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Course Title
Environmental Degradation of Materials

Module 01 Lecture 15
Broad Subject: Mixed potential theory, Explanation of corrosion events on the basis of mixed potential theory, Galvanization

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So last lecture we have started mixed potential theory, and in this theory you would understand some of those corrosion -- corrosion problems, which can be understood much better in this mixed potential theory and some of the problems, for example, you will see that Zinc corrodes in HCl as well as iron corrodes in HCl, but when they are -- they are in -- they are inserted in HCl solution, you will see that corrosion rate of iron is more than the corrosion rate of zinc, but when you connect this iron and zinc together and put it in HCL solution, you will see that the corrosion rate of zinc is more than the corrosion rate of iron.

So this kind of observations rather observations, all those corrosion observation can be easily understood from this mixed potential theory, and we have started with two postulates -- mixed potential theory. We have started with two postulates or hypotheses. One says that any corrosion reaction can be divided into two or more number of partial reactions or either oxidation or reduction reactions.

We have given example in case of iron -- in case of zinc, if you -- if you dip a zinc rod in deaerated HCl, then the main reaction is hydrogen evolution and zinc corrosion. That reaction can be divided into one oxidation reaction that is zinc going into solution as zinc ion and hydrogen ion in the solution is getting reduced to hydrogen gas. So reduction and oxidation reaction both the things, there would be a singularity in reduction as well as oxidation reaction.

But now if you have oxygen into it, then you can have one more cathodic reaction. So you have two cathodic reactions, but the anodic reaction or the oxidation reaction would be a singular one, that is the zinc going into zinc ion going into the solution as zinc ion. So now you can segregate into two that means one says that corrosion can be divided into one or more oxidation reaction and second is one or more reduction reactions.

So now second thing is corrosion -- second hypothesis which says that there will be charge conservation and we have seen that the rate at which rate of electron generation, which is nothing but corrosion, for example, zinc is going into zinc ion and that time zinc needs two electron, that means here is a electron generation or oxidation -- or oxidation and would be equal to rate of electron -- electron consumption, which is nothing but reduction -- reduction reaction.

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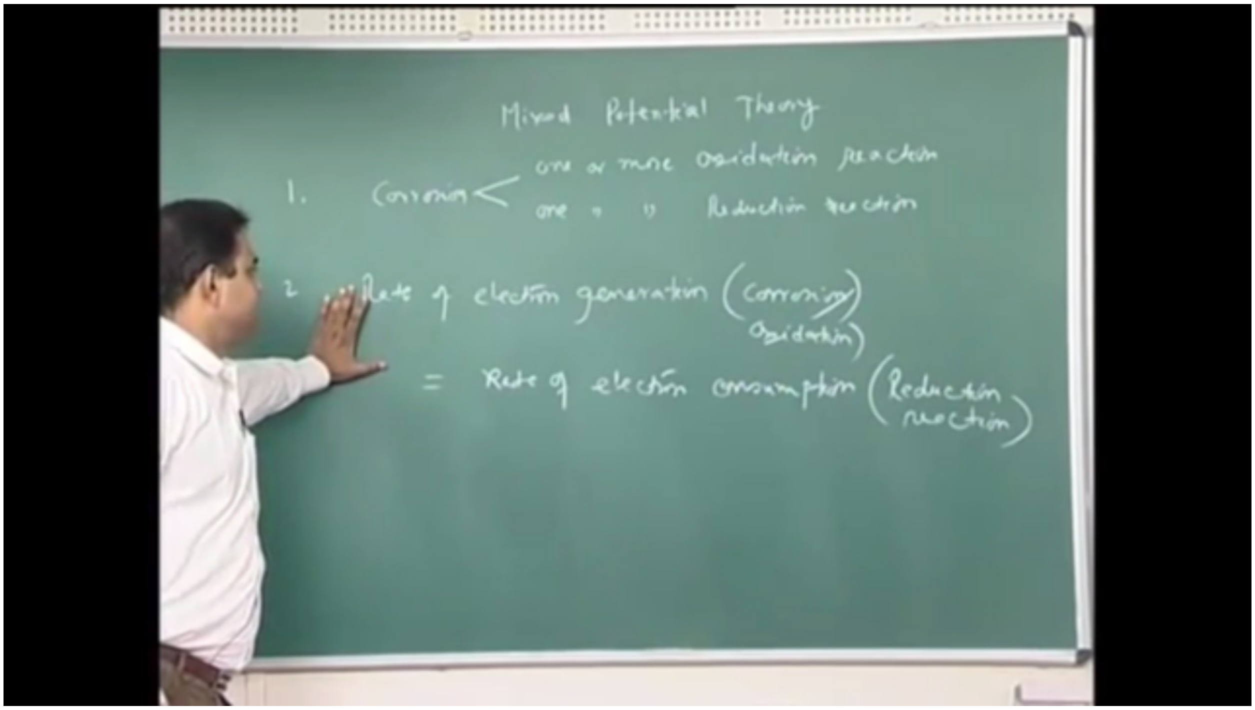

Mixed Potential Theory

1. Corrosion < one or more oxidation reaction
one " " Reduction reaction

2. Rate of electron generation (Corrosion
Oxidation)
= Rate of electron consumption (Reduction
reaction)

So now this says, these talks about the charge conservation. Now these are the two hypotheses. On that basis the mixed potential theory has been constructed.

Now we have to see another part. For example, if you have a beaker with deaerated HCl, now you put a rod or piece of zinc. Then you will see that there would be bubble formation on the zinc surface and these bubbles are nothing but H_2 gas. Now here if you take a small part of it and then blow it, so you will see that you have blown it, this small part and this is the surface which exposed to the solution. You have -- one case you have zinc going to zinc^{++} and two electrons. These two electrons is coming from this end to this, so here would be a corrosion. Okay. So there will be a dip because zinc is going as a zinc ion, so these two electrons will be consumed by two hydrogen ion going to H_2.

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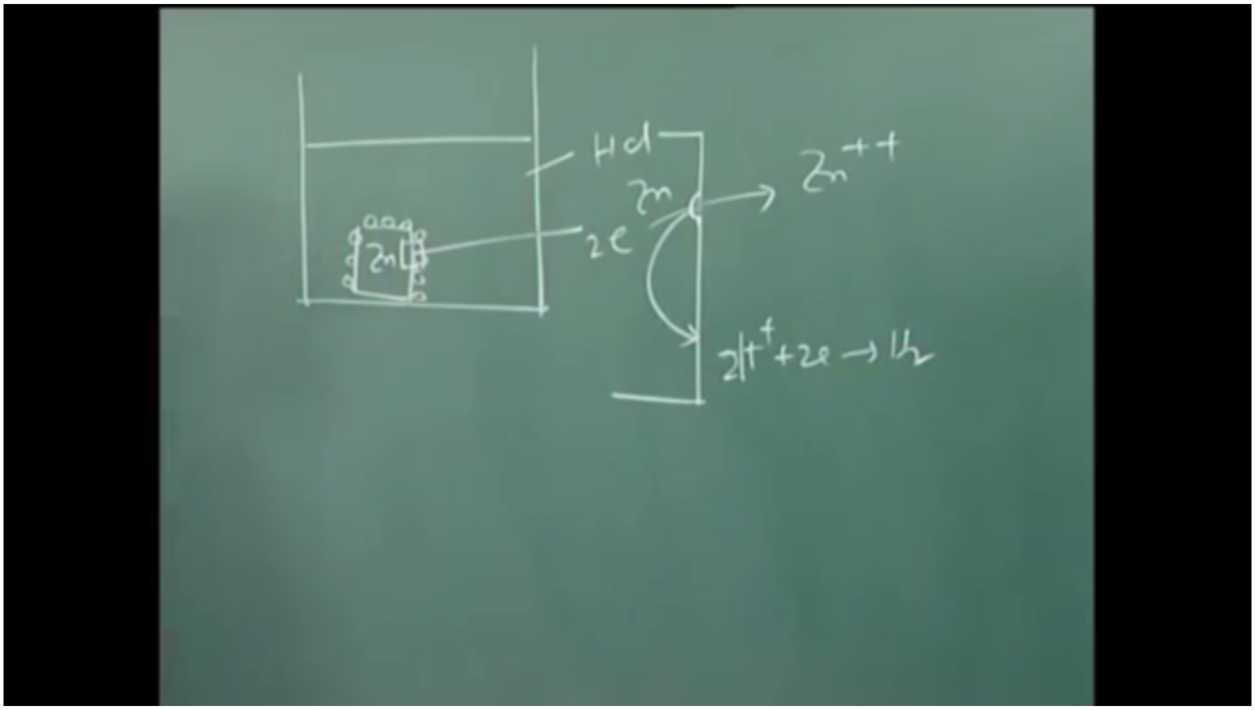

So now you see this is nothing but oxidant, O. Okay. Now this is reductant. Now here in this case, this is reductant -- this is oxidant and this is reductant. So now you can see that you have metal ion formation, okay, and one oxidant, so you can mention as O is going to reductant like that. So an electron is coming from here to this place. This is electron flow, n electron.

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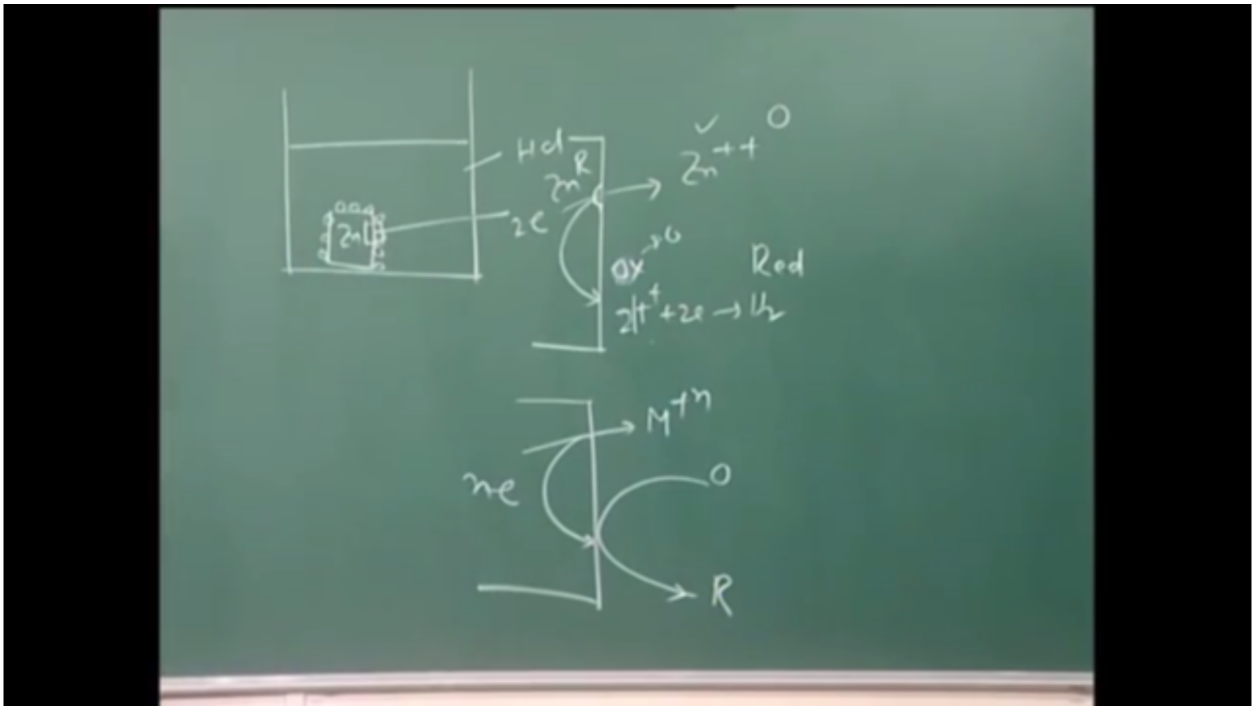

So this is the process. That means on the same surface, you are getting oxidation reaction as well reduction reaction. Fine. So the same surface is acting as cathode as well as anode. That's why the same surface, this one is called mixed electrode. Mixed electrode.

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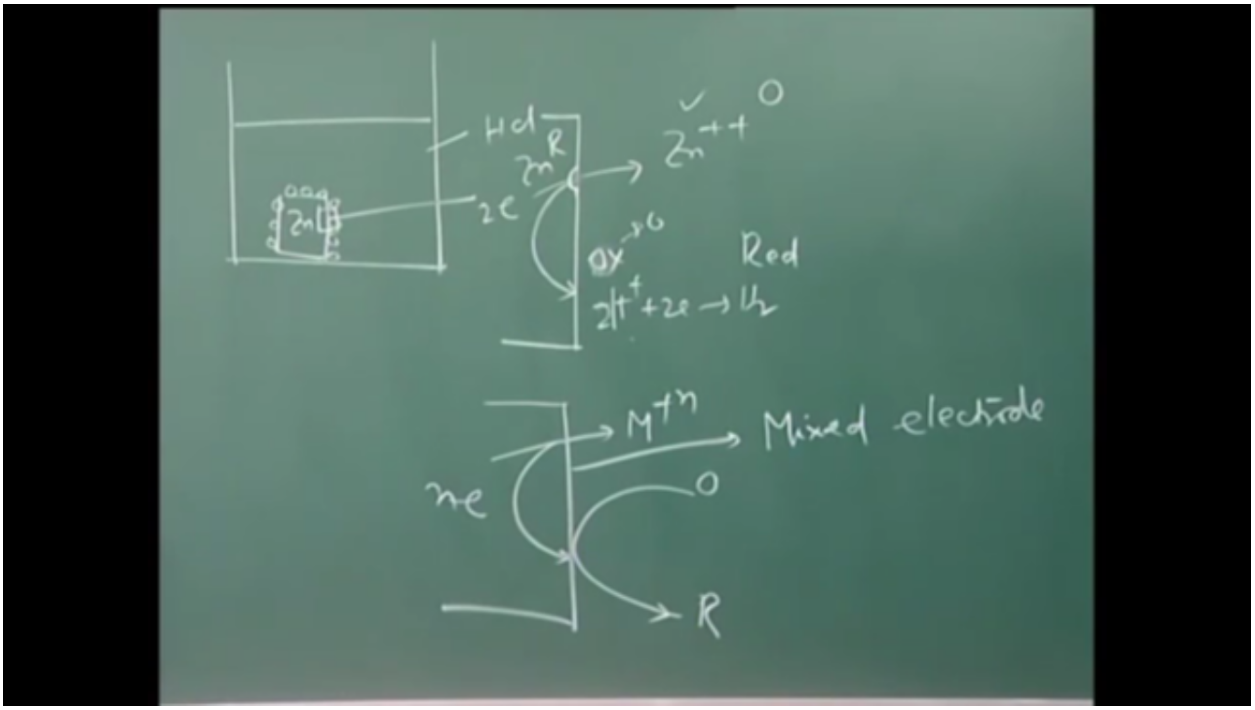

Now in this case, this can be, for example, in case of zinc in deaerated HCl, there would be one cathodic reaction and one anodic reaction like this, but if you have oxygen into it, so there could be one more reduction reaction, which is oxygen reduction. Now that case this could be one, this could be one. Oxidant one can go to reductant one and there could be one more reduction, which is to 2. This 2 is nothing but the second oxidant, okay, going to second reductant. So like that there could be two more reduction reaction, one oxidation reaction, but all the reactions are happening on the same electrode surface, same surface. So it is called mixed electrode. So mixed electrode concept will be used while understanding this mixed potential theory again.

Now let us come to the some of the observations. One observation let's say you have a beaker where you have a zinc rod. This is zinc rod, and here you have zinc^{++} ion already present. That means let's say here Zinc sulphate. Now if this is at one activity is 1, the ionic activity is 1, then the potential developed on this electrode would be standard reduction potential.

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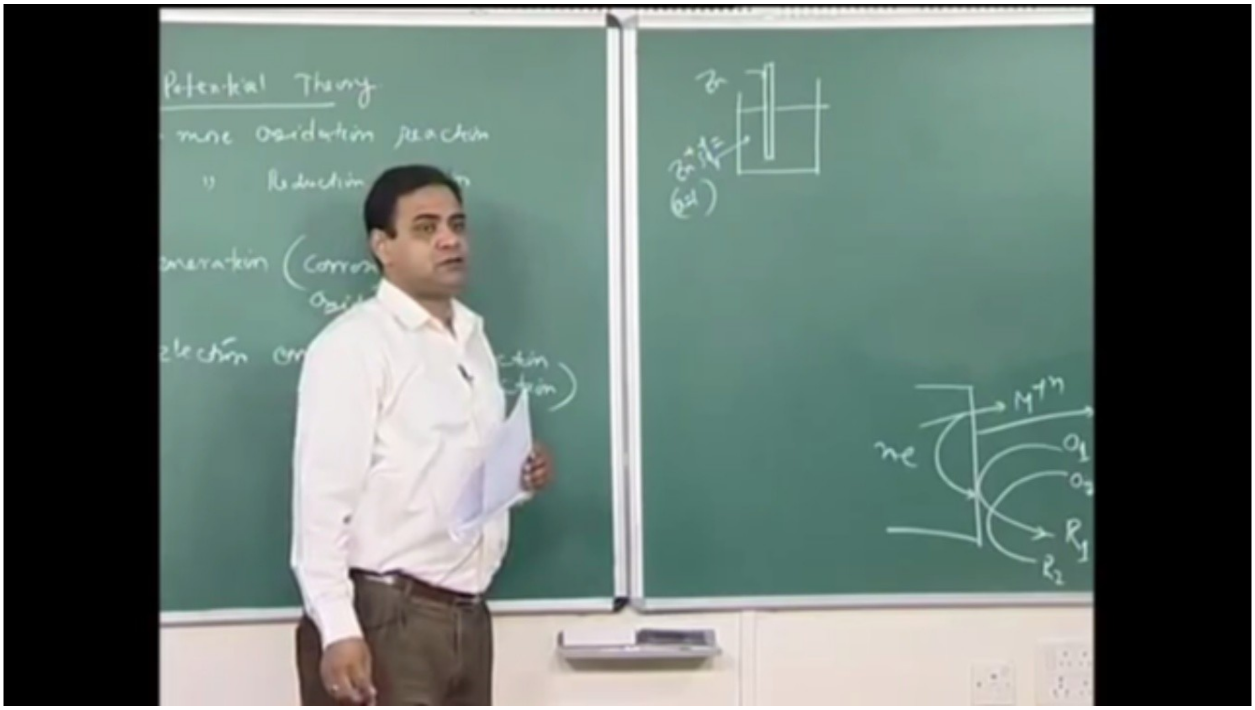

Now similarly, you can have a standard hydrogen cell, standard hydrogen cell where it is a platinum rod, and then you have hydrogen -- hydrogen gas you can supply here, and like that you can have this is one normal HCl and you can have a standard hydrogen electrode.

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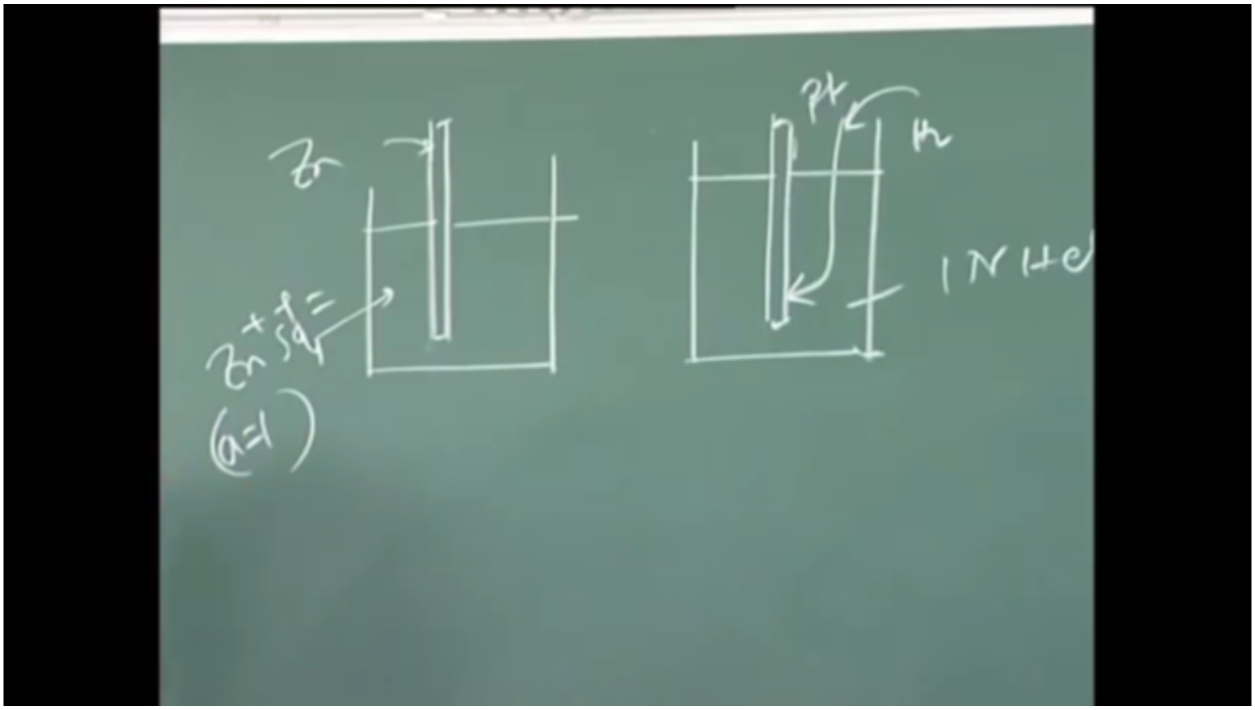

Now when they are separate, let's say they are separate, they will be both at standard reduction potential. So its potential would be zero volt. This potential would be -0.76 volt. Fine, no problem.

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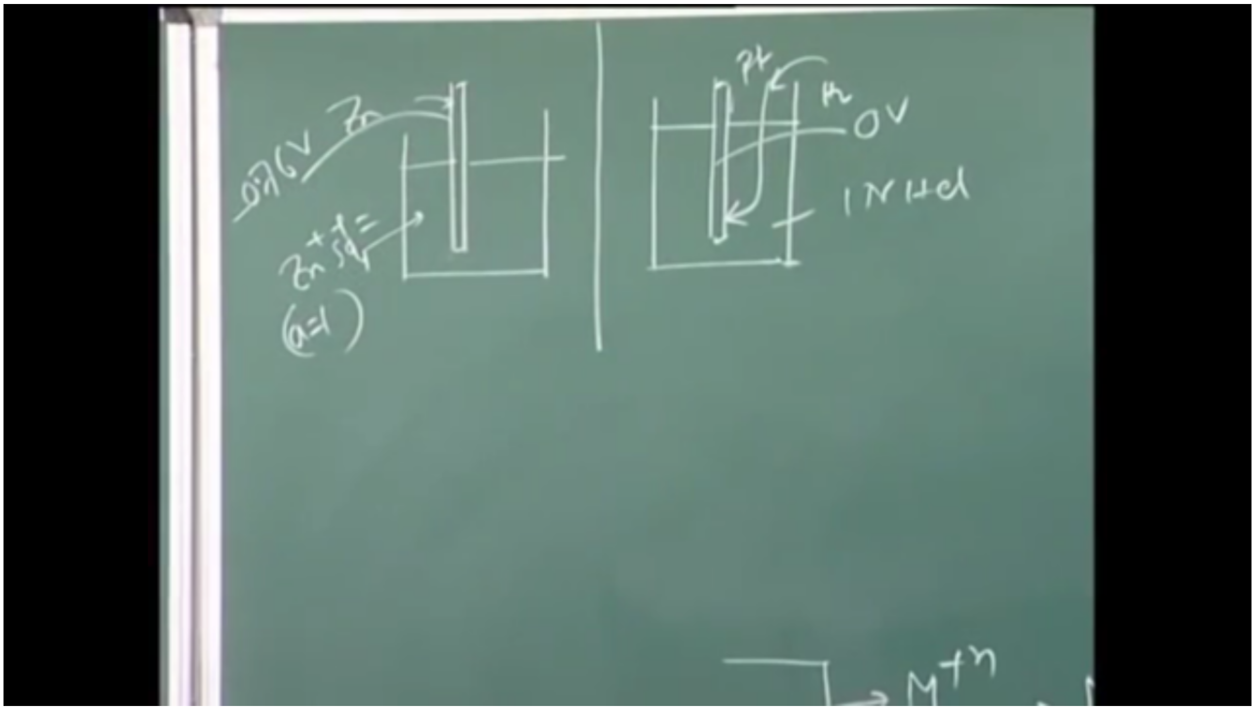

So here you have reversible reaction zinc^{++} plus 2e, zinc, this reaction is taking place in this and in this you have 2H^{+} plus 2e, H_2 gas. So this reaction, this reversible reaction is happening.

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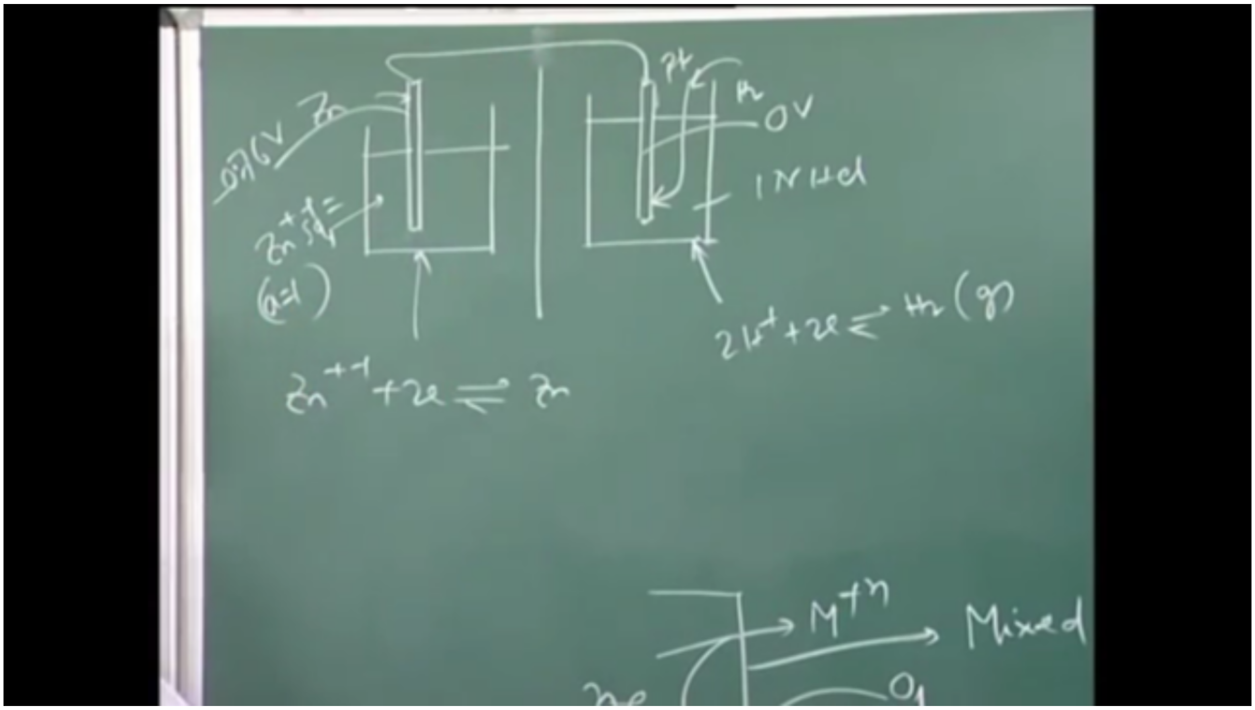

Now if you connect it now, let's say I connected these two ends, what we will see? You will see that current is flowing this way. So this way the current will flow and this would be acting as cathode, this would be acting as anode, and the total voltage difference between these two half-cells would be minus 0.76 plus volt because you have to see this right minus left, so by that you can see that the potential difference between these two half cells would be plus 0.76. So you have a potential difference, so current will show.

Now the point is this is with respect to two half-cells. Now let me see the situation where you have one zinc. Let me see the situation where you have a beaker, and you have a rod of zinc inserted into it, and here it is HCl.

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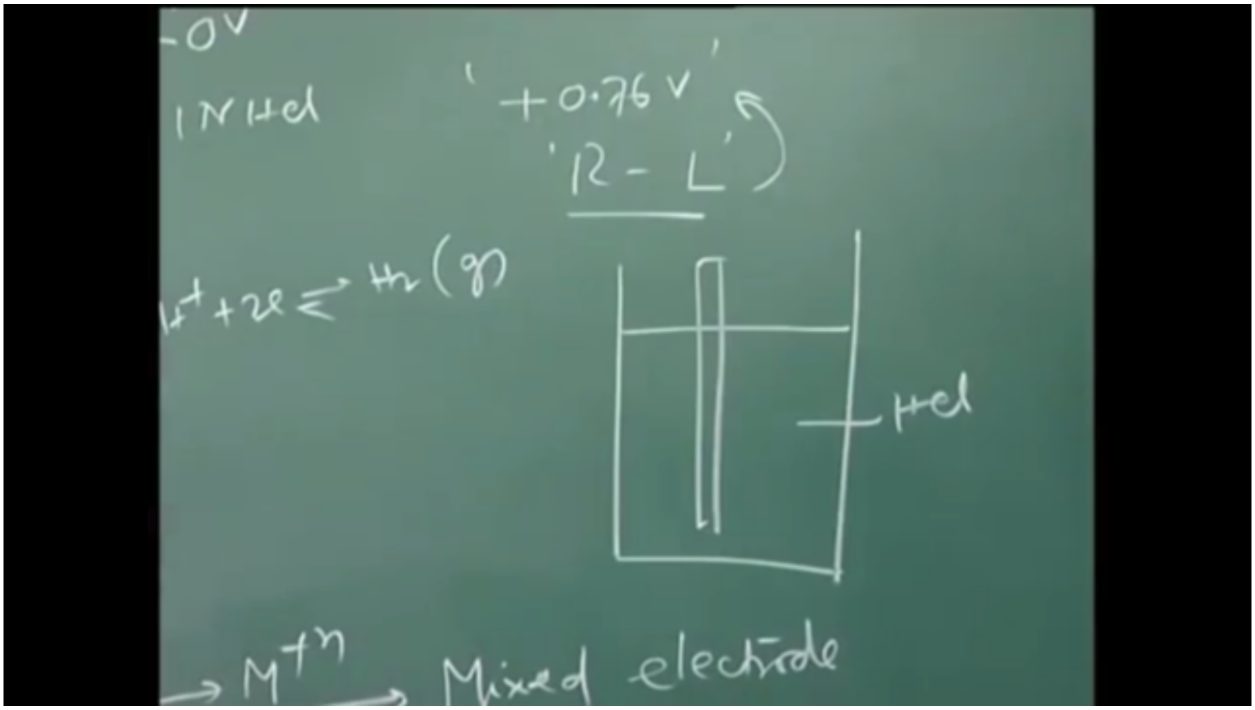

Now here once you have this situation then you will see that there would be bubble formation of hydrogen, bubble formation of hydrogen. As we have also seen the observation would be like this. There would be bubbles and it will come out like this and zinc will gradually corrode. Zinc will gradually go into the solution, and that time we have also seen that these two reactions cathodic.

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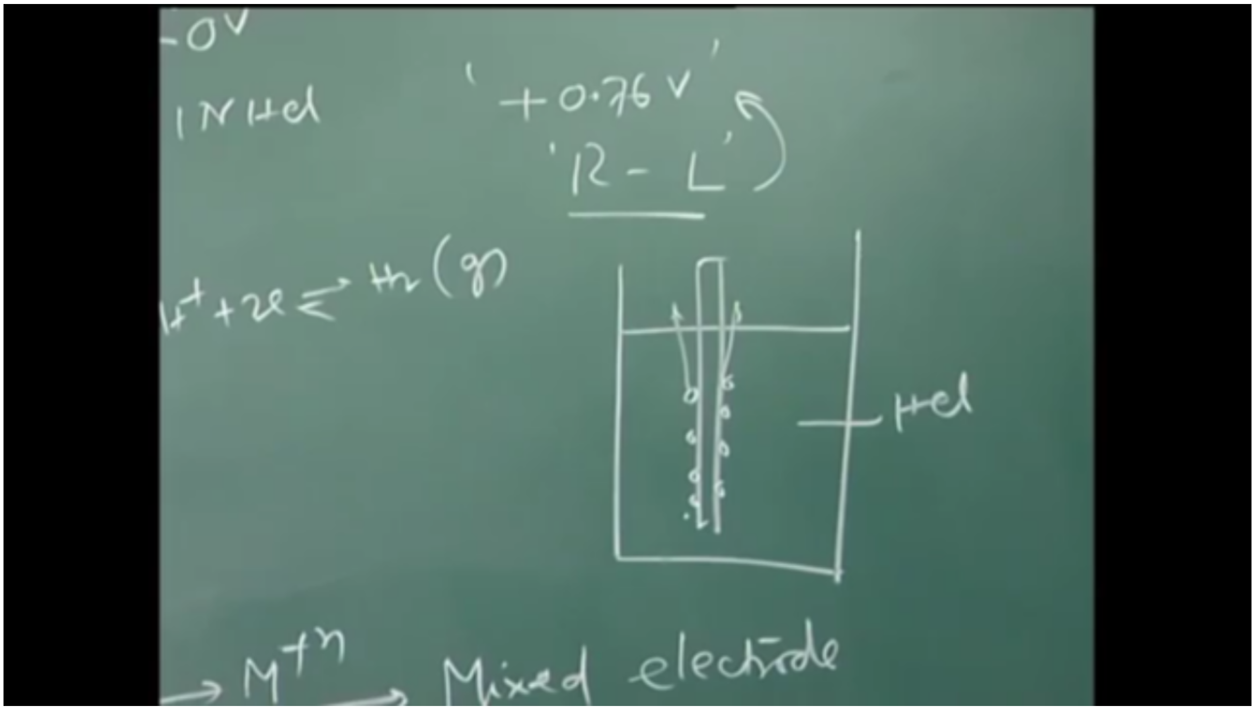

Here if you compare these two situations, here both the cathodic as well as anodic reactions are taking place on the same electrode. So zinc electrode itself is acting as a mixed electrode, but here you see only the when the current will start flowing, only the oxidation reaction will take place here and hydrogen evolution reaction will take place here. So now with reference to this mixed electrode, but in the actual situation you don't have this kind of situation. You have this kind of situation.

In actual situation what we will see that initially, zinc has its own oxidation reversible potential and hydrogen also has its own reversible potential, but finally, if you connect these two system, let's say one level is this, one level is this, but the system -- that means you have two energy level. This is E_1. This is E_2. If you have two energy levels and if you leave it to -- leave it by connecting these two, then you will see that gradually this energy level will try to come to a midpoint where the energy level becomes equal. System doesn't allow anything to be at a different energy levels if you connect them and leave it like this on itself, but on itself it will try to reach to some energy level, okay, so which is E so that means E_2 will go to E and E_1 will go to E.

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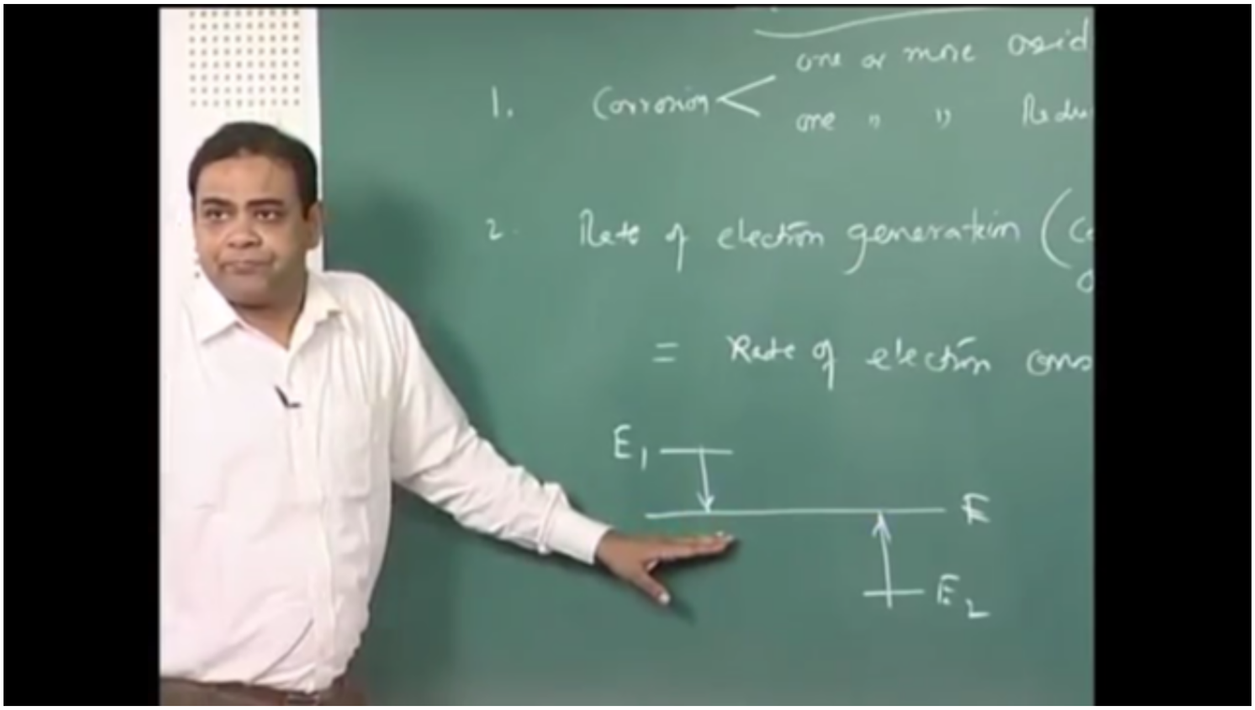

So like that here it goes to positive side, here it goes to negative side, and this concept we have already learned. This is nothing but the polarization. Fine. So this polarization concept will tell us what would be the equilibrium potential which would be achieved after some time because the system will try to reach to a same energy level all the time. Fine. So energy level, that equilibrium energy level we have to find out with the help of Tafel expression.

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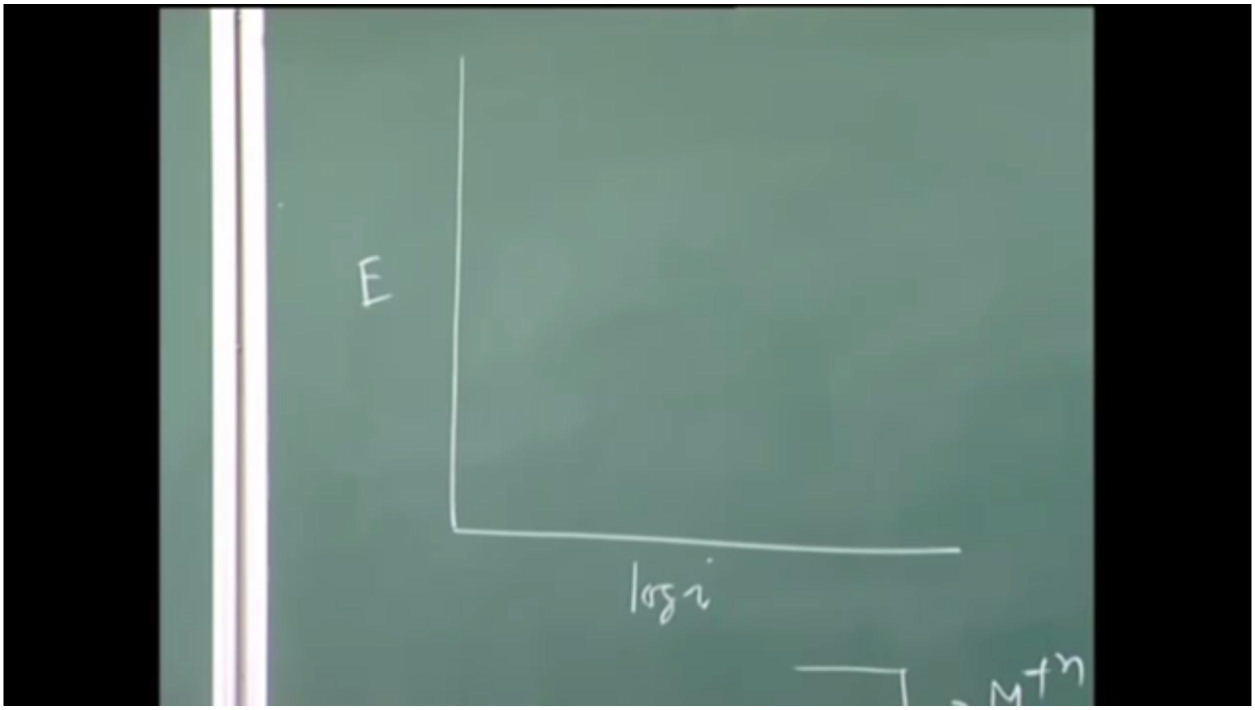

Now let me plot potential versus current log i. This is potential. Now if you see the standard reduction potential of zinc, it is minus 0.76 volt and for hydrogen it is 0 volt. Now if you consider only in case of hydrogen and try to see what would be its polarization behavior with respect to the Tafel equation, then you will see that it varies like this. This is -- this is nothing but H plus -- H_2 going to H^+ -- $2H^+$ plus 2e. That means this side is anodic polarization and this side is cathodic polarization where you have this reaction -- this reaction.

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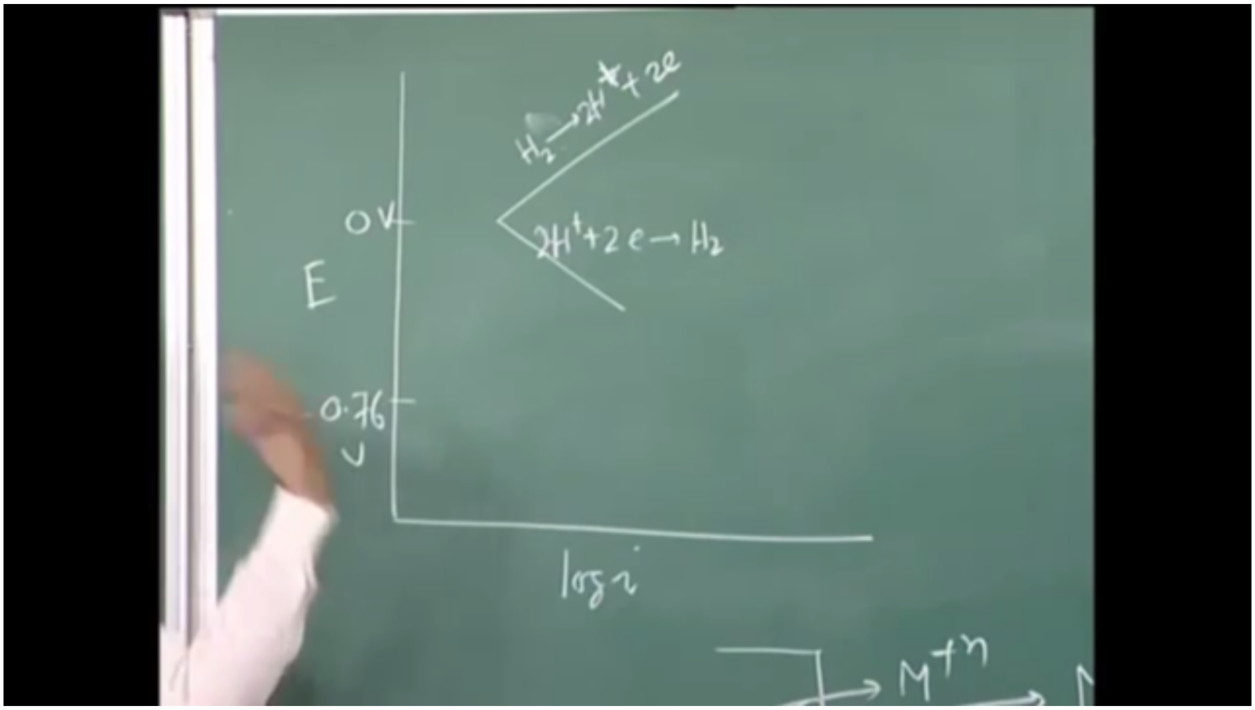

So if you have a cathodic polarization in case of hydrogen only, this will follow this line. If you follow the cathodic -- anodic polarization for hydrogen, this will follow this line, and this equation is nothing but anodic or cathodic, a for anodic, c for cathodic would be beta a for anodic, c for cathodic log of i a for cathodic, c for anodic, i_0 and i_0 is nothing but this one, i_0 or log i_0 since I am plotting with respect to log I, so it would be log i_0.

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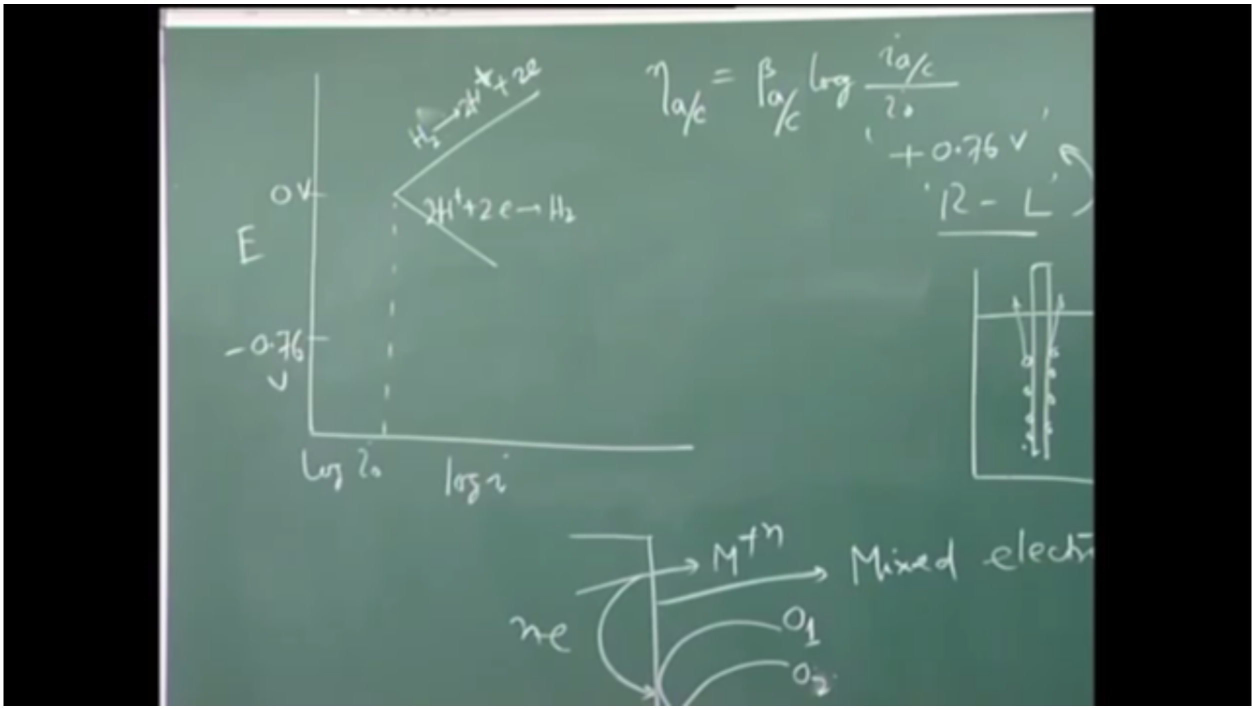

And on what surface? If you see this, we have to understand on what surface cathodic reaction is taking place or anodic reaction is taking place. Here the cathodic reaction is taking place on the zinc surface, so I have to mention that i_0 on zinc. And again, if you consider individually, the polarization behavior of zinc, it will follow this, this. So this is in this line, it would be zinc going to zinc^{++} plus 2e anodic reaction or anodic polarization line and in this case it would be zinc^{++} plus 2e cathodic reaction.

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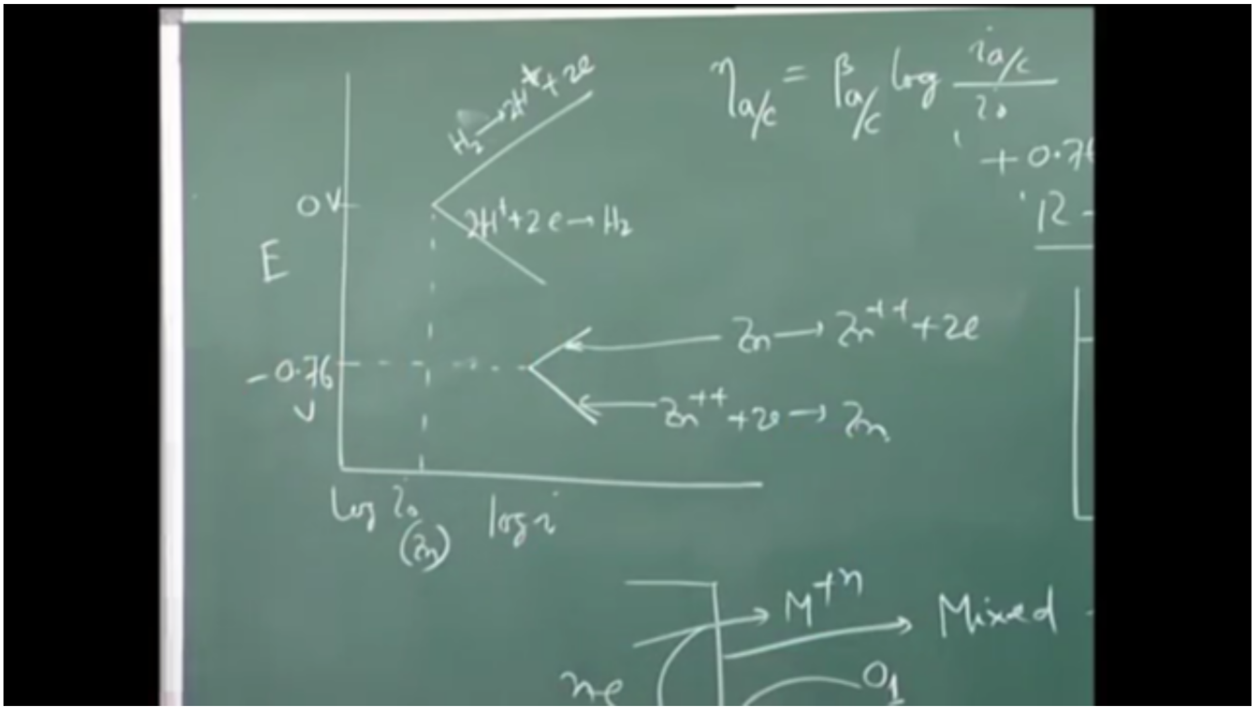

Now we have to see the equilibrium point where the potential will reach the same value for both anodic and cathodic reaction. Now where it can reach that equilibrium value? The equilibrium value would be in between some potential, okay, in between some potential. Now we have to see, let's say I am drawing this line. I am drawing this line. So initially, I thought that it will reach to this value, but again, you see that though it has reached to the same value, it has reached to the same equilibrium value, but what happens to the -- if it is equilibrium, then, again, we have to -- we have to consider this second consideration for mixed potential theory, the rate at which electron generates, the rate at which electron is -- electrons are consumed, both the rates should be same, but you see the rate is guided by the current value. At these two points, current values are different. So this cannot be this point.

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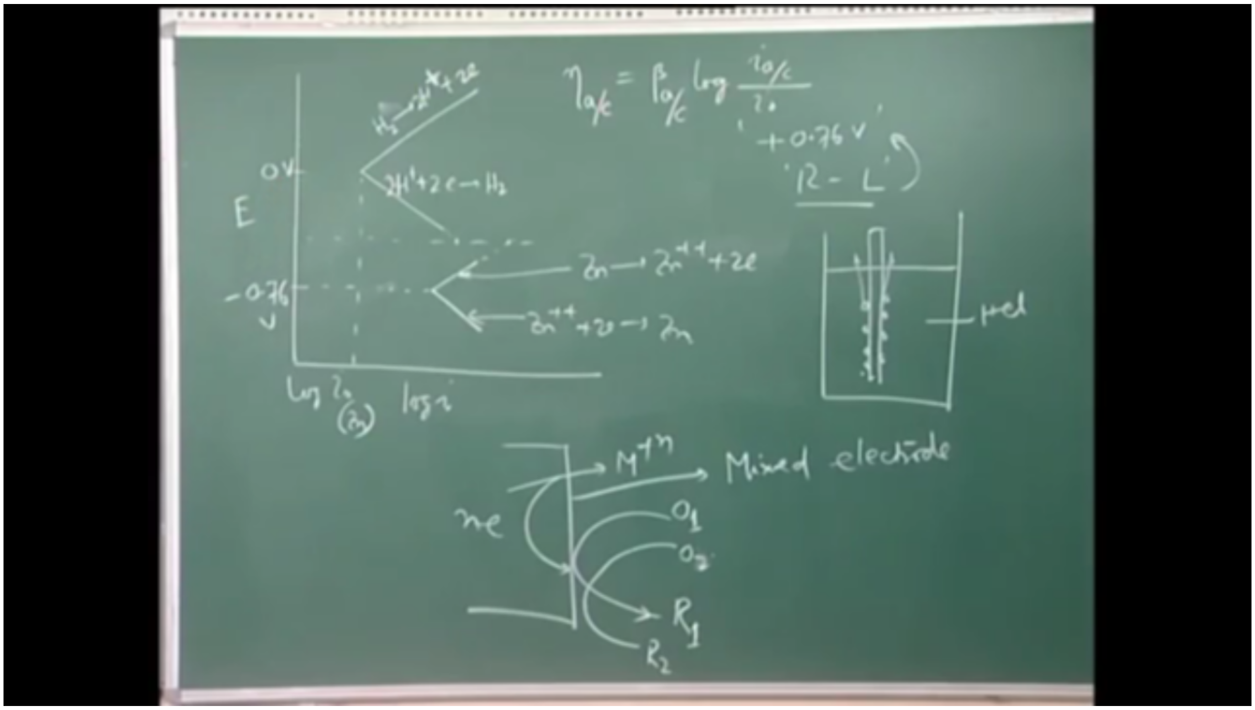

We can see that if we -- if we extend this, this line, I see that at this point, at this point I see that the potential for cathodic reaction which is this and potential for anodic reactions are becoming same, which is nothing but this one, this one. This is let's say E double dash I am putting.

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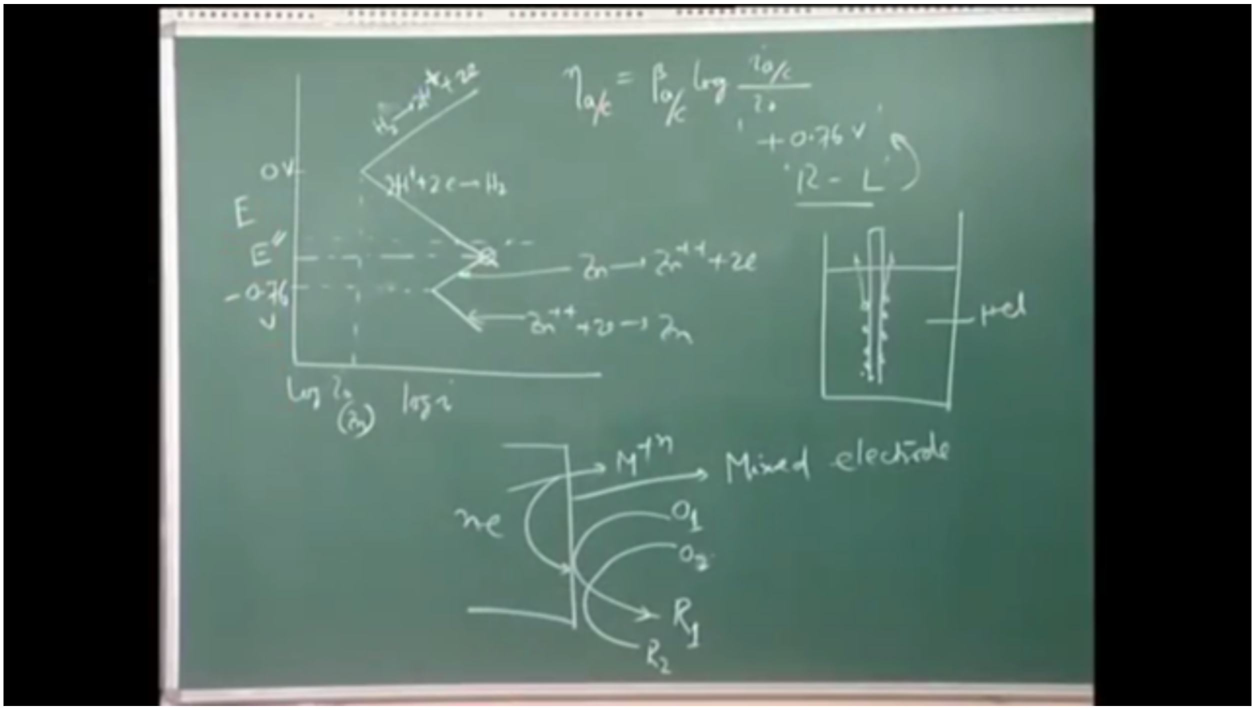

Now, interestingly, at this point, I see what is my i_c. This is my i_c because this, if you consider this line, this is my i_c. Same time what is my i_a, which is anodic current? Along this line if you see this point is nothing but i_a and you see the magnitudes of those two currents are same. So these are equal and if I have to see their directionality, so I will see that this is valid at this point.

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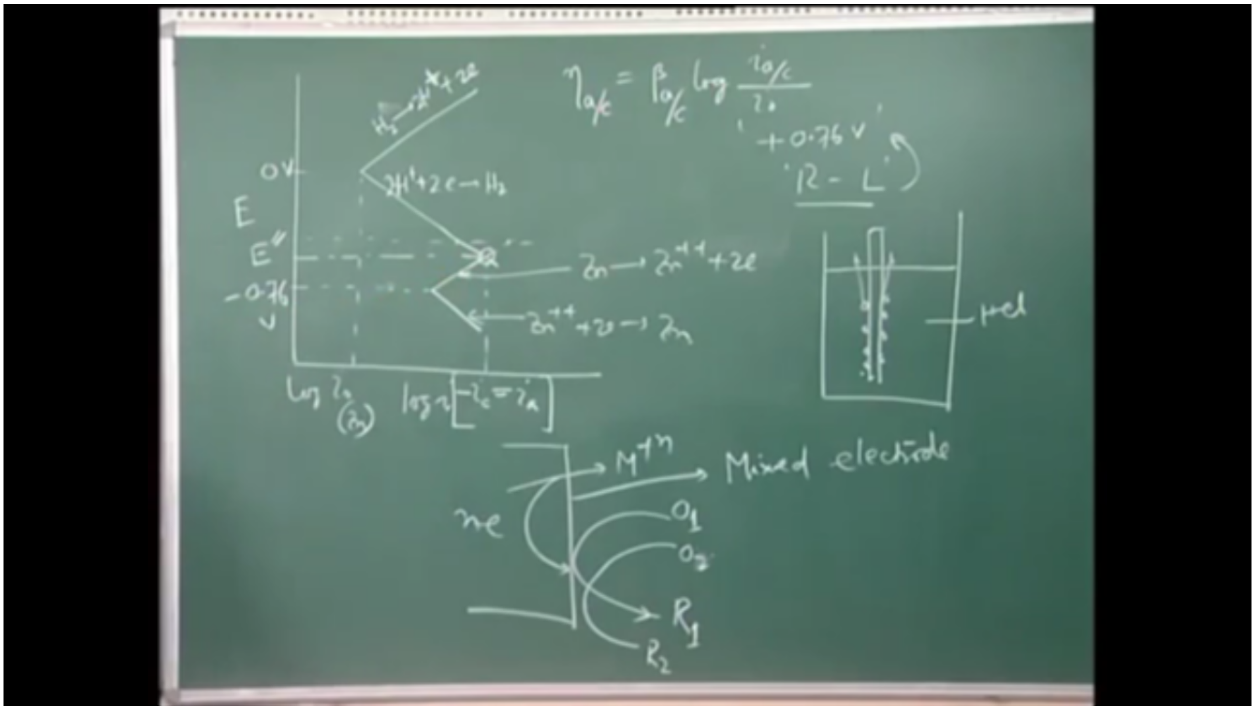

So what would be the new point where it can reach? This is my new point where my potential becomes equal for the both cases as well as that means potential means it is a free energy. So free energy is reaching to a particular value. Again, I see the second concept is also valid that is the rate at which cathodic reaction which is this is happening is nothing but the equal to -- is basically equal to the rate at which anodic reaction is taking place so -- or we can say that the rate at which electron generation is taking place is same as the rate at which electron consumption is taking place. Fine.

So that means we are also following the mixed potential theory, those two, two considerations, and another consideration is whether we can divide into one or two oxidation or reduction processes, partial reactions. Definitely, because we are dividing this reaction into this reduction process and into this oxidation process. Fine. So we have reached to a point which is considered to be nothing but i_{corr}. Corr means i corrosion. Fine.

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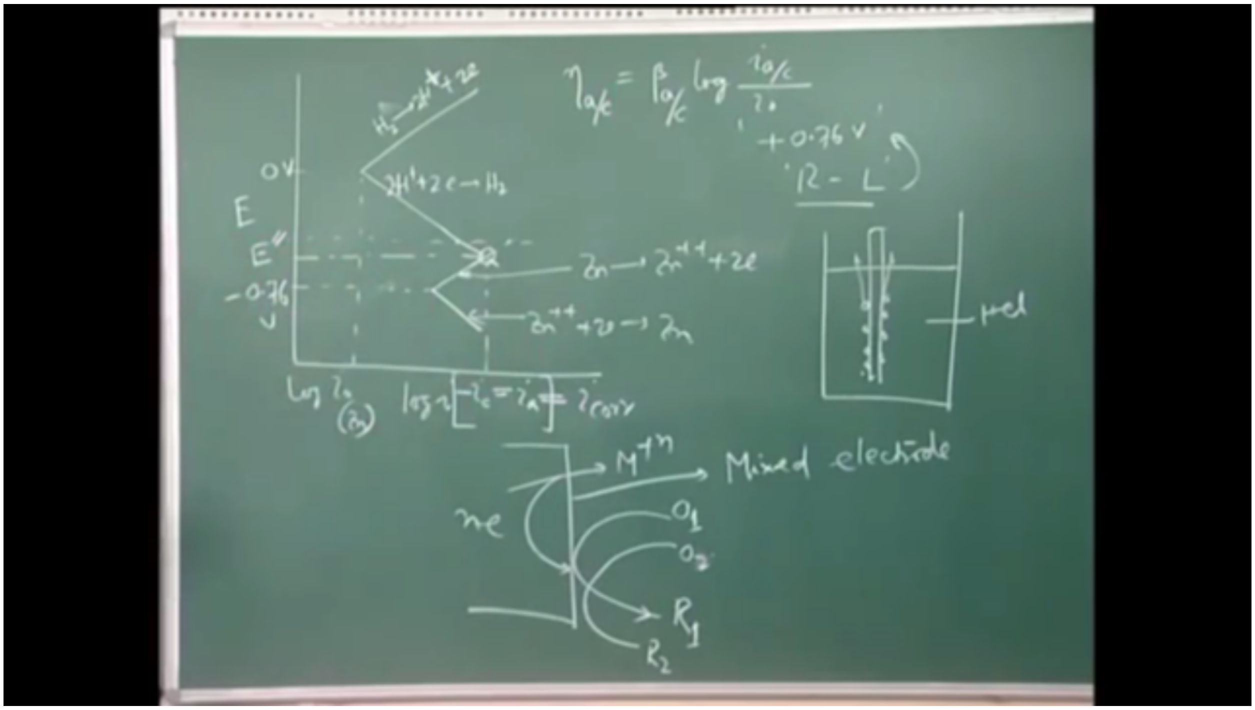

So this would be my point where after sometime you will see that the equilibrium will be reached and this would be my point where I will have equal i_c and i_a would be equal to i_{corr} because i_a is nothing but i_{corr}. So this with this point, this would be the potential which would be reached and this potential is called instead of double dash, double prime I will put E_{corr}. This potential is called potential for corrosion and this current is called current -- current density for corrosion. Fine.

With this understanding, we would proceed further, but one point let me tell you. This equilibrium can be reached if you can see, if you extend the backline and extend this line also. We can also have a common point here where the current density for cathodic as well as anodic reactions are same, but we cannot reach there because this is having higher reduction potential than this. So always this will try to have a reduction process and this will try to have oxidation process, so it cannot reach there. Rather it will reach to this point. Fine.

So let us see the example for iron. So iron case, again, it would happen. Let me plot log i versus potential. Fine. Now in this case for iron, again, I have to see where is my reduction potential for iron. Reduction potential for iron is 0.44 volt. Fine. This is in volt and hydrogen is 0. Now this line I have to consider. This parallel -- this straight line we have to consider and here one point I have missed, this point nothing but i_0 for zinc on zinc surface.

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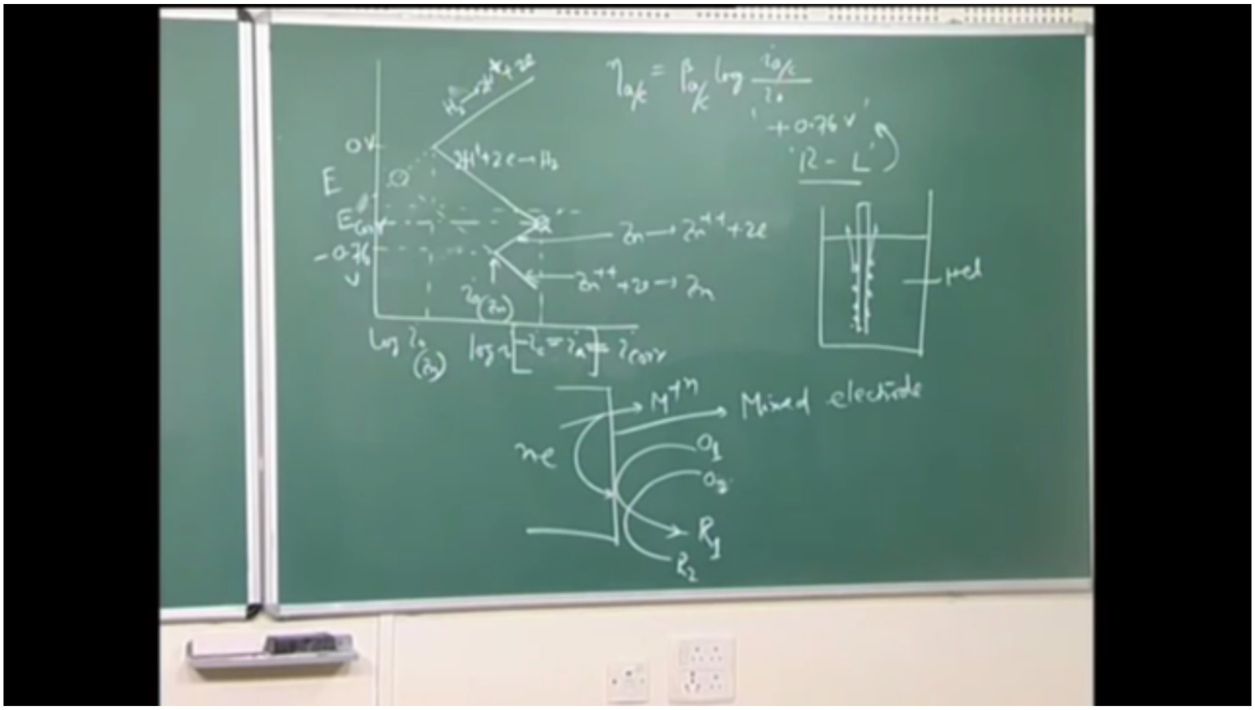

Similarly, in this case also, I have to see where is my i_0 point for reversible reaction of iron going into iron^{++} ion and also hydrogen reaction exchange current density i_0 on that iron surface. So this value would be let's say here and it is value is almost at this point. So, therefore, you have to consider two reactions and this is my anodic reaction for hydrogen. This is my cathodic reaction for hydrogen.

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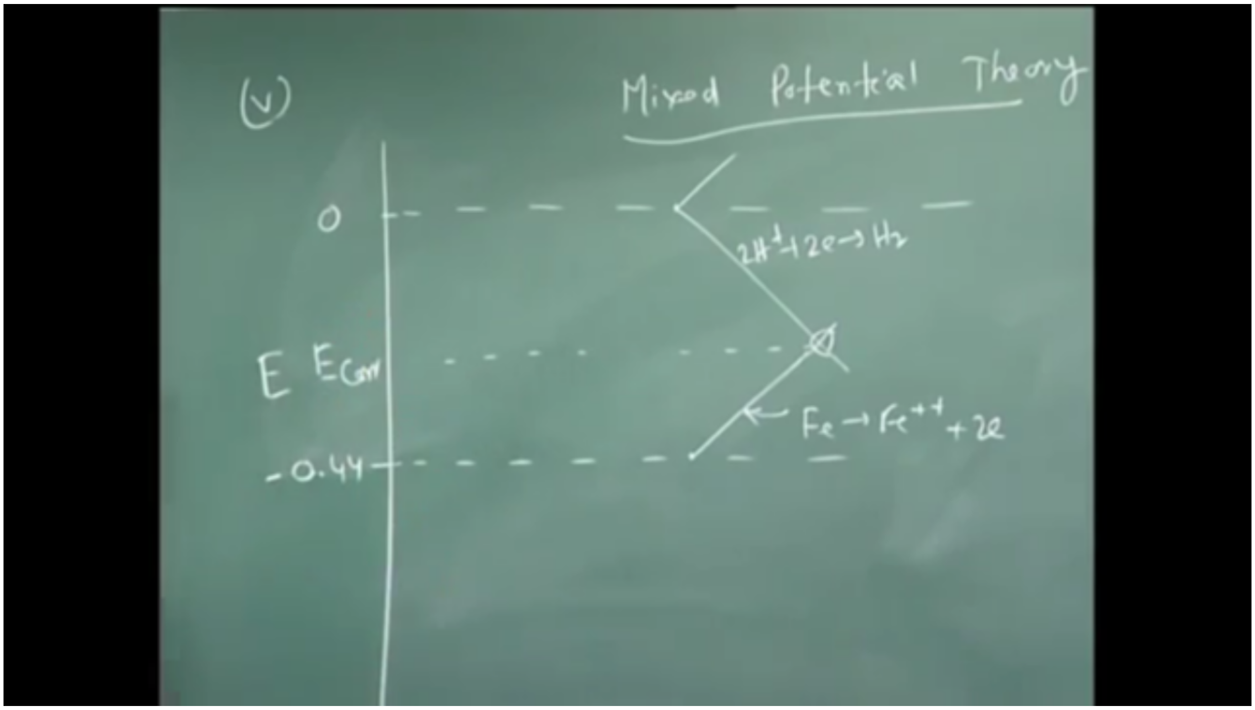

I am only writing because this part is not coming into picture, only writing the hydrogen reaction, and this is my iron reaction, which is iron going to Fe^{++} plus 2e and at this point I see -- at this point I see that both the charge transfer reactions are rates are same. Electron consumption by this process and electron generation by this process both are the -- both the rates are same. So -- and this is E_{corr}. Okay. Now this is my reduction process for this iron, but I will see that since this is having higher potential, so always if you connect this both the things, then always this process will move this way as well as this process will move this way, and this is cathodic polarization, this is another polarization.

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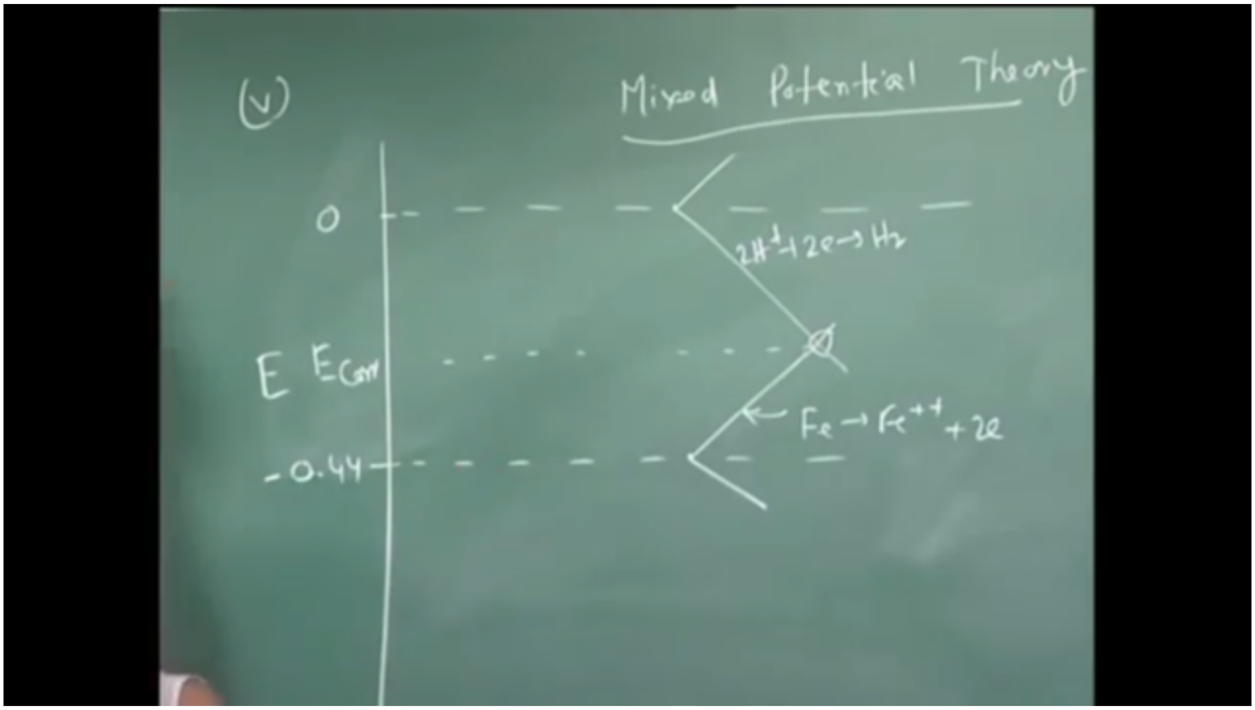

Now see the situation. In one case here you are doing the individual dipping. One beaker, you have taken the same concentration of HCl, same concentration and deaerated. Okay. No oxygen in it. So you have dipped one iron surface, pure iron rod in this -- in this medium, okay, and you are seeing this process and this is my corrosion rate. This is my corrosion rate.

Now similarly, if you see HCl and one zinc is dipped into it separately, you see the corrosion rate is this. Now I know that and where is my the potential? If you see the potential E^0 of iron^{++}/iron is greater than E^0 zinc^{++}/zinc because here it is minus 0.76 volt and here it is minus 0.44 volt.

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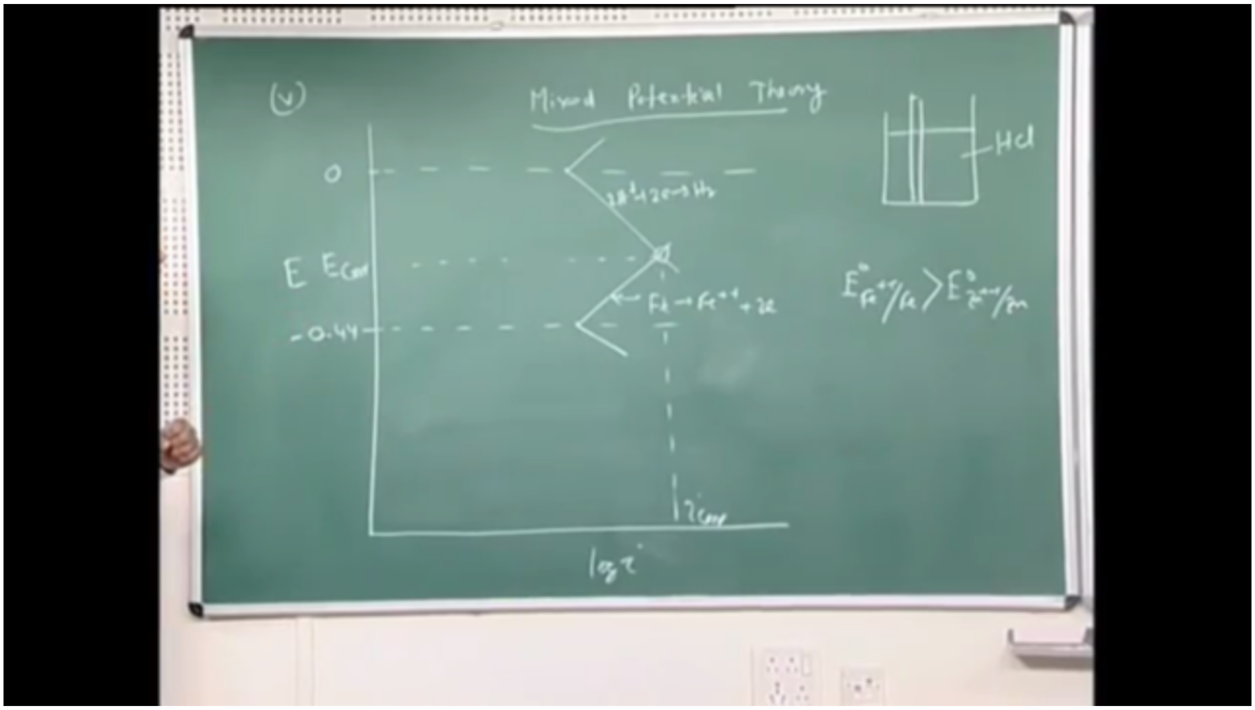

Now the point is if you would like to see in which case you can get higher corrosion, whether this case, this is iron, whether this case or in this case, which is zinc? Fine. So for that let me also superimpose the same curve on to this. Then I would be able to answer this question, but the point is if you go by the thermodynamics, what is thermodynamics? Thermodynamics is nothing but E^0. E^0 talks about the standard free energy change and the relation between the free energy change and minus nFE^0.

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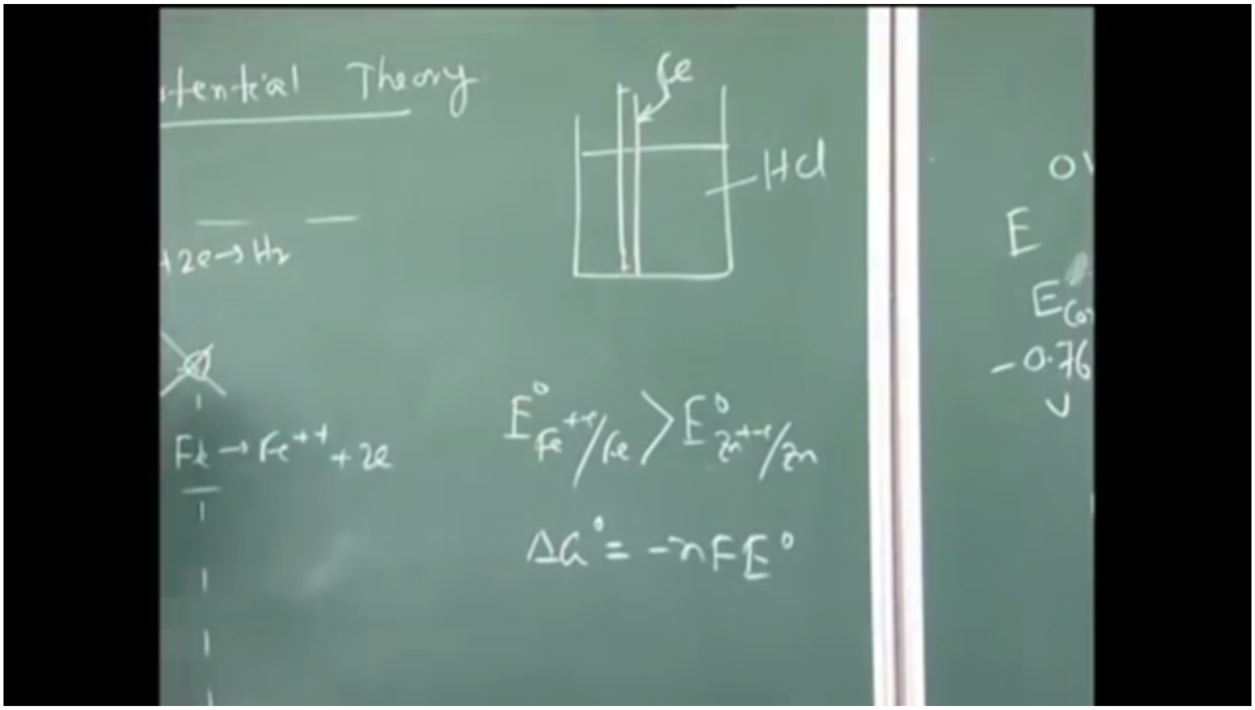

So E^0 nothing but because these two are constants, E^0 are nothing but ΔG^0, which is the standard free energy change. So it talks about free energy. Free energy is only free energy means it's thermodynamics and thermodynamics if you go by the thermodynamic things, it's very clear that this has higher reduction potential. That means it has higher reducing ability than this, but let me see which case should it should -- which case would be more detrimental in HCl medium if you dip them separately? Which one, whether iron will corrode at a higher rate or zinc will corrode at a higher rate? Let us understand that part.

Now I am just superimposing this on to this and let me put some values. Okay if you see the values, then values would be around this is about -- this value, this i_0 value for hydrogen evolution on iron surface is about 10 to the power -- iron of the range of 10^{-5}, 10^{-5} ampere centimeter square, and this value is about -- this value is on the little almost on the same level, almost on the same level.

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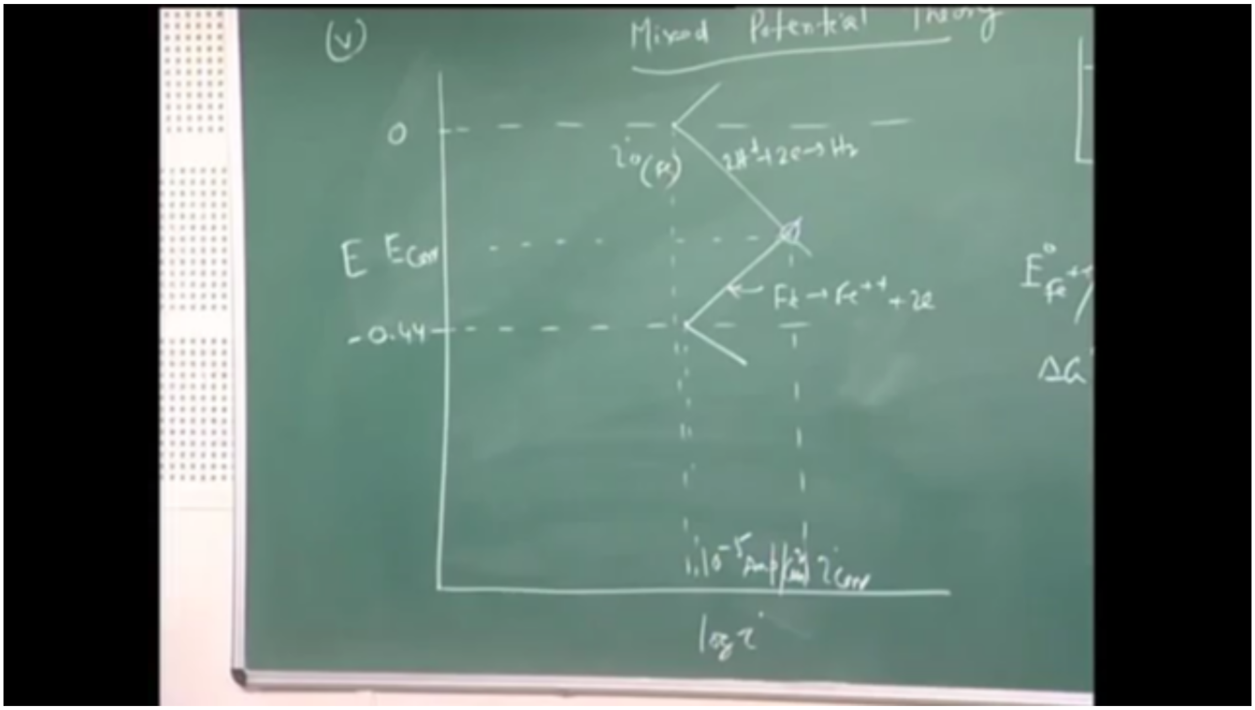

Now if you see the values here, this value is of the order of -- this i_0 value is of the order of 10^{-11} ampere centimeter square. This is of the order 10^{-11} ampere centimeter square and this is of the order of 10^{-7}. This value, if you see the value 10^{-7} ampere per centimeter square. So i_0 values for zinc, i_0 values of hydrogen on zinc surface, these are the values. Okay.

Let me see on the scale where would my i_0 value for hydrogen evolution on zinc surface lie. So this is 10^{-5} and I know that it's 10^{-11}, so it would be around this point, 10^{-11} i_0, and this is same hydrogen evolution reaction and I am just putting this on this. So this is again this one and this would be parallel because it's the same reaction, and if you extend this, let me extend this. Okay, and then let me see where would my -0.76 volt for zinc reaction and that case my value is 10^{-7}, let's say this is my 10^{-7} so -- and this my -- this is my i_0 for zinc on zinc surface and this would go like this. Fine.

So let me connect it with a different color. So which one is the point here where you have rate of electron consumption and rate of electron generation, both the rates are same? So this is the point. This value -- let this value -- this is i zinc. Let me put i_{corr} zinc and which one is i_{corr} for iron? This is my I_{corr} iron. So which one has the higher value? I_{corr} iron is greater than i_{corr} zinc in HCl deaerated -- deaerated.

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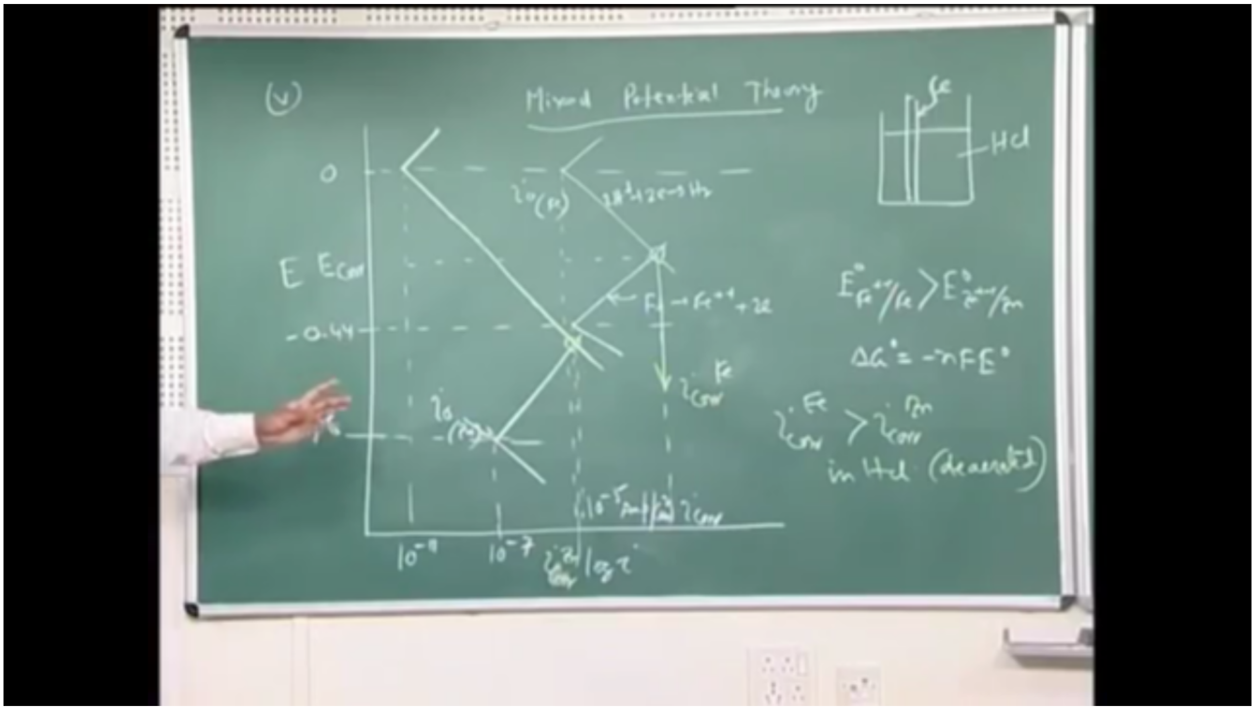

So now you see though iron has the higher reduction potential in the reduction potential series than zinc, but if you put it in HCl separately, separate two beaker, you are putting, one case you are putting iron and one case you are putting zinc with the same concentration of HCl, then you will see that iron corrosion rate is higher than the zinc corrosion rate. Fine.

So that means with the information from the standard reduction potential series, we can only say that which one is active, which one is -- which one is noble, but rest thing we cannot say, but actual situation will be different like this. The actual situation says that even if a metal is noble in the reduction potential series, that can be -- that can corrode at a much faster rate in a medium than the other which has -- which is far below that reduction potential and that has active nature. Fine.

So that means you have to understand thermodynamics for the understand -- for understanding what would happen and you have to understand what is the kinetic which tells you what actually happens. So this is the situation in one situation, one case.

Now let me come to another interesting observation. Now you have heard galvanization is done to protect iron surface and galvanization is done with zinc coating. Fine. Let me come to this side. Now one thing, let me tell you one thing before going into the galvanization part. You see there is one more governing factor, one important governing factor rather which decides which one would corrode more at a higher rate than the other one.

For example, iron here, it is corroding at higher rate than this even if iron has higher reduction potential compared to zinc. The main guiding factor, one of the main guiding factors is i_0 of hydrogen evolution reaction on iron surface as well as zinc surface.

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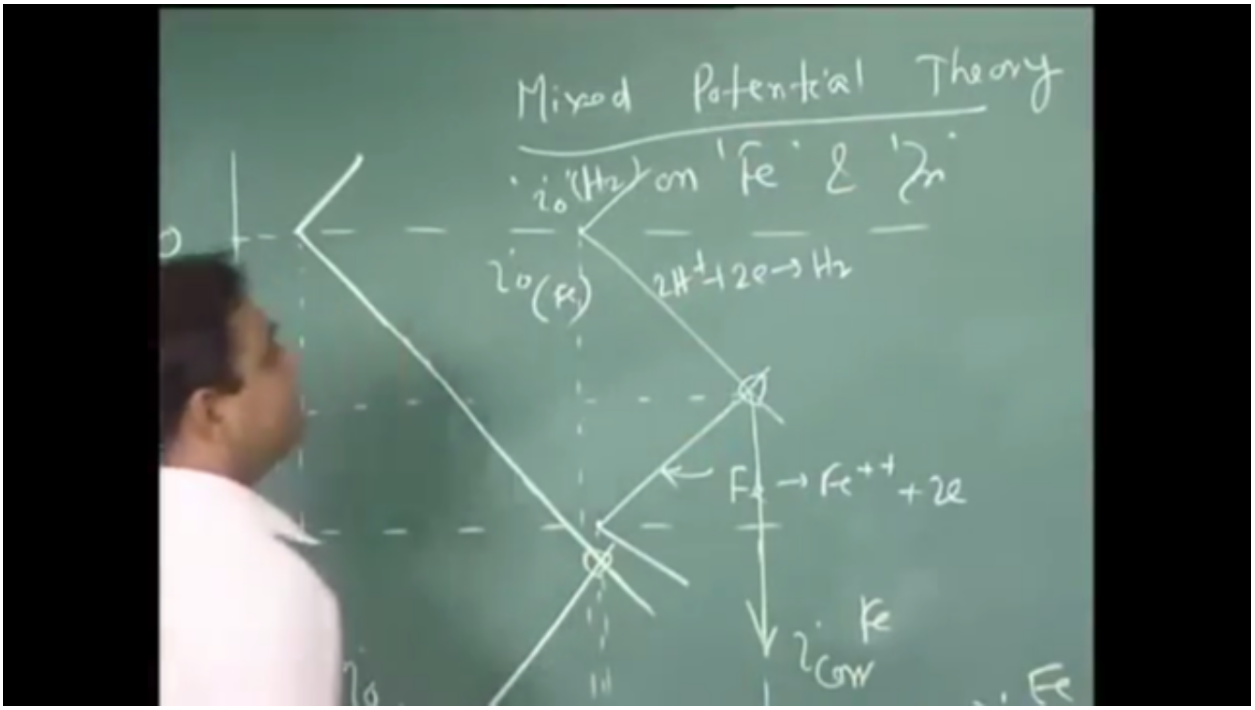

Now here you see the main difference what is coming because of i_0 values because i_0 of hydrogen evolution on zinc surface is less than less than i_0 of hydrogen evolution reaction on iron surface. That is the main culprit. That is why iron has higher corrosion rate than zinc and this i_0 apart will be very, very important factor in the coming discussion.

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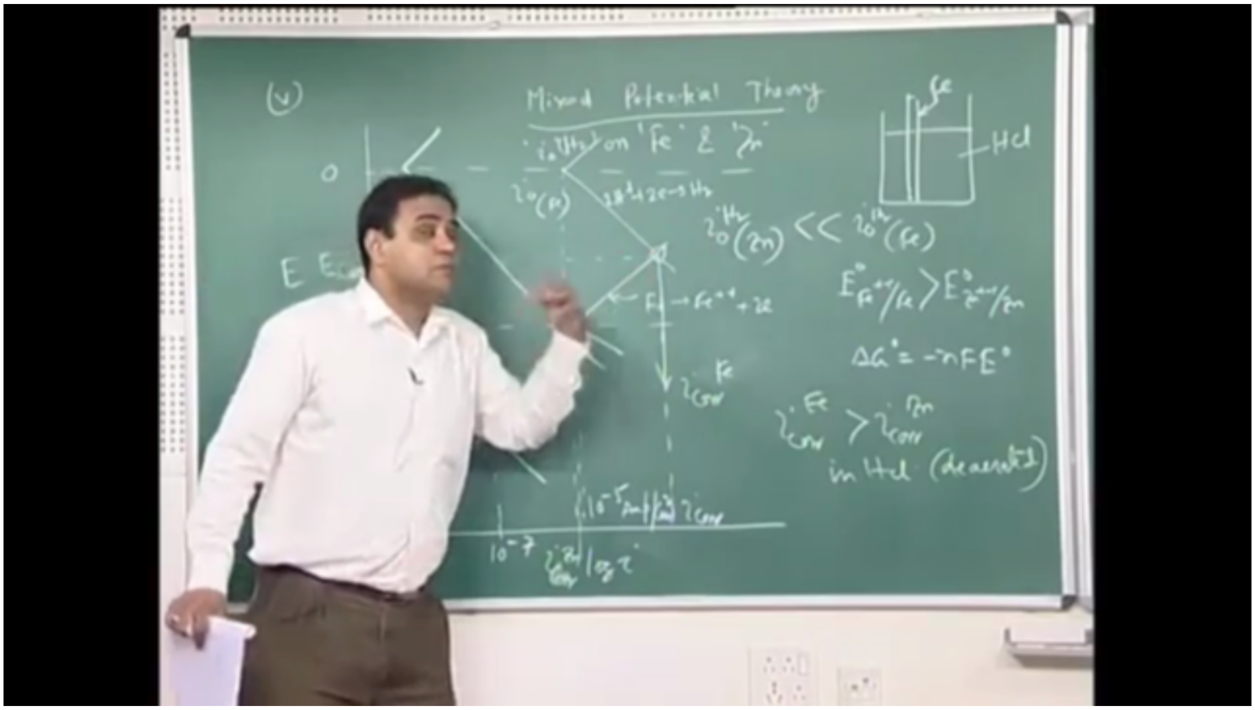

So we have seen what happens if you dip iron and zinc separately in two beakers in HCl of same composition, but let us see if we combine iron and zinc, that means if you galvanically couple iron and zinc at the same area and dip it in HCl, what would happen and that too in deaerated HCl? That situation will be little complicated.

Now, again, let me plot the same graph. This is log i and this is potential. Now I know what is my hydrogen point this is my 0 volt and this is my 0.44 volt for iron. This is minus volt for iron, the standard reduction potential and this is my standard reduction potential for -- 0.76 volt for zinc.

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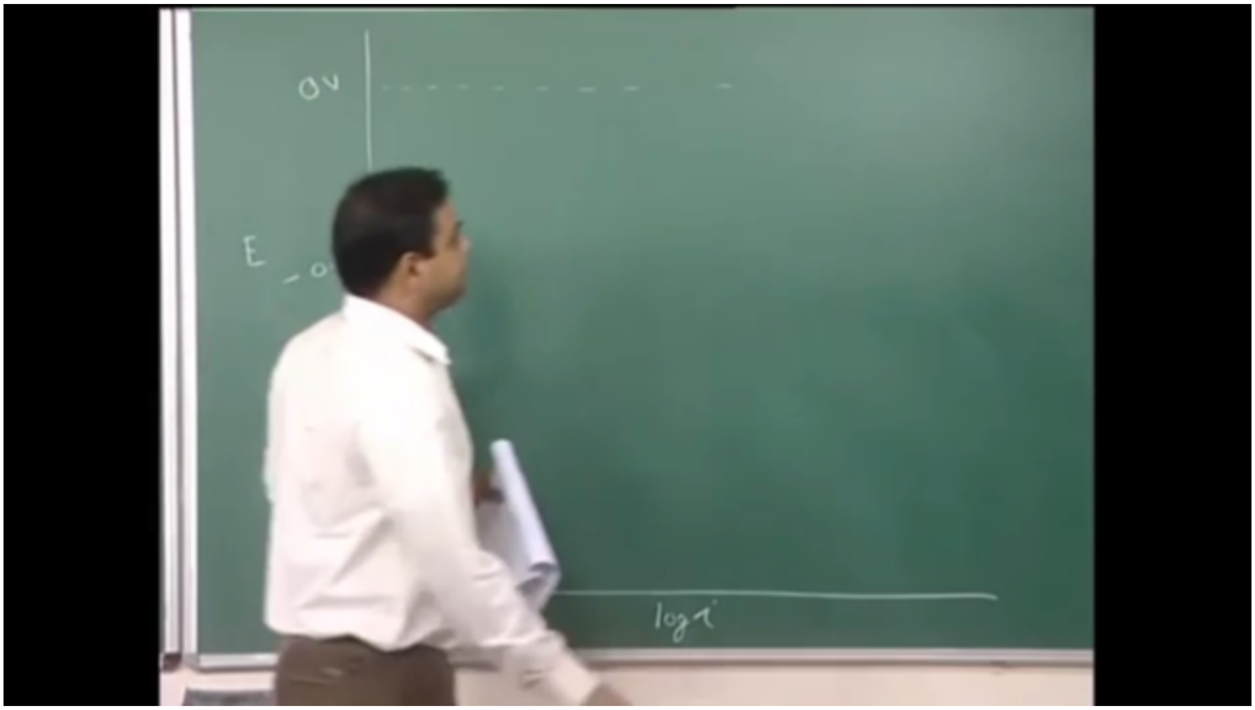

Now here the experiment is this. You have a beaker where you have HCL which is deaerated and this is also very pure. You don't have any other ions in it, and that case you have a block with the same area fraction and this is iron. This is zinc. Both are galvanically coupled.

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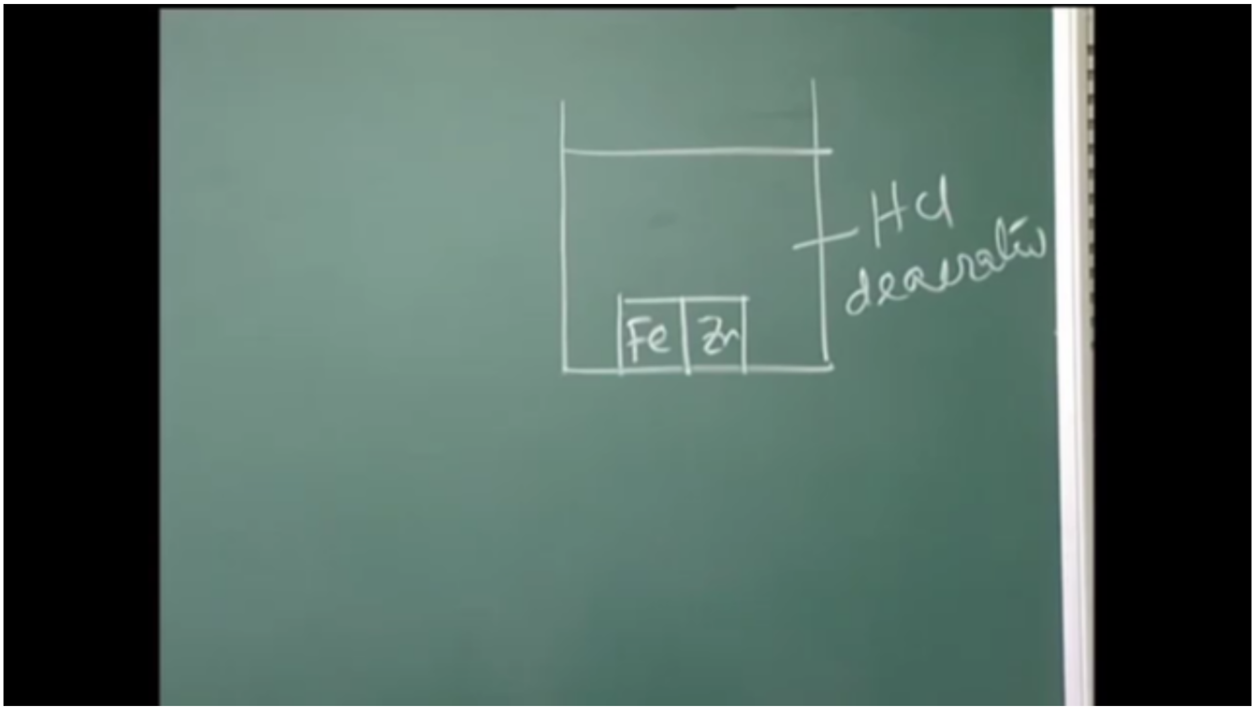

Now in that case we have to see which one corrodes faster whether iron or zinc because here iron corrodes faster, but let me see what happens here. Now, again, I will start plotting all those individual lines seeing the position of that -- of those i_0s. So I will have this. Similarly, I will have for iron and in this case it would be -- let me start from here. This would be this. Let me first plot all the lines, then I will come one by one. Now again this point, which is, okay. Now this is my -- this is my i_0 for zinc. Just let me plot the zinc part with a different color -- with a different color, zinc line with a different color. Fine.

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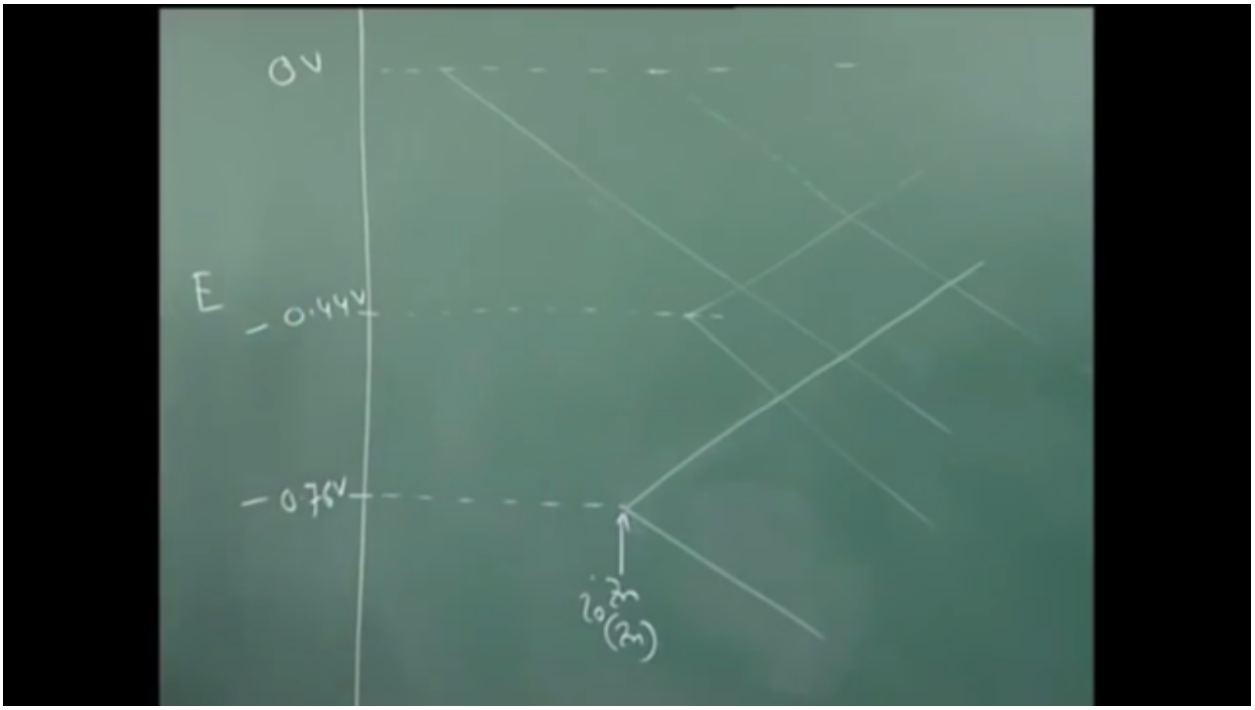

Now hydrogen evolution on zinc surface that too I will put the same color where -- which one I have used for zinc. Okay. Now this is i_0 -- this is i_0 for iron on iron, zinc surface, on iron surface rather. This reaction is taking place on iron. So this is iron, and this is i_0 for hydrogen on zinc, and this line, this white line, and this white line, this line is for iron, iron going to Fe^{++} plus 2e and this is H^+ plus 2e equal to H_2, and this is i_0 H_2 on iron surface, iron factors.

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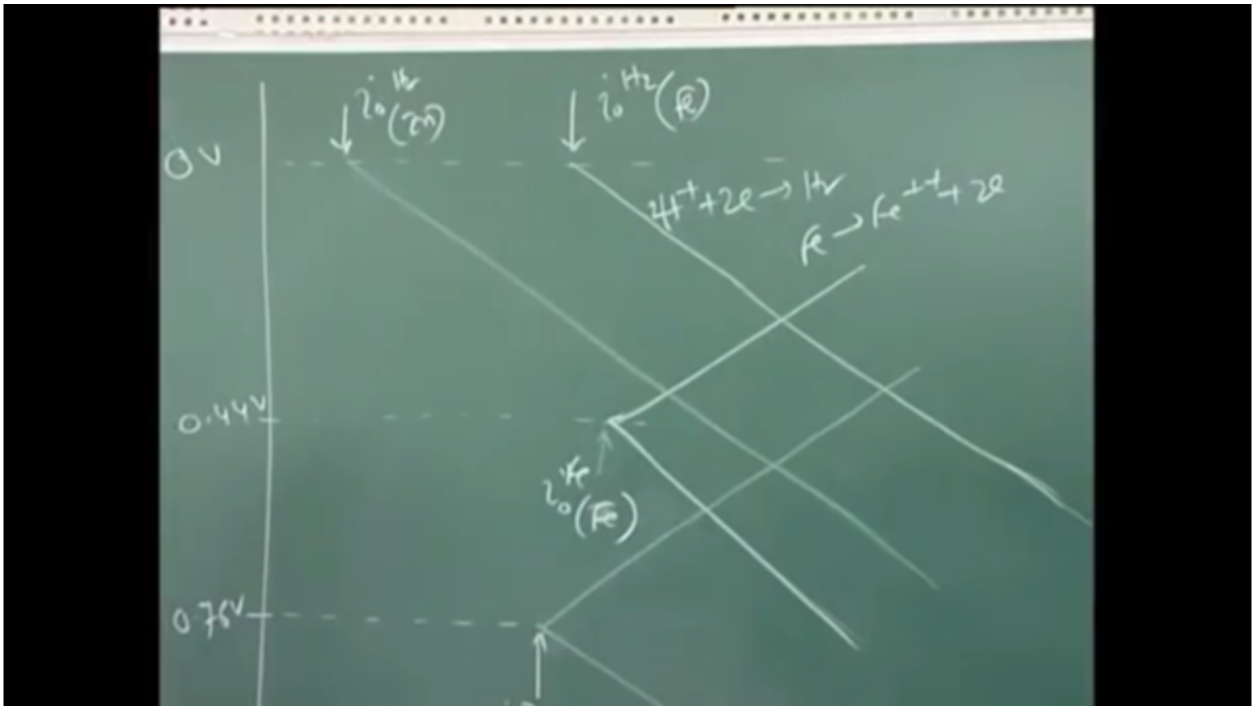

Now here we have mixed electrode of iron, mixed electrode of zinc. So here this reaction is taking place and iron is going into solution, and here O reduction and zinc is going into solution.

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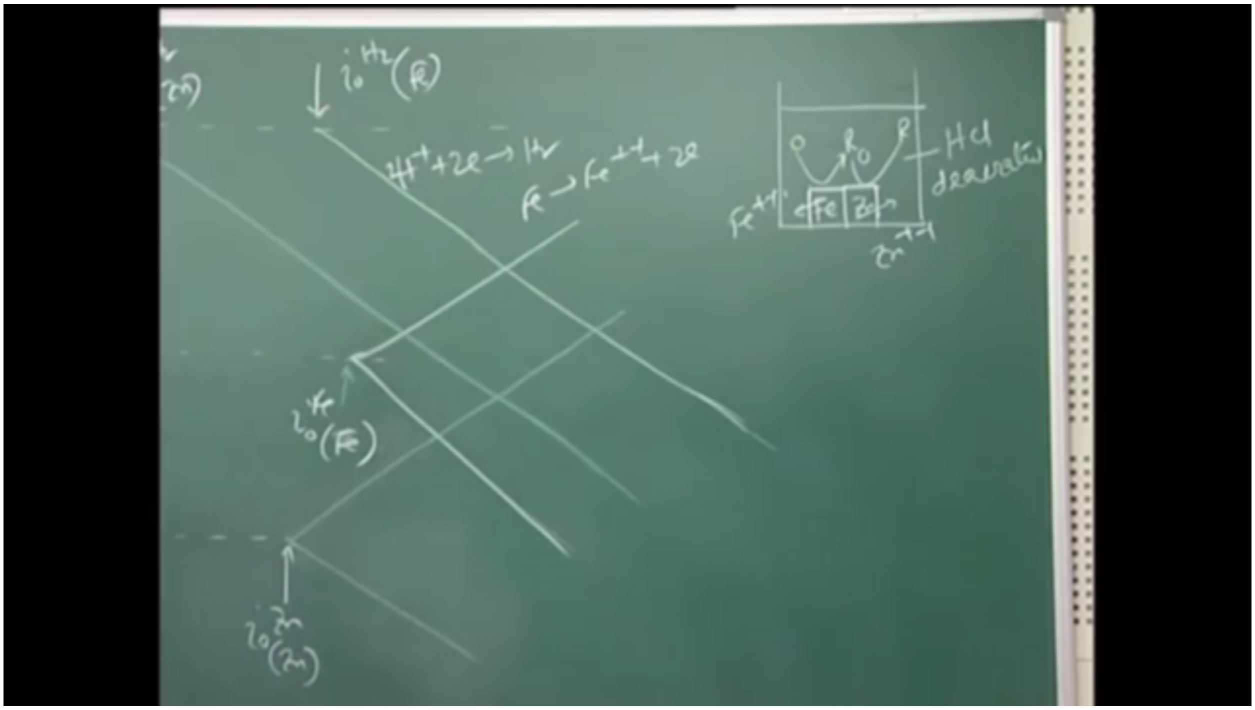

Now the point is we have to see this is a mixed electrode total, in total, if you see the mixed electrode, I have to see what -- at what point the rate of electron generation and the rate of electron consumption, these two rates are same, and this is zinc going to zinc^{++} plus 2e, fine, this -- this line, and this is basically 2H^{+} plus 2e, H$_2$. So this is for hydrogen.

Now as I go, let me start with this -- with this line. As I go along this line, when I reach to this only the anodic reaction if you consider, when I reach to this point, as I am going along this line, I will reach along this line, I will reach to this point at this. I will reach to this level of potential at this point.

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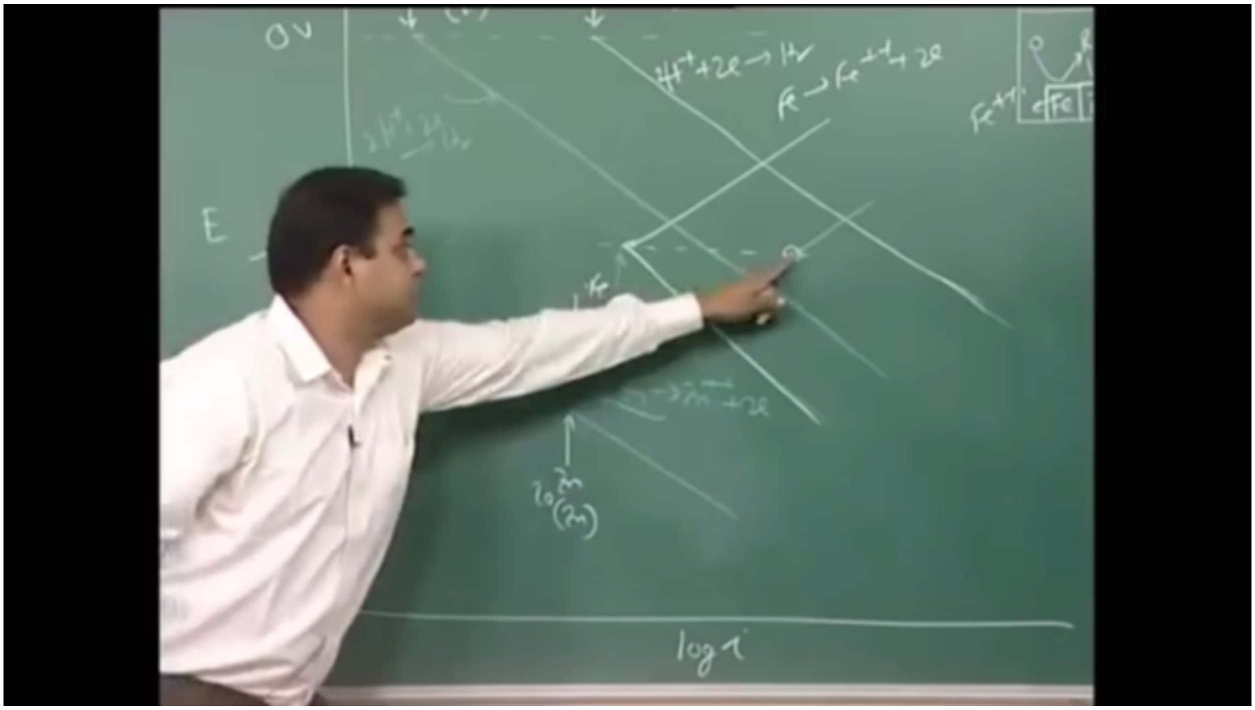

Now from this point if we further go ahead, I see that I am coming across one more anodic reaction, which is nothing but this, this, this anodic reaction is coming across. So if I go along this line, I have to see what would be my total anodic reaction, and the total anodic reaction, if I understand, then I can understand what would be my total generation rate of electron.

And here we have an anodic reaction and also it is related to log i, i value, which is current density, which is nothing but the rate of electron generation. Here also I am having one more reaction. So you have to add these two. We have to add these two reactions at this point because from this point onward you have two more reactions. So that case I will have to construct one more line. I have to go ahead. I have to add this current to this and then, accordingly, I will move along this line.

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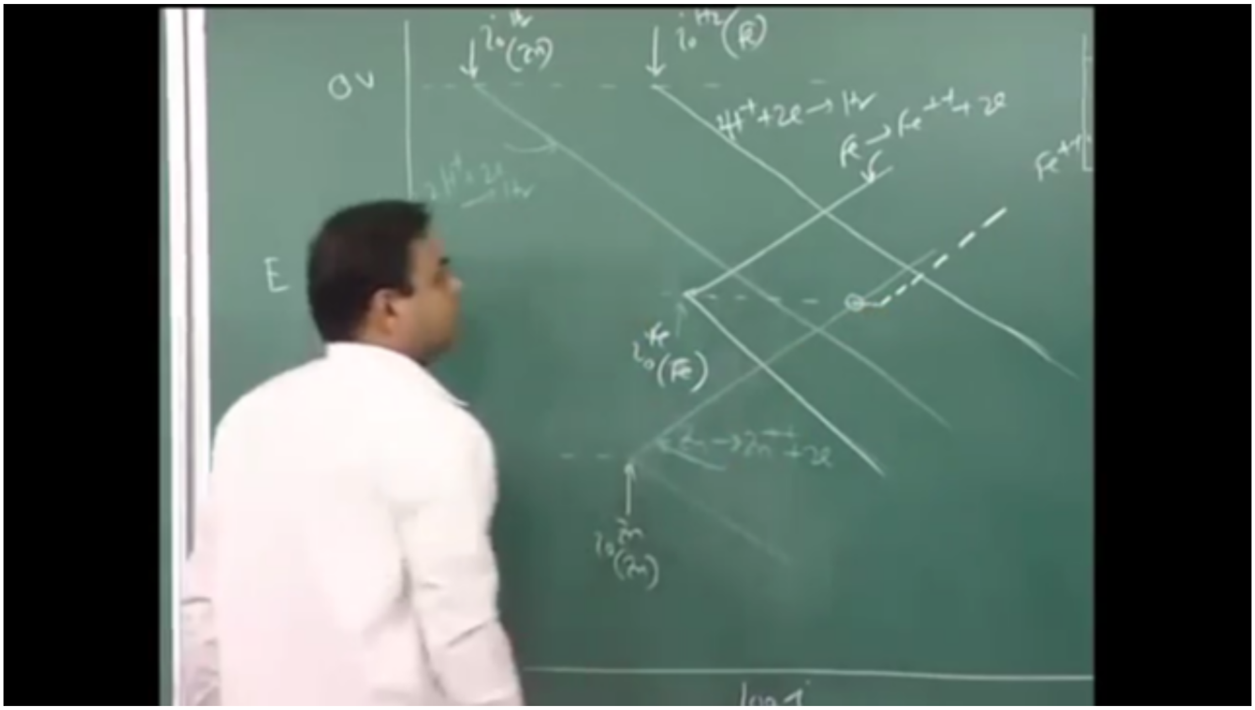

The total anodic reaction rate I have to consider. So from that point onward my polarization line will shift from this to this. So my actual plot would be this dotted line. Actual polarization, anodic polarization line would be this dotted line. And similar way, if I see what would be my let's say at from this point if you see, there are two hydrogen evolution reactions. One is this and one is this. So in that case also, if you see from this, so we have to understand what is my total electron generation rate, electron consumption rate?

Electron consumption rate, that means we have to add up the both the cathodic reactions. Here we have two same cathodic reactions are happening on the same on both the sides, so we have to understand what is my total generation rate of electron. So total generation rate of electron would be decided if I -- if I combine these two currents. This is current for hydrogen evolution reaction on zinc surface. This is current for hydrogen evolution reaction on iron surface. And what would the total hydrogen evolution reaction? This would be decided by these two, addition of these two. You have to add these two. So my line will start on the right side of it. So it will move like this.

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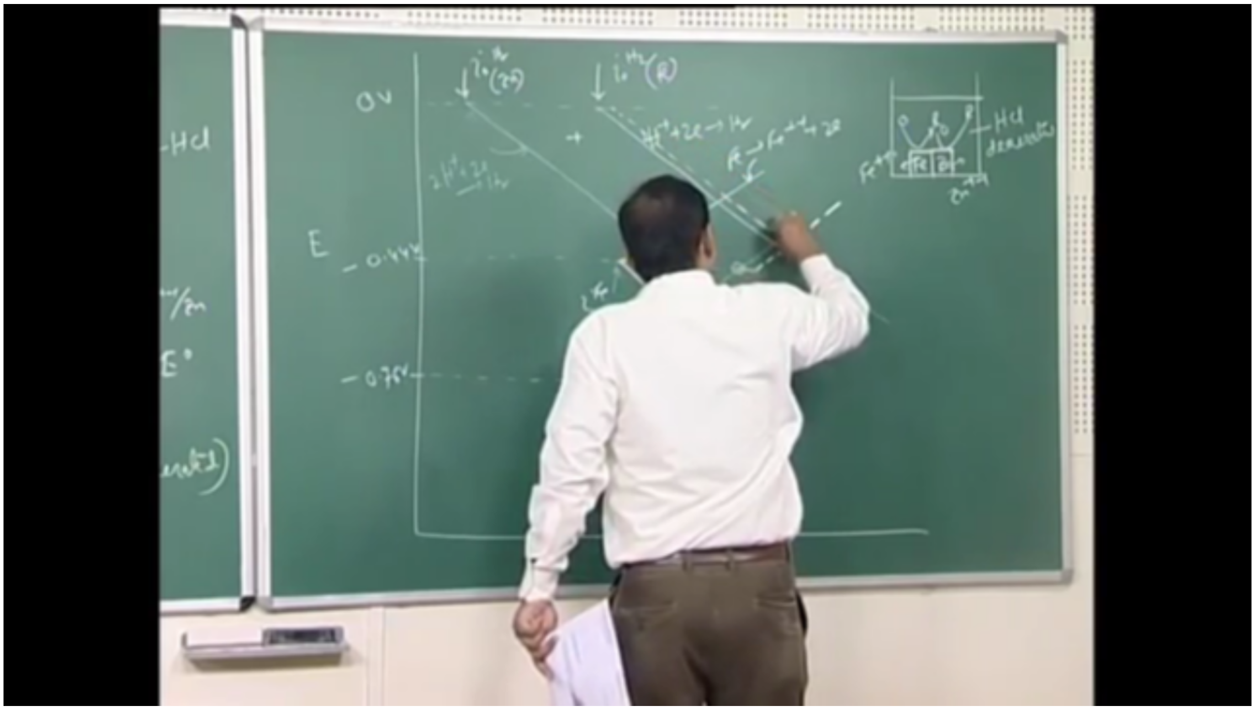

Fine. So this is my new line for my cathodic -- total cathodic reaction. Fine. So at what point these two are combining? This is the point. This is the point. And you see this line is nothing but total anodic reaction rate which is nothing but i_{Fe}/Fe^{++}. Plus plus I am just showing the anodic reaction plus i_{Zn}/Zn^{++}. So this is nothing but -- this line is nothing but this and what is my total cathodic reaction? Total cathodic reaction is this, which is nothing but H_2 on zinc surface plus i H_2 on iron surface. Fine.

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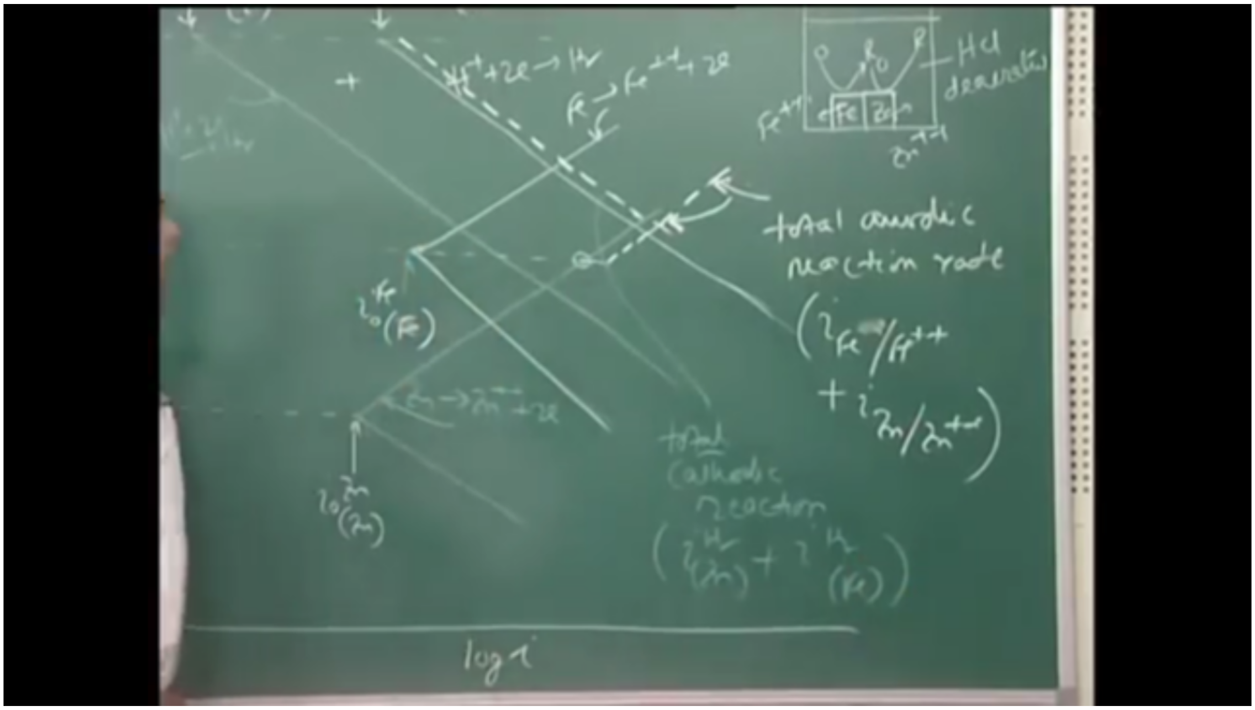

Now if I have to see that second consideration in case of mixed potential theory, it says that there should be charge balance. Charge balance means the rate of total anodic reaction should be equal to the rate of total cathodic reaction. So at this point you see the rate of total cathodic reaction is equal to rate of total anodic reaction. So my new corrosion point would be this, this point.

Now, correspondingly, I have to see at this point, what is the corrosion rate of zinc and iron? So since I know this point is my new corrosion point, so I will have corrosion of this point is nothing but let's say i_{corr}. So i_{corr}, let me put it here, i_{corr} equal to i_{iron} plus i_{zinc}. Now I have to find out where is the point of i_{corr} zinc and where is the point of i_{iron}. So I have to draw a straight line.

So I will just draw a straight line. This is my straight line which connects and this is my potential. This would be my E_{corr}. This would be my E_{corr} and what would be my i_{iron}? I_{iron} is this, i_{iron}, and what is my i_{zinc}? I_{zinc} is my this point, zinc, which this line connects this, this line at this point.

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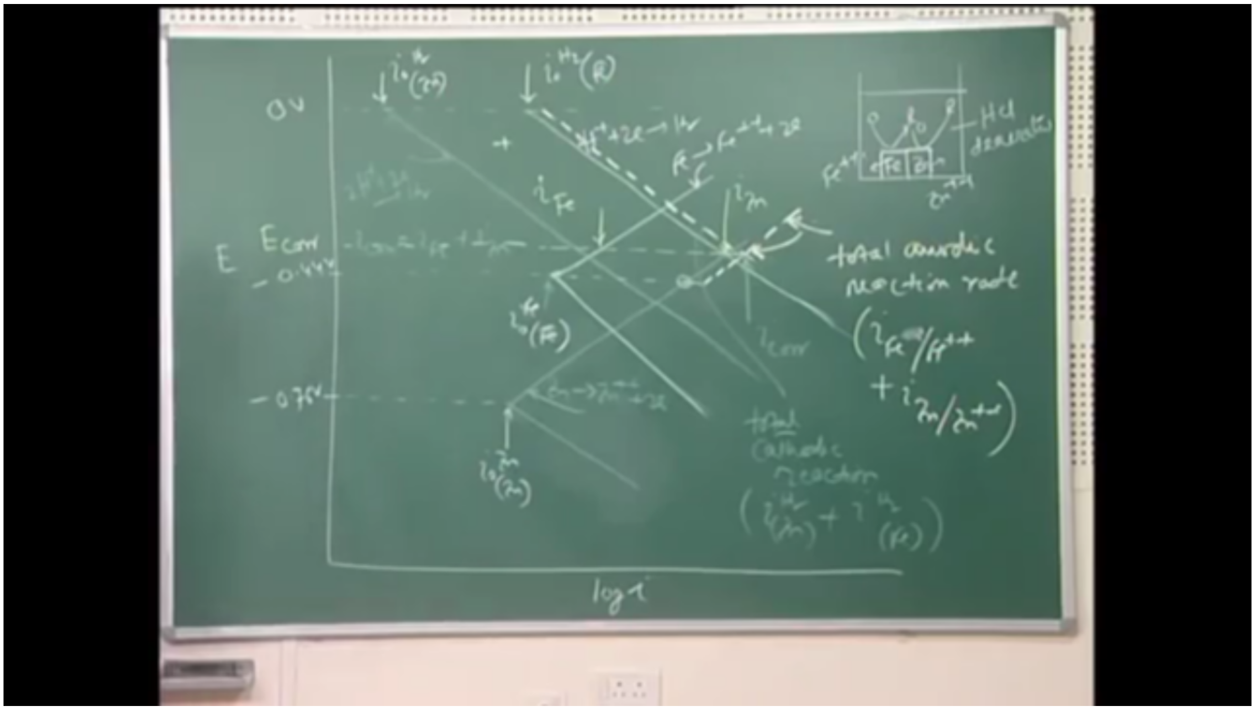

So what is the rate of iron and zinc? Then from this, from this plot, you can easily see this is for iron corrosion, and this is for zinc corrosion individually, if you consider, then i_{Fe} is less than less than i_{zinc} since this is on the left side of this and this is in log scale. So once you have it in log scale, so it increases or decreases in order of 10. Fine. So that means iron corrosion would be less compared to zinc corrosion.

So this is interesting because now you see this plot and that plot. In this plot, iron corrosion rate is more than zinc if you dip these two pieces separately in HCl, but once you connect them on the equal area ratio, and then dip it in HCl of the same concentration, you see that iron corrosion rate is decreasing. Fine. And this is the reason why zinc is used for galvanization on iron surface.

So if you use zinc on iron surface, let's say you have -- have a galvanized iron piece. This is iron and on that surface, you have zinc. This is zinc layer. Due to some reason there is a crack in the -- there is opening in the zinc coating. So you have a open part. Now you are coming across all those corrosives in the environment. So that case it would act as just like this. The coupling will happen between zinc and iron and there would be -- so zinc will preferentially corrode. Iron corrosion rate would be less as we see from here. So this is an interesting -- this is an important understanding and that is why zinc is used for galvanization on iron surface.

So the point is to be noted wherever you come across one more anodic reaction, so that anodic reaction is to be added up. Okay. So that adding a part will give you the final anodic reaction current.

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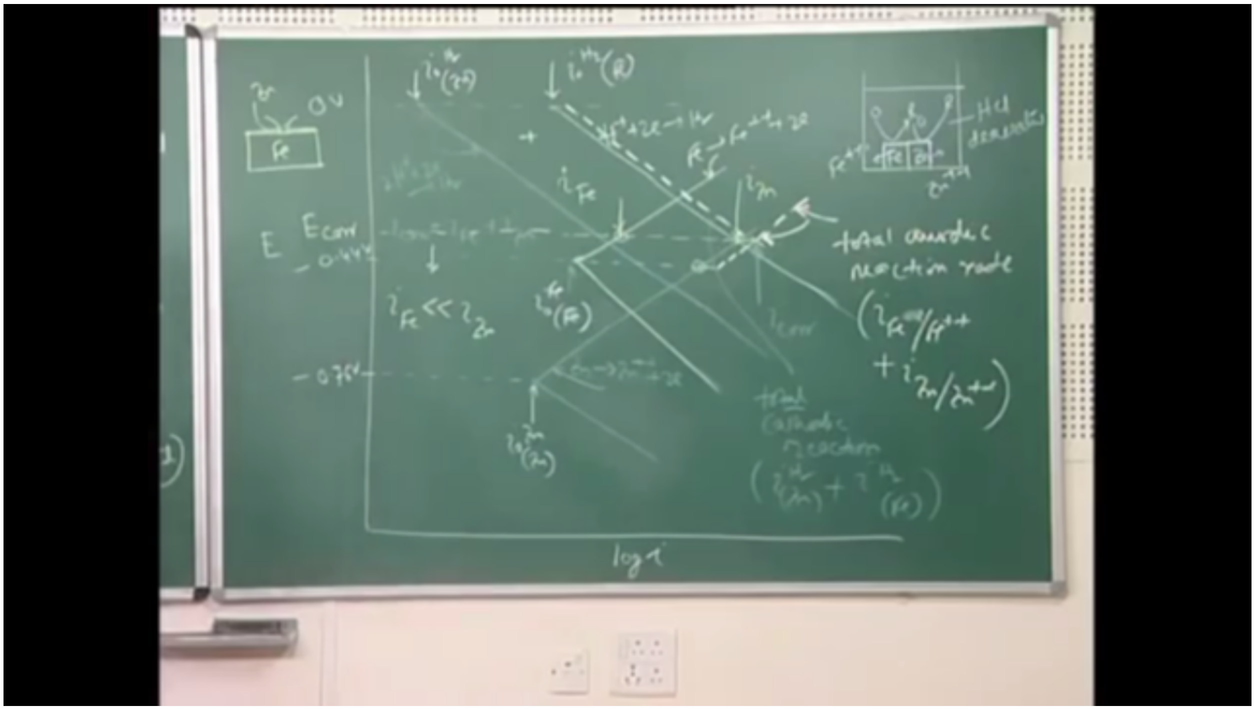

Same way for cathodic reaction if you come across another current, another cathodic reaction while during polarization, you have to add that cathodic line -- cathodic current along with the existing polarization line. So that case, this is my -- this dotted line is my total reduction rate, and we have to see that where my total reduction rate is equal to total oxidation rate or the total -- the rate at which electron is generated would be equal to the rate at which electron is consumed. Fine. So this is that point.

Now individually if you have to see what is the corrosion rate of iron and zinc, so I have to see that which point that line, that potential line cuts the individual line of iron and zinc and from that we can understand that i_{iron}, which is the corrosion rate of iron in that coupling condition, coupled condition would be less than i_{zinc}, so iron is protected.

Now it's understood, it's said that whenever you have zinc coating on iron surface, iron corrosion is stopped. It's a wrong statement. Iron corrosion doesn't stop. Rather iron corrosion is controlled. That means or iron corrosion rate is reduced to a great extent, but it doesn't stop because still we are seeing that there is some sort of anodic current and this anodic current corresponds to the iron dissolution. Okay.

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