Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part – 2

Module – 16
Electrochemical Machining Processes (ECM)

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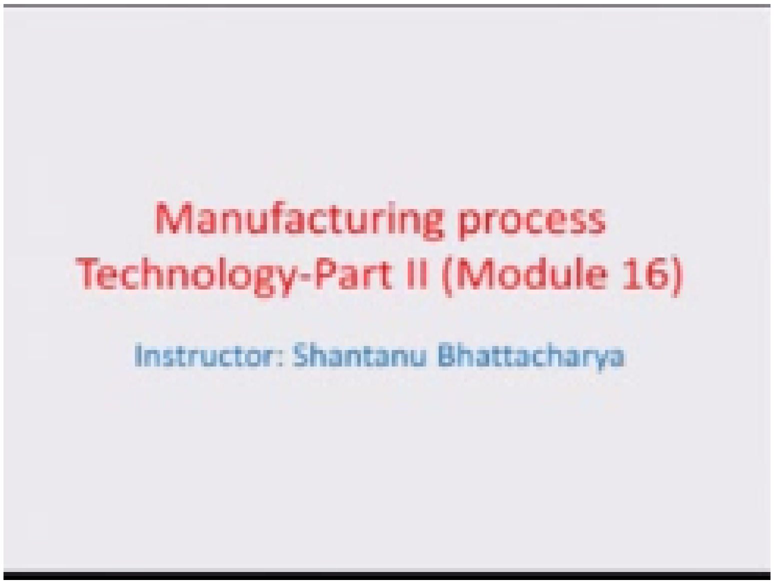

Manufacturing process Technology-Part II (Module 16)

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Hello and welcome to this manufacturing process technology part 2 modules 16; we will be discussing all together the new advanced machining process today which is the ECM or the electro chemical machining. So this process electrochemical machining is typically you know it is you can you can call it the reverse of electroplating which is a very common process used in the industry and here the idea is that you have a read a red ox reaction because of which there is a deposition of one kind of material on the surface and alternately the taking away of another kind of material.

So the material because of electron flow maintained outside the flow cells of the electrolytic cell is basically dissolved in one side and deposited on the other side. Now think of it that in this electrolysis process if the material were to be dissolved on one hand but somehow be precipitated. So that it does not get deposited on the other electrode then it would be a machining process typically.

So that is how electrochemical machine a machining is realized and there are a lot of modalities associated with this process of electrochemical machining it is a die sinking process, so whatever is the shape or size of the electrode it would create just a negative map of itself on the on the surface that it's machining. And so you can you can consider this to be a die embedding in nature or you know the dye gets embedded into the surface when we talk about the material removal through electrochemical means okay.

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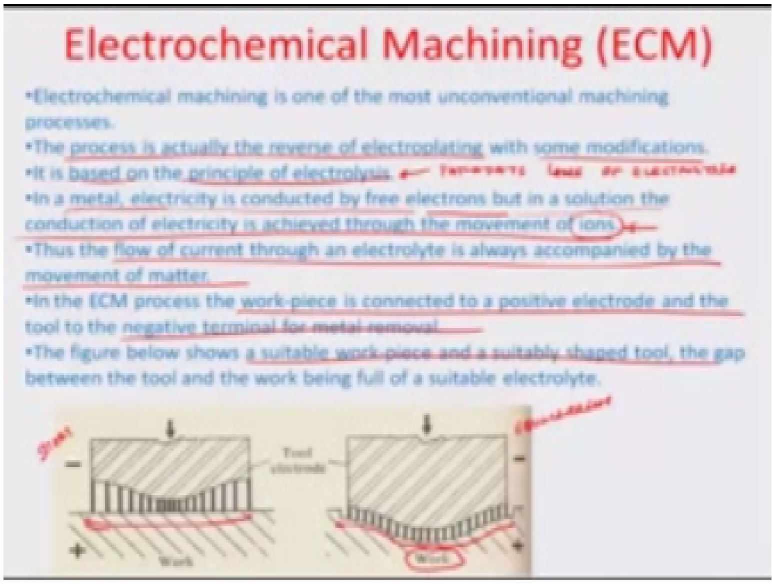

Electrochemical Machining (ECM)

- Electrochemical machining is one of the most unconventional machining processes.
- The process is actually the reverse of electroplating with some modifications.
- It is based on the principle of electrolysis. ← FARADAY'S LAWS OF ELECTROLYSIS
- In a metal, electricity is conducted by free electrons but in a solution the conduction of electricity is achieved through the movement of ions. ←
- Thus the flow of current through an electrolyte is always accompanied by the movement of matter.
- In the ECM process the work-piece is connected to a positive electrode and the tool to the negative terminal for metal removal.
- The figure below shows a suitable work-piece and a suitably shaped tool, the gap between the tool and the work being full of a suitable electrolyte.

So in brief the electrochemical machining you know is a process which is the reverse of electroplating with some minor modifications I am going to talk about that in great details there based on principles of electrolysis and this typically comes under the ambit of Faraday's laws of electrolysis. So we will try to estimate the material removal rate using some basic principles of electrolysis and Faraday's laws that has been suggested probably almost one century back.

So in metal electricity as you know is conducted by free electrons and typically the conduction and the valence bands have more or less overlapping energy levels but in the solution the conduction of the electricity is attained by the movement of ions okay. So these are free moving objects there can be negative ions there can be positive ions where typically it is one electronics s for one electron deficient or even multiple electronics sand multiple electron deficient depending on what is the valiancy that is there in the in the solution.

So all the charge across solution is typically carried by the ion movement, so when we are talking about a solid which is in interface with such a liquid you have to understand that the problem which lies there in the basic physics is that on one hand the charge carriers are the electrons and the holes which are bound to the to the orbital's or bound to the nuclei which are participating to formulate the solid bond together. And on one other hand on the other hand on the solution side it is basically the ion transport which happens.

So there has to be a balance between two different completely different physics which is involved in transportation of ions visa via transmitted transportation of the electrons and holes within with in solid. And so there has to be a interplay between the iron transport processes of the solution and the anti solid and that is what makes this whole electrochemistry very interesting where there is a formation of some kind of a dual layer across which this transverse charge transportation takes place and we will do in details about all that theory when we talk about iron transport equations okay.

So the flow of current through an electrolyte is always accompanied by movement of matter and in an ECM process the work piece is connected mostly to the positive electrode tool to the negative terminal. So the idea is that the electrode of the work piece would be responsible for sending out the ions to the solution and if we can somehow be able to precipitate those without getting deposited onto the tool side we are left with a process which is subtractive in nature or a machining process as such.

Figure below shows a suitable work piece and a suitably shape a tool and you know you can see that this is the start of the process, so this is the beginning of the process and this is how it looks as the process goes to equilibrium okay. So you may have a question as to why it is a die sinking process or in other words the flat surface here on the tool has been converted typically the negative shape of the tool surface. So here is the answer to this kind of a query.

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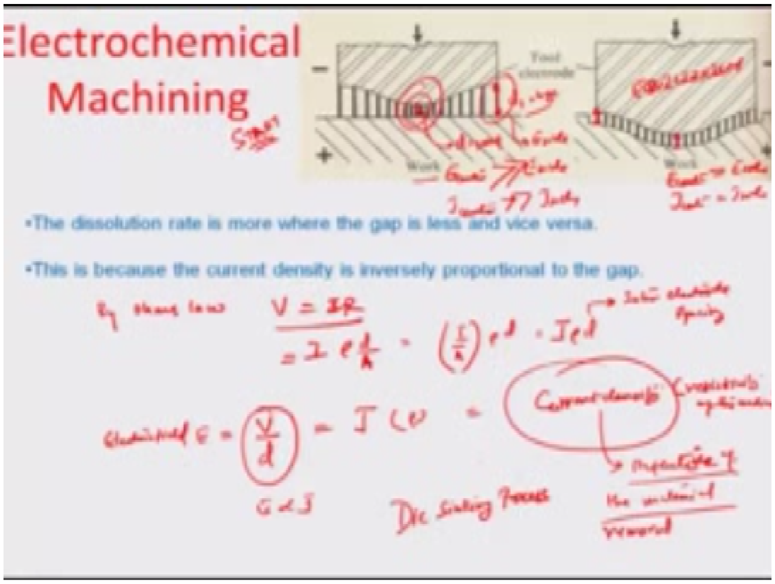

Electrochemical Machining

- The dissolution rate is more where the gap is less and vice versa.
- This is because the current density is inversely proportional to the gap.

So if we look at the Ohm's law which takes place even in solution just as it takes place in solids okay, obviously the conductivity levels are very different in solution as opposed to solids the conductivity is too high in solids you know in comparison to that in solution. So by the Ohm's law the voltage V is represented through the current I times the resistance of the flow path of the charge in this case the flow path is the solution.

So we are talking about the solution as a flow path of the charge, so if I were to consider the resistivity and the resistance in terms of the resistivity ρ. So we can say that resistance is ρ times of the distance of separation D divided by the area of the interface you know, so if the electrons are the current is transported in a vertical direction let us say from the cathode to the to the anode side okay.

So the interfacial area is really the area of the of the work piece which is being exposed to such an electron flow in the perpendicular direction to the path of the electrons or to the flow of the electrons. So I would say that V becomes equal to I x of ρ and d / a. And in other words we can call this as I / a x of ρ d I / a is the current density and we have resistivity here times of the distance of the inter electrode spacing okay.

So this is the distance of the inter electrode spacing, so if I am wanting to find out what is the field across this gap so the field would definitely be equal to the voltage per unit length or the potential difference per unit length so that is how the electric field is represented? And so in this case the electric field would be written as j x of ρ okay, our electric field is equal to the current density current parent area times the resistivity of the medium.

So obviously if I was to look at this shape at the start of the process and we have different values of D let us suppose in this particular case we have a D which is very close to the work piece okay. So let us say for instance this particular distance D is small okay on the other hand the distance D here let us call it D one is quite large okay. So obviously the electric field at the center here would be more in comparison to the electric field at the side.

So if the electric field e at the center here let us say is E you know at the center and this is let us say the electric field at the side, so obviously the center is much larger in comparison to the e side. So obviously the current density which is also sort of you know reflective of the material removal would actually be higher at the center, obviously as you see here the electric field E is proportional to the current density, so at the center obviously the elect the current density would be much larger in comparison to that at the side so therefore the material removal would be much higher at the center in comparison to the side.

Which is what is visible in this equilibrium case so after some time when equilibrium happens you can see that you know the field has almost equalized whether it is center or side the field is more or less same here, as opposed to hear so E Center is actually equal to E side okay in other words the current densities are same okay, so that is one of the reasons why there is an inverted shape of the tool which is imprinted upon the work piece when we are talking about electrochemical machining.

And typically that is the reason why this kind of process is known as a die sinking process, so let us learn a little more about.

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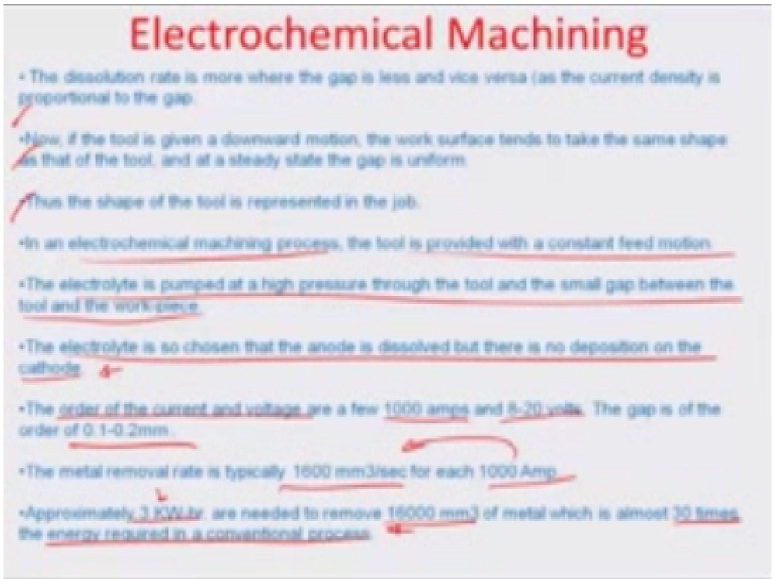

Electrochemical Machining

- The dissolution rate is more where the gap is less and vice versa (as the current density is proportional to the gap
- Now, if the tool is given a downward motion, the work surface tends to take the same shape as that of the tool, and at a steady state the gap is uniform
- Thus the shape of the tool is represented in the job.
- In an electrochemical machining process, the tool is provided with a constant feed motion
- The electrolyte is pumped at a high pressure through the tool and the small gap between the tool and the work-piece
- The electrolyte is so chosen that the anode is dissolved but there is no deposition on the cathode
- The order of the current and voltage are a few 1000 amps and 8-20 volts. The gap is of the order of 0.1-0.2mm
- The metal removal rate is typically 1600 mm3/sec for each 1000 Amp.
- Approximately 3 KW-hr. are needed to remove 16000 mm3 of metal which is almost 30 times the energy required in a conventional process

Electrochemical machining the electrochemical machining process comprises of a tool which is provided with constant feed motion obviously, this part I have already made clear that how it is a die sinking process and work piece assumes the same shape as that of the tool. so the electrolyte is pumped at a high pressure through the tool and a small gap between the tool in the work piece the electrolyte is so chosen that the anode is dissolved but there is no deposit back on the cathode so that is how it is a micro machining or a machining process.

Whatever is dissolved goes as a precipitate that is carried away by the circulating electrolyte and the order of the current and voltages in this particular case are about 1000 amperes for a kilo amp current and a 220 volts and the gap is of the order of about close to 100 to 200 microns the module removal the metal removal typically is about 1600mm^3 /s for each one kilo ampere current it is actually an energy intensive process if we talk about mechanical vis-a-vis this form of energy.

But you have to understand that the reason for non conventional processes is because you talking with tough materials like tough alloys on one hand another is that you are also trying to make as complex geometry as can be possible and sometimes with conventional machining that that capability may not arise okay, so approximately 3kw hour power is needed to remove about 16,000$\text{mm}^3$of metal and there is about 30 times the energy required in a conventional process so it is almost 30 times more expensive in terms of energy utilized when we talk about electrochemical machining.

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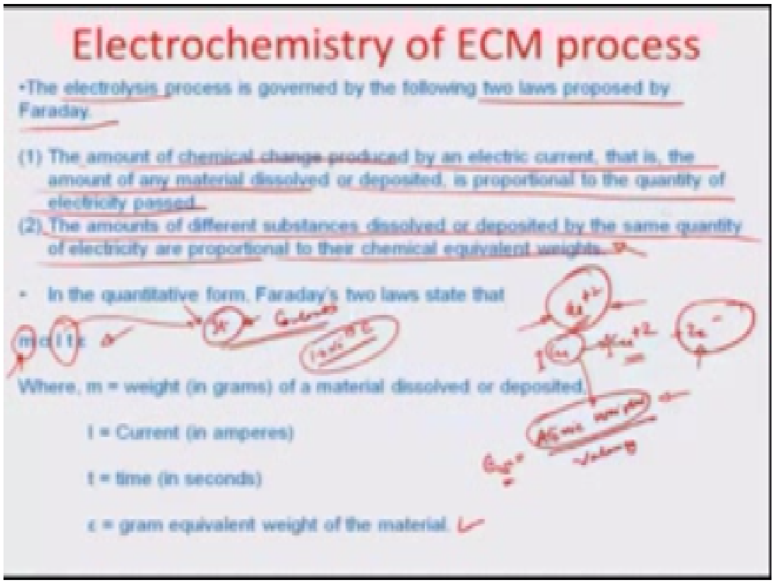

Electrochemistry of ECM process

- The electrolysis process is governed by the following two laws proposed by Faraday.

(1) The amount of chemical change produced by an electric current, that is, the amount of any material dissolved or deposited, is proportional to the quantity of electricity passed.

(2) The amounts of different substances dissolved or deposited by the same quantity of electricity are proportional to their chemical equivalent weights.

- In the quantitative form, Faraday's two laws state that

$m \propto I t \varepsilon$

Where, m = weight (in grams) of a material dissolved or deposited

I = Current (in amperes)

t = time (in seconds)

ε = gram equivalent weight of the material.

So let us look at approximately how this electrolyte flow would happen in conventional electrochemistry electro chemical machining system, you have a tool which flows the electrolyte from the center to the sides okay, so there is a nation and a flow of the electrolyte from the coaxial center of this particular tool and it goes and you know it spreads across the work piece and then tries to escape from the gap between the work piece and the tool there are installations which are put in

To ensure that you know you do not get a taper which is a major problem in ECM sometimes there is a splashed electrolyte and it creates lot of defects as I will be explaining in great details later on and typically this tool needs to be at a constant feed motion, so that once the equilibrium gap is established between the tool and the work piece you know the motion and the way that the surface recedes or the work piece surface recedes a sort of equilibrate to each other okay so that is how that is why it is called equilibrium gap.

And obviously the work piece needless to say is made the anode and the tool made the cathode and a low-voltage high-current DC supply is used for feeding the process, so with the ECM the rate of metal removal is independent of the work piece hardness so you can go as hard as possible on the material front and still be able to do machining which is may not be the case in case of mechanical removal ECM becomes advantageous when either the work material process is a very low machinability.

Or the shape of the machined item is very complex I have already discussed about, very limited there is some tool where but practically very less tool where tool where what is whatever is here is mostly because you know there is some kind of warping you can think of the gap between the tool and electrode to be too small where there is obviously a velocity head at which the electrolyte flows and, so there is some kind of a electrolyte pressure which creates a tool deformation in any event.

You have to choose the parameters in a manner so that such deformation does not go anywhere that kind of a pressure which is generated does not go anywhere near the ultimate yield strength of the material where there may be warping in the tool etc. Which is happening which happens so this is a very critical situation to be looked at or a critical design aspect to be looked at whenever you are designing electrochemical micro machines, okay but as of now we are more concerned with the process at the macro scale in totality.

So we will probably keep this towards the later part of the lecture when we will talk about how pressure and stresses ultimate real stresses need to be equalized for designing the velocity at which the electrolyte needs to flow between the tool and the work piece, so this is basic theory about electrochemical machining let us now get into the physics of the machining process and try to estimate the material removal rate so as I earlier described the governing laws for this electrolysis process typically the two laws proposed by Faraday.

The first law says that the amount of chemical change produced by an electric current and that is the amount of any material dissolved or deposited is proportional to the quantity of the electricity that is passed and the second law says, that the amounts of different substances dissolved are deposited by the same quantity of electricity are proportional to their chemical equivalent weight so I am going to come to this what chemical equivalent weight means graham way, so in quantitative form obviously.

The mass which is deposited is a function of the current time product which is the amount of charge which flows in so here the argument that is provided is supposing there is exactly one mole of univalent time which is deposit or dissolved into the solution, exactly one mole of charge should flow from the anode to the cathode to keep external charge balance okay and so therefore the quantity of charge that is involved there is obviously, going to define how much mass is going into the solution so the other important issue here is the gram equivalent weight of the material so the gram equivalent weight of this material is basically the atomic weight divided by the valiancy of the particular ion.

So if I am talking about let us say the Cu + 2ion okay, q + ion then the atomic weight of copper / 2 would be the equivalent weight of the copper okay + 2ion so that is how the equivalent weight is mentioned so if I were to look at this equation the logic is standard lying logic is very simple that the amount of charge that is involved or the charge transport that is involved is really the current time product, so this is actually the number of coulombs right which is flowed and supposing if I wanted to have the Q + ion to be balance.

So in order to generate cuprous ion out of copper, you exactly give out two electrons right. So somehow if this factor can we put in the number of available charges, available here are so many coulombs okay so if I wanted to multiply this by the number of electrons.

For example I know that in one electron the total amount of charge that it carries is let us say 1.6 x 10^{-19} coulombs okay. So if this is the electronic charge that is there, so how many moles of electrons are available in this Coulomb would actually be another you know term which is known as the faraday constant okay. So charge of one mole electrons, so in a way I am trying to see whether what is the availability in terms of number of moles and I know that1 mole of charge exactly coming out of the system would generate one mole of the particular I and in one mole of this particular ion you know or let us say the material that is being converted into iron an electron constitutes.

Its atomic weight okay, so there is a relationship between the charge and the number of charges needed per species to get converted into the corresponding iron okay and then there is that if one mole of such our species is spent an amount equivalent to the atomic weight of the material will be coming out. So that is a relationship between mass and charge which is being made through this Faraday's laws of electrolysis.

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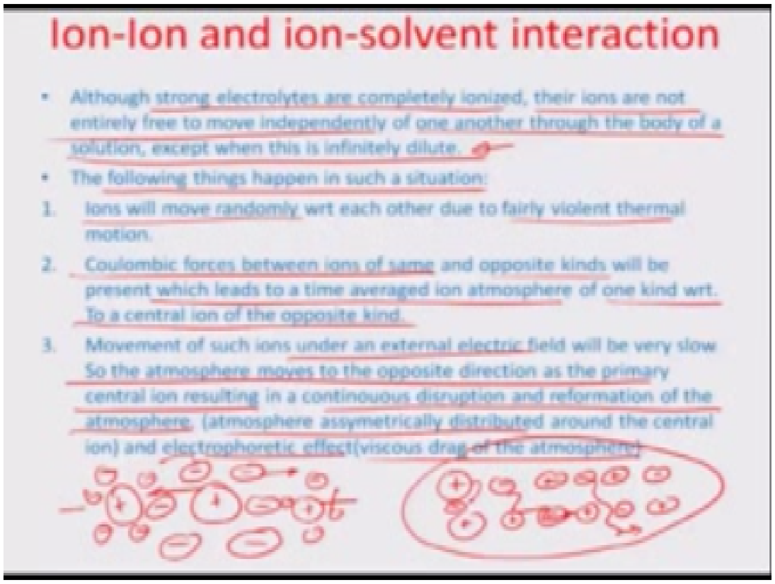

Ion-Ion and ion-solvent interaction

- Although strong electrolytes are completely ionized, their ions are not entirely free to move independently of one another through the body of a solution, except when this is infinitely dilute.
- The following things happen in such a situation:

1. Ions will move randomly wrt each other due to fairly violent thermal motion.
2. Coulombic forces between ions of same and opposite kinds will be present which leads to a time averaged ion atmosphere of one kind wrt. To a central ion of the opposite kind.
3. Movement of such ions under an external electric field will be very slow So the atmosphere moves to the opposite direction as the primary central ion resulting in a continouous disruption and reformation of the atmosphere. (atmosphere assymetrically distributed around the central ion) and electrophoretic effect(viscous drag of the atmosphere)

So let us now before going ahead start to delve a little bit into the ion and the ion solvent interaction, wherever there is an electric field given to let us say a solution which is present and it is you know comprised otherwise it is electrically neutral but it is comprised of all the positive charge centers and the negative charge Center let us say NACL solution, so we have NA+ and CL-well dissolved because of the because the water is a dielectric, so therefore there is a tendency to split up these ions into NA + independent ion and CL- independent ion and we want to find out what is the ion or the ion solvent interaction okay.

Between the various positive charge centers and various negative charge centers, so all those strong electrolytes are completely ionized, their ions are not entirely free to move independently of one another through the body of a solution, except when it is a infinitely dilute solution in the mean free path is almost infinite 49 to move. So the following things or events may happen in such a situation number one obviously is that the ions would have their own random walks which are because of thermal motions or Brownian motions, where the iron would actually you know let us say there are positive and negative ions which are there in a medium okay.

And so there is always a random walk that such ions would make and each ion would have it is own you know track or trajectory and that is one kind of motion that is prevalent in such systems and it's of course a function of the temperature state that the system is in there are columbic forces between the ions of same and opposite kinds obviously there would be forces of attraction between the positive and negative charges and similarly forces of repulsion between two negatives or two positive charges and, so this will be present which leads to a time-averaged I an atmosphere of one kind.

With respect to a central ion of the opposite kind here, as I was drawing this figure as you see here there is obviously we have these polarity differences maintained, so a positive ion in a close proximity of a negative ion. So if I want to consider only one positive ion there in fact would be a situation when it is engulfed or surrounded in many negative ions together okay and that is how you can say that you know it is a one central charge followed by the other charge of the opposite kind as its cloud you know or its environment. So this would be one state one state obviously is the temperature based movement of the ions and the other is that the movement of such ions under an external electric field will be very slow.

So the atmosphere moves to the opposite direction as the primary central ion, so now I apply a field here let us say I make this positive this negative, so obviously the positive charge will start moving to the negative electrode and vice versa the negative will move towards a positive electrode and so if there are many such charges and many such environments there is a continuous you know making and disruption of such charged environments, for these charges to migrate towards the electrode of the opposite kind okay.

So you can think of that movement of such ions and external electric field will be very slow atmosphere moves to the opposite direction is the primary central ion resulting in a continuous disruption reformulation of the atmosphere and yes atmosphere it is kind of a symmetrically distributed around the central ion, and there are many effects like electro poetically, that is the movement of a charge, in a solution which has exactly the other kind of charges and there are also effects related to viscous drag of the atmosphere mind you this is all in fluid. So therefore any movement of any particular ion would definitely have a drag force which is exactly in the other direction.

So this is how the whole eye on space is now defined and we want to now find out what is going to be the implication of you knows, let us say if we consider a certain distribution by net volume at infinity, what is going to be the implication of a certain positive charge? and it is ion atmosphere because of completely zero electric field at a distance infinity from that charge so basically we are trying to arrive at the transport kinetics you know and this was basically this is also known as the Debye hackle s equation, which was formulated way back in 1920s.

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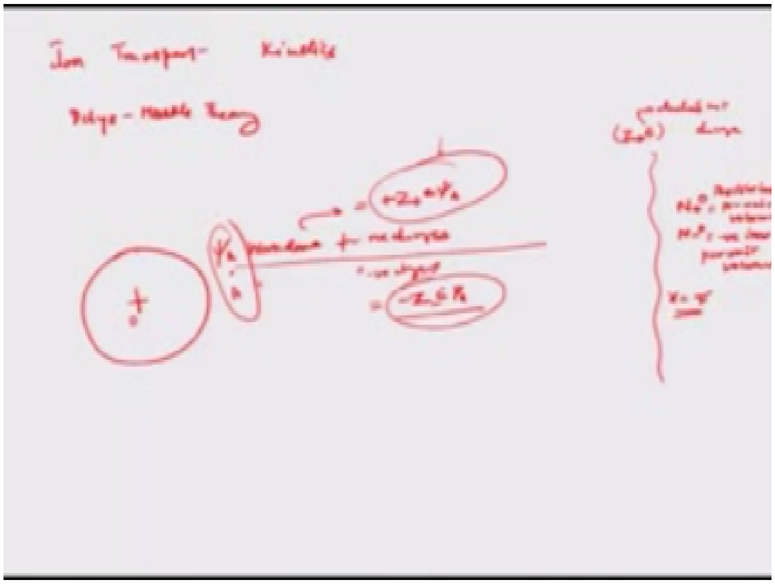

So this we call as the ion transport kinetics, so we have a positive charge somewhere here and we have a distribution which is let us say far away from this at let us say X equal to infinity okay, a certain distribution of the positive charges and the negative charges okay. So this is actually number density, so we have positive ions per unit volume and negative ions per unit volume are infinite distance from the central charge central positive charge as shown in this particular case okay. So if I wanted to bring a positive charge from let us say infinity the total amount of work done in order to move such a charge to a distance, a let us say a near in the near vicinity of the positive charge.

Would be dependent on really what charge is being moved, so supposing there is a charge which has a valence z + so there therefore the total amount of charge that is there on this particular charge entity Z + epsilon is the electronic charge okay, so if I am wanting to move this pretty close to this point a here where there exists afield sigh a, so the total amount of work done for positive charges would be given x + Z + Epsilon sigh a and that for the negative charges would be given by - obviously the charge value is - in this particular case - Z - epsilon is IA.

So this is the kind of work that is done to move either positive charges or negative charges in a way that you know you can assume that negative value here means that the system is doing work on you and then the positive value here means that you have to do work on the system for bringing a positive charge close to a positive charge center. So with this module on board in the next module what we are going to do is to understand, what is going to be the final number distribution in this region a okay and what is the kind of potential which will be generated because of that number distribution in the near vicinity of a charge.

Somewhere located somewhere along the solution, so once we have that figure we can simply extend that to the case of a solid-liquid boundary and can formulate something which is also known very commonly as the zeta potential of a solid. So with this I would like to close this particular module in the next module we will try to further solve this transport equations thank you so much.

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