welding Processes

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Electrical resistivity of welding arc

Ok, so we will so move on to the derivation what we have done last class, so we looked at I mean previous classes, the ionization, the effect of ionization, the how do we calculate the fraction ionized in a gas medium and then if use an a diatomic gas, molecular gas so how the dissociation can influence the ionization process because then you will have another endothermic reaction which is which will happening instead happen to supply the electrons and ions, ok.

So by dissociation and the ionization, now the ionization fraction and the dissociation change as a function of temperature and then we derived an important equation which we will also see in this class as well to calculate the electrical conductivity or electrical resistivity of an arc, ok this very important derivation because the heat generation in determined by the resistant to the motion of the electrical charge carriers is not it, so more the resistance so obviously high heat is not it, it is like an a normal conductor, ok.

So if your resistance is high, so obviously you collide or you dissipate more energy because of the mutual collision will be much higher is not it, say we looked at the first equation to begin with is to balance the electrical (cur) charge, ok of an arc, is not it.

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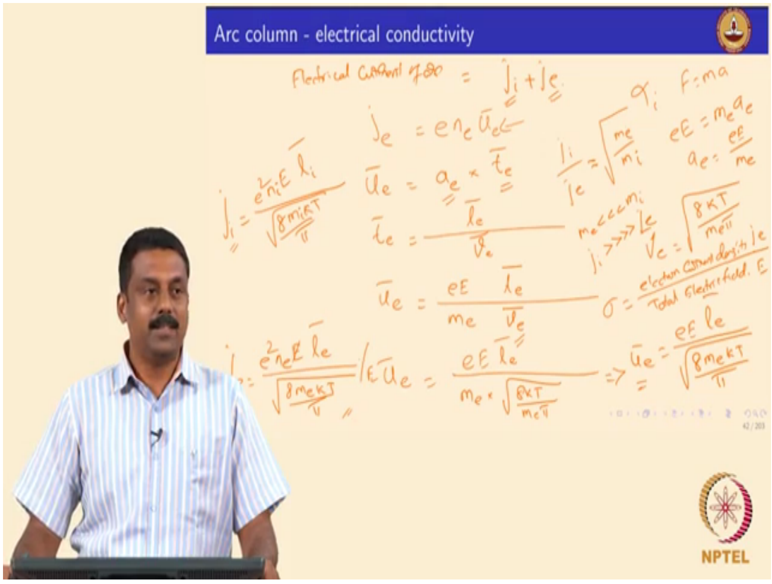

The total electrical current of an arc if you see that, so what we do it to the electrical current of an arc is nothing but the ionic current and then electron current is not it, so electrons would travel from the cathode to anode, the ions will travel from anode to cathode, ok. If you provide resistance to this path obviously that mean is that they are collide into each other and they will drift after the collision and if they completely stopped obviously that mean is that the entire energy will be dissipate there itself is not it, that mean is that the resistance is so high you will end up producing enormous amount of energy at that spot.

So by knowing how difficult the path of the electrons and ions then we can also calculate how what is resistance of the arc? That determine the heat generation in principal is not it, so the deriving the electrical resistivity or electrical conductivity of an arc is extremely important because from that we can also calculate the heat generation is not it, so how do we conduct, how do we calculate the heat generator in a simple conductor? What is formula?

Student is answering:

i square.

i square r, is not it. So once you know the resistance of a conductor obviously you can generate how much you can calculate how much heat is generated, ok. In other words in this case we are going to calculate the resistivity (resist) with the of an arc, ok that determines again the how difficult the path of electrons and ions in this arc, more the (difi) more difficult to the path obviously then the collision will be higher is not it, then what is the result of that then the heat generation will also be higher, is not it.

So that why that is why this sequence is extremely important and we will use this derivation in the various welding perspectives. So for example if you want to calculate the efficiency, what is efficiency again? How much amount of arc energy is transferred to the work piece? Again if you want to know the efficiency then you need to know how much energy is actually generated is not it in the arc.

So generally you can calculate the efficiency of the process, so we will always use when you are doing a heat input calculation we use the efficiency but then efficiency should be calculated from this fundamental derivations, ok. So it is very simple derivation what I showed you how to calculate the electrical conductivity. So what we have done we just balanced the flow of ions and currents, so if you add together obviously that is the electric current of an arc.

So now we calculate individually j i and j e, ok j i it is amp ampere per square meter, right per square meter area, so it is nothing but what we have done the electrical the charge of an electron and the number density of electron, ok again number density of electrons how do you calculate? How do you calculate the number density of electrons?

Student is answering:

Average disturbance.

From

Student is answering:

Average disturbance.

No, from the saha equation, ok so in saha equation give you the fraction ionized, right is not it. So fraction ionized what is that? Amount of electrons you generate or ions you generate 1 minus electrons, is not it. So n e we can be calculate later from the saha equation and then if you the multiply with the drift velocity, average drift velocity is extremely important does not matter whether it goes this side or this side after a collision, so the average is very important, ok.

So average drift velocity, if you multiplied with number density times the charge of electron so that is the total ionic current, a total electron current sorry is not it. So now from this equation we can see that if the (dist) velocity is higher that mean is that the collisions are lower, if velocity is higher obviously current density will be higher, the electrons can easily move, so then obviously you can also calculate the current generation will be lower, is not it.

So if (dist) drift velocity is higher that mean is that electrons are collide into each other, ok or there will be a close to perfect collision is sustain that drift velocity upon collision is decreasing that mean is that, the energy generation will be much higher is not it, so that is the simple logic of this equation, so when you say that drift velocity again drift velocity can be calculated between the acceleration times, the time between two collisions is not it.

So that is what if acceleration is higher obviously, so then the time between collision will also be higher or lower?

Student is answering: (())(06:44)

If it is accelerating much faster that is means that it is not colliding frequently is not it, so suppose if you want to calculate the average drift velocity we need to multiplied with acceleration, ok times time between the collisions is not it, so this is meter per second square time second millimeter per second that is the drift velocity. But acceleration how do you calculate acceleration? So we will have to transfer this equation into the quantifiable entities you cannot the calculate the acceleration of the electrons or ions in arc medium is not it.

Similarly the time between collisions also very difficult to find it out, so we can convert that into more quantifile quantifiable variables, ok that is the purpose of transferring these two terms into the energy the electric field and the thermal velocity is under mean brief part that can be calculated from the basic equations is not it, right. So now then we replaced the acceleration, so how do we replace acceleration? Very simple, so equation is F equal to m a is not it, right and F is nothing but so that is the electric field you apply is not it, the electric field you apply times the charge the elementary charge of an electron, ok so then this must be equal to the mass of an electron times the acceleration of the electron.

So now we can replace the acceleration of the electron into by m e is not it, yes so this equation we can replace the acceleration into the energy terms on mass terms which are quantifiable because heat you apply, heat is the one you apply the electric field in the circuit, mass of an electron, it is known entity is not it. So now similarly we are also derived another relationship for time between two collisions and time between two collisions, how do you derived? Is.

Student is answering: (())(09:04)

The mean free path of an electron, ok so that is the average mean free path of an electron for a given temperature you can calculate that is not it , divided by.

Student is answering:

Thermal velocity.

Thermal velocity, the average thermal velocity, right. So average thermal velocity that is your the time between collisions sorry, right. So now you have relationship between seconds meter per second meter meter cancel outs you have seconds, so that is your time between two collisions. So now we calculate the drift velocity is nothing but you have E divided by m e is not it and then time is time between two collisions is nothing but l e divided by v e, yes it is simple right ok.

Now we have a relationship for v e that is what I asked you to derived in the last class, the average thermal velocity of an electron is a function of temperature very simple relationship, ok so that is luckily all the fundamental physicist from early 20th century they derived for us is not it, ok so we should be thankful for them. So v e is nothing but thermal velocity is 8?

Student is answering:

kT.

Boltzmann, right is not it. So now we can replace v e with this equation, so now what will happen? Is u e E l e and then m e times square root of 8kT divided by m e pi, so m e goes inside into m square m e square, right and m e m e cancels out and then u e becomes divided by 8m e kT divided by pi, yes it is clear so now we have the equation for drift velocity of an electron, right under an electric field right.

So now if you use this u e in this equation now we have the electric current l e the current density by electrons is not it, so that will be, so e times there are other an already e right, so e becomes e square n e number density of electron, ok and then you are applied electric field and then l e is not it divided by square root of 8 m e kT by pi it is clear, yes or no, ok. So now we have the relationship for the electron current density, so the ampere per square meter, similarly the same thing can also be derived for ion is not it and everything is a same, the same thing can be derived for ion as well.

So again the electron charge number density of ion, the applied electric field, mean free path of ions divided by square root of 8 mass of an ion kT by pi, there are the same it is also fundamental particle, it is a charge particle, right is not it. The same derivation can also be derived for the ion density as well is not it, you guess the same charge carriers the velocity thermal velocity of particle it is the same as an electron.

If you look at these two equation, ok the electron density or ionic density is fully determined by temperature is not it because the n e and n i when a deionization is happening it is the same is not it, the number density of electrons and ions e is a same, ok. Mean free path is more or less the same at a given temperature, ok. So the important factors that determine the field the electric current in the arc is temperature, the other important thing is here if you divide j i by j e, so assuming that mean free path is the same and this will become, sorry is not it, yes or no.

Student is answering:

Yes.

Yes, so if you divide j i by j e because all of the them they are almost same assuming that mean free path is a same j i by j e equals to square root of m e by m i, so we all know the m e is much less than m i because the mass of ion a e is an atom close to an atom electrons compare to the ionic mass is negligible is not it, so if that is the case then j e must also be much bigger than the ionic current is not it, according to this relationship what we derived? Is not it, it is clear.

So we derived the electron density and ionic density in an arc, the current density is inversely proposal to the mass square root of the mass, so if you divide j i by j e obviously it must be equal to square root of m e by m i, we know that name the mass of an electron is much less than the mass of an ion, therefore according to this relationship j i the electron current must be much greater than the ionic current of an arc is not it, that mean is that the entire current flow in arc is determine by only electron current, right.

So that mean is that the entire heat generation is determine by the flow of electrons is not it, so we can safely neglect the ionic part, so when you are doing calculation because the mass of an electron is much little tiny compare to the in atoms mass, compare new york comparing elephants and the small orange is not it. So if you look at this relationship the entire current flow in arc is determine by the flow of electrons, right.

So we can safely neglect because of the mass effect, the ionic density can be safely neglected, right. So now we can derive we can safely say that the electrical conductivity is how do you calculate the electrical conductivity from the electron density is nothing but suppose if you want to calculate the electrical conductivity sigma is nothing but the electron density divided by it is total electric field, ok that mean is that j e divided by E, so that is the conductivity right.

Conductivity is nothing but j e that is electron density in an arc because j i the ionic density can be neglected because of the mass effect, ok. So you will you can do the calculation but it will be 10 power minus few fractions phi 100 according to this equation, ok. So the (ele) electrical conductivity of an arc is nothing but j e divided E, so this equation if you divided by E then E goes away and this becomes sigma, so that is the electrical conductivity of an arc, 1 by sigma is.

Student is answering:

Electrical resistivity.

Electrical resistivity, so if you do (())(19:12) this equation, then it becomes electrical resistivity, wow happy. Now we have arc, we can calculate now, ok if you know the resistivity obviously we can also calculate the resistance, if you know resistance obviously we can calculate the voltage is not it, if you know u e and if you know voltage and current we can calculate?

Student is answering:

Heat.

Heat is not it that is what, so this how we can calculate the heat generated in the arc, it is clear is not it, ok good. We will look at the slide again, if you have any question please let me know, right it is clear.

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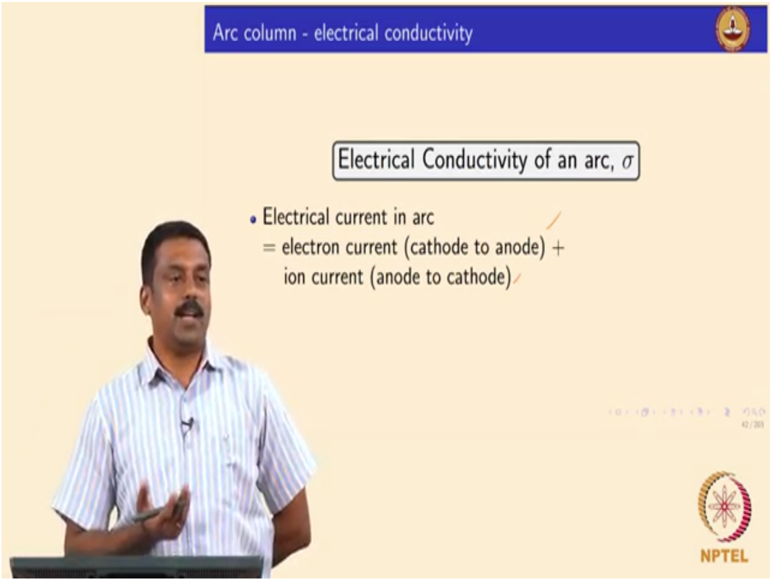

So we will just quickly look at the derivation again, so electrical conductivity of an arc, how do you derive that sigma? So electrical current is we can assume that it is a total current, the electron current plus the ionic current, electron would travel from cathode to anode and ion would travel from anode to cathode. So now we are deriving the equation for the electron current and the ion current.

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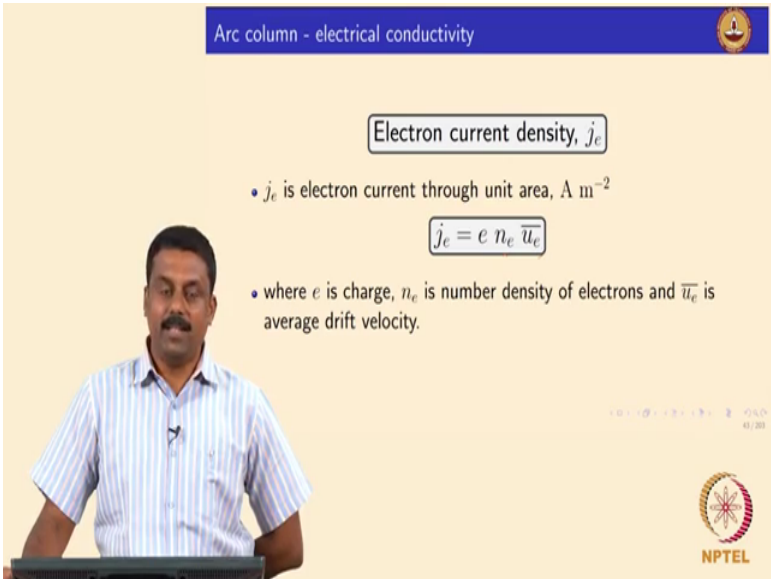

So electron current is nothing but e times the number density and then drift velocity, number density can be calculated from saha equation, ok that gives the amount number of electrons percent is not it, as a function of temperature and drift velocity we even do not know, so we will have to derive many an expression for drift velocity, ok.

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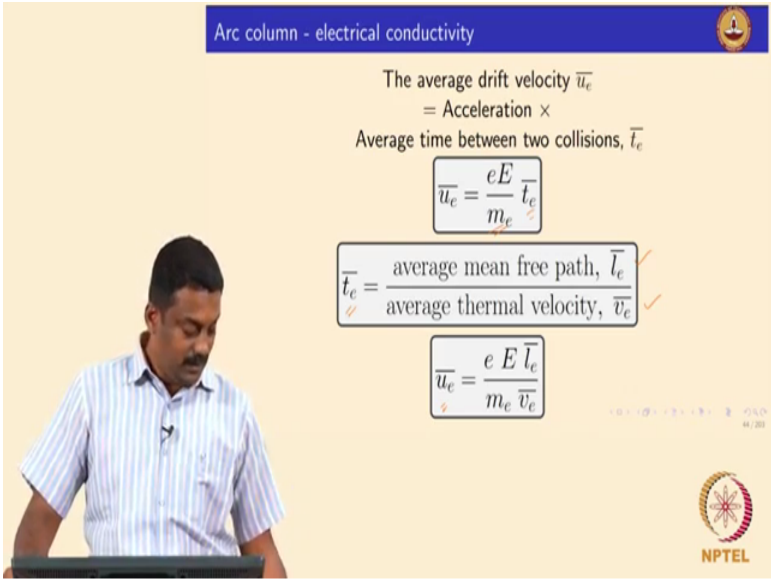

Drift velocity is nothing but acceleration times the time between two collisions is not it, acceleration again we do not know, so we will have to find some expression for that f equal to m e, f is here is the electric field you apply, ok so that is times u e the electric charge that gives the force is not it and force equal to m e, so m e is nothing but force divided by mass that is what here, ok.

The times the time between two collisions, so we do not know time between two collisions as well right, so that can be either converter into mean free path divided by thermal velocity, right. So mean free path is l e by thermal velocity and that is expression for the average drift velocity.

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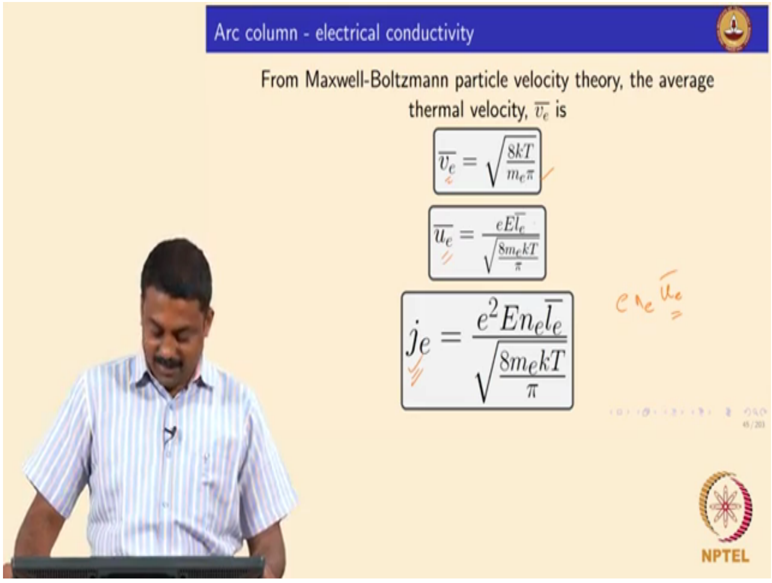

So once we know the drift velocity and we also know that the thermal velocity is square root of 8 k T by m e pi that is the average thermal velocity, so now we have the predictable means of the expressions, ok so we already converted all the variables into the predictable variables. So now if we can replace the (the drif) thermal velocity into this square root of 8 k T by m e pi then we have the expression for the average drift velocity.

So nothing but e times the field, the mean free path of an electron divided by square root of 8 k T by m e pi. So now the electron current is e times n e times drift velocity is not it, so he replace u e with this expression you will get the expression for the electron current in an arc, ok. This is very simple derivation, ok it is not even plus two physics, good.

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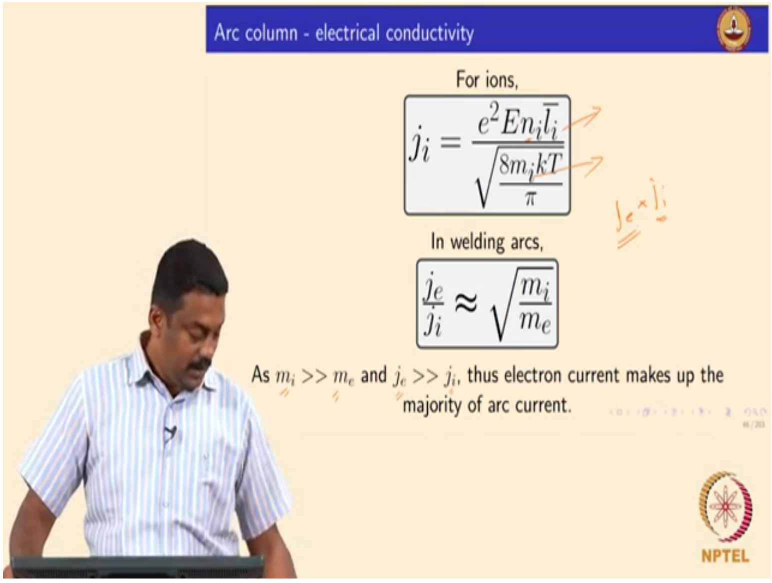

So similarly we also derived for ion, we replace n e with n i, number density of ions, ok then the mean free path of ions, mass of an ion, ok. So assuming that the mean free path of ion and electron is the same, ok so if we divide j e by j i so obviously it becomes square root of m i by m e or other way around, does not matter, right so that is the basic expression, understanding we can have from this derivation, the understanding what we have easy if divide these two obviously mi the ion mass is much higher than electron mass, ok.

So because it is an ionize is an once electron less than an atom, ok where as an electron is nothing compare to an atom, so the mass of an ion is much higher than the electron mass. So obviously according to this derivation if this is the case, ok the electron current will be much higher than the ionic current even if you use the total electric current j e plus j i, ok and this is negligible could be 10 power minus 23 or so, there is no point in using that, ok so the entire current is determine by the j e, ok the electron current.

So therefore we always assume safely when you doing the calculation for heat generation the ionic part is neglected. So we will always use the electric current part, the electrons determine the heat generation that is rate controlling, ok it is good. So we can always safely say that the electron current makes up the majority of arc current, we can neglect safely the ion current, ok.

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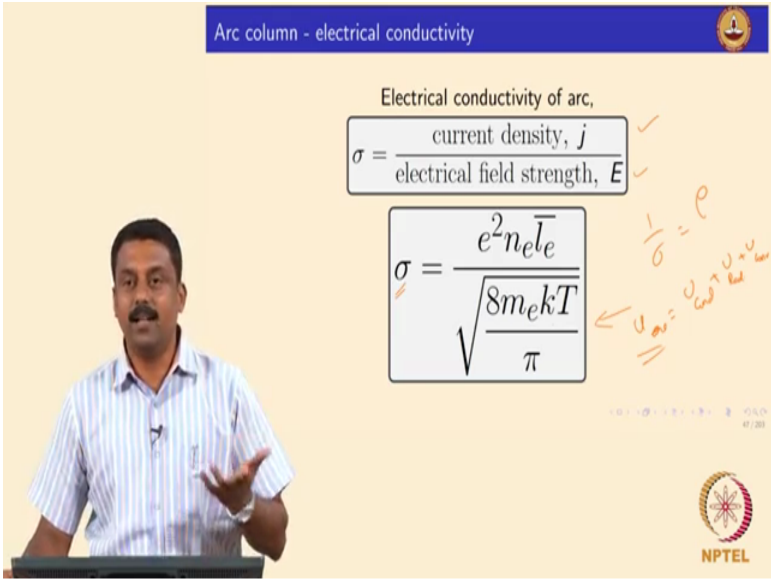

So once we know the expression now the conductivities, current density, the total current density where we can even still keep j e plus j i but again j i is negligible we can take it out, by the field strength E, so that is what conductivity of an arc, ok. So if there is a case the electrical conductivity of an arc, so we give the expression for j E, the E goes out in j E and this is expression to calculate the electrical conductivity of an arc and 1 by sigma is.

Student is answering: (())(26:03).

Resistivity, right that is it. So now we can do the welding, right if we safely calculate the heat, ok now we can ignite the arc and then we can calculate but then there is one more trick before going to the welding process. Now we have the heat generation but that is transferred through conduction convection radiation, right. But now we have to understand whether all the heat we generate it is effectively transferred, ok so then it is 100 percent efficient process but it is never the case unfortunately in most of the cases we lose whatever heat you generate by this equation, ok it is not transferred properly.

So now we need to have a balance, suppose if you calculate the arc energy, ok so that is u conduction radiation, u conduction, right that we saw in previous class, this u can calculate here but then how much heat transferred by conduction convection radiation, so that determine the efficiency of the process, ok. So now we will see in subsequent slides how the conduction convection radiation happens in the arc, ok.

So then in subsequently when you look at in each process the conduction convection radiation can be different for example in submerged arc welding he completely shield the arc by flux that mean is in the radiation heat loss is almost negligible, ok. In some processes they also melt this consumable and deposit to the best material like an g m a w process that mean is that heat require to melt the consumable it is again transfer to the work piece, where as in a non-consumable welding process like g t a w gas tungsten arc welding whatever heat is used to heat it consumable or the electrode it is not transfer, it is getting wasted is not it, that means the efficiency goes down, so each process base on the it is characteristics the efficiency change, ok.

So we will see one by one but you are looking at the process how we can use the this equation to calculate the efficiency of the process, ok. So if you look at the electrical conductivity and we can calculate this equation very beautifully.

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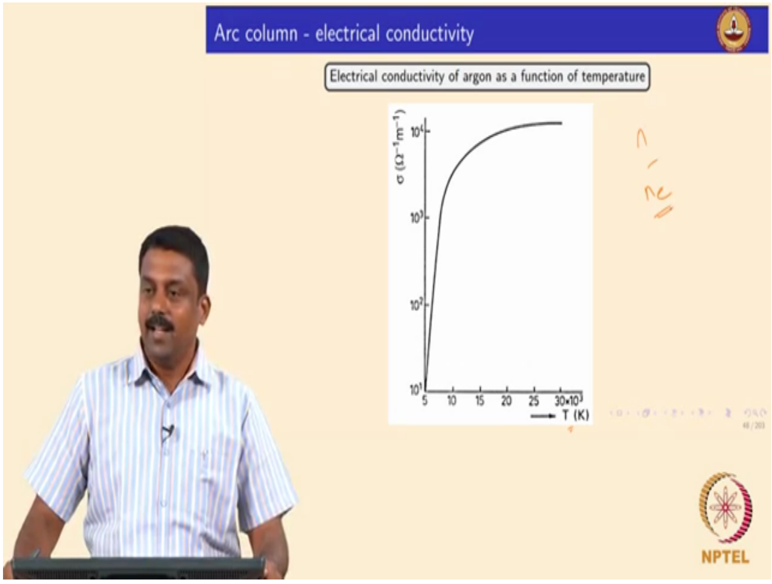

For example this curve shows the electrical conductivity of an organ as a functional temperature, ok. So obviously at lower temperature you are still ionizing is not it, so the ionization is still continuing and upon increasing temperature the ionization saturates that mean is that n e saturates is not it, upon increasing temperature sufficiently, so obviously the conductivity increases, so once the temperature increase sufficiently if n e becomes saturated, so then conductivity approaches at a constant value, right it is clear, is not it. So n e is a functional temperature, saha equation when temperature determines n e from saha equation, right.

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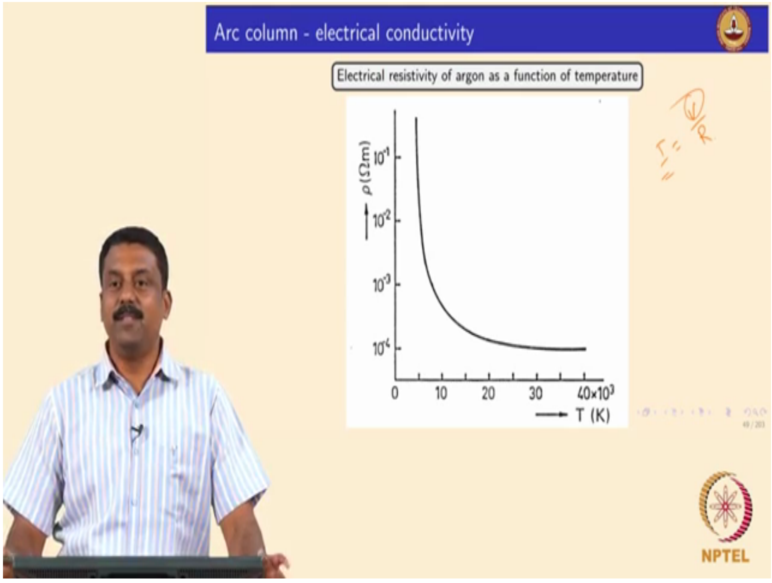

So once you know that we can calculate the conductivity and if you reciprocate, it becomes resistivity is not it, so once you know the resistivity obviously you can calculate resistance and then I equal to again I is nothing but your e the field strength, what is depth is V, we can calculate and then the entire heat generation is nothing but V by I sorry V times I. So now we have an expression to calculate the electrical resistivity of an arc, right it is clear, good, from the fundamental physics.