**Indian Institute of Technology**
**Kanpur**

**NP-TEL**
**National Programme**
**on**
**Technology Enhanced Learning**

**Course Title**
**Environmental Degradation of Materials**

# Module 01 Lecture 16

## Broad Subject: Explanation of corrosion events on the basis of Mixed potential theory, Effect of impurity, Effect of area factor

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Let us continue mixed potential theory and let us see whether we can explain some of the corrosion examples. Last lecture we have seen the effect of galvanization on steel. Let's say you have zinc rod and iron rod, both are immersed separately in two beaker -- two beakers containing the similar HCl acid of the similar quality, then we have seen that the zinc corrosion rate is less than the iron corrosion rate if they are immersed separately in HCl solution.

But we have seen that if iron and zinc are gavanically coupled and immersed in HCl, then the situation is reversed. Now the situation would be here the iron corrosion rate would be greatly reduced and whereas the zinc corrosion rate will -- will enhance. We have seen -- we have tried to explain with -- with reference to mixed potential theory.

Now let us take few more examples. Let's see one -- another one example is let's say that if that one was -- let me take one example, that example if you are -- if we have HCl acid, which is not pure and which is all still deaerated, deaerated HCl acid, and in that HCl acid we have impurity and that impurity is nothing but ferric ion, $Fe^{+3}$ ion.

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Now you have two beaker and one beaker you have HCl, deaerated HCl, which is pure. It doesn't contain any impurity, but in this case you have HCl plus $Fe^{+3}$. Now you -- if you immerse one zinc block, here also you immerse zinc block of the same quality, then you will see the corrosion rate in this case will be much more -- much more than -- than that -- that of zinc in HCl.

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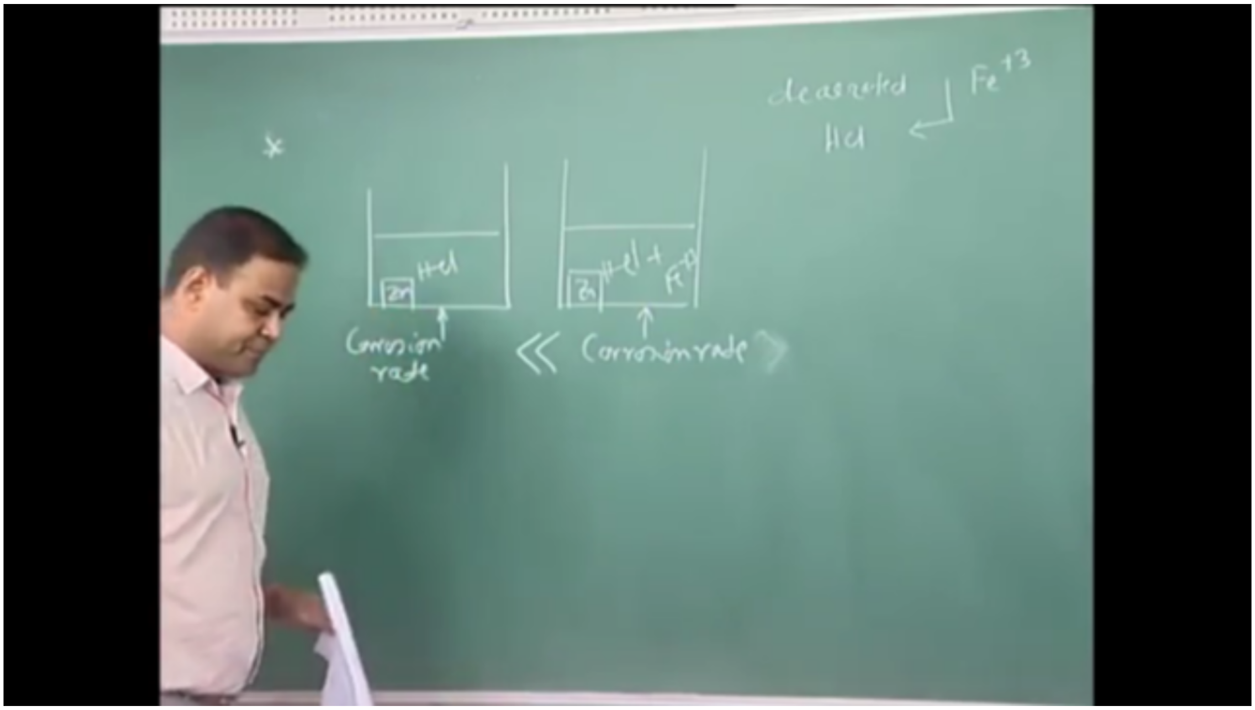

So if you consider the corrosion rate in this case would be greater than -- would be greater than corrosion rate in this case. So, sorry, this is just reverse. Yes, it is fine. So corrosion rate in this case would be much more than the corrosion rate -- what? The corrosion rate of zinc in pure HCl. So let us find out what should be the reason.

Now again let us plot two diagrams. In one case let me first try with, this is potential, which is nothing but (indiscernible 03:33) diagram and this is log i where small i means the current density.

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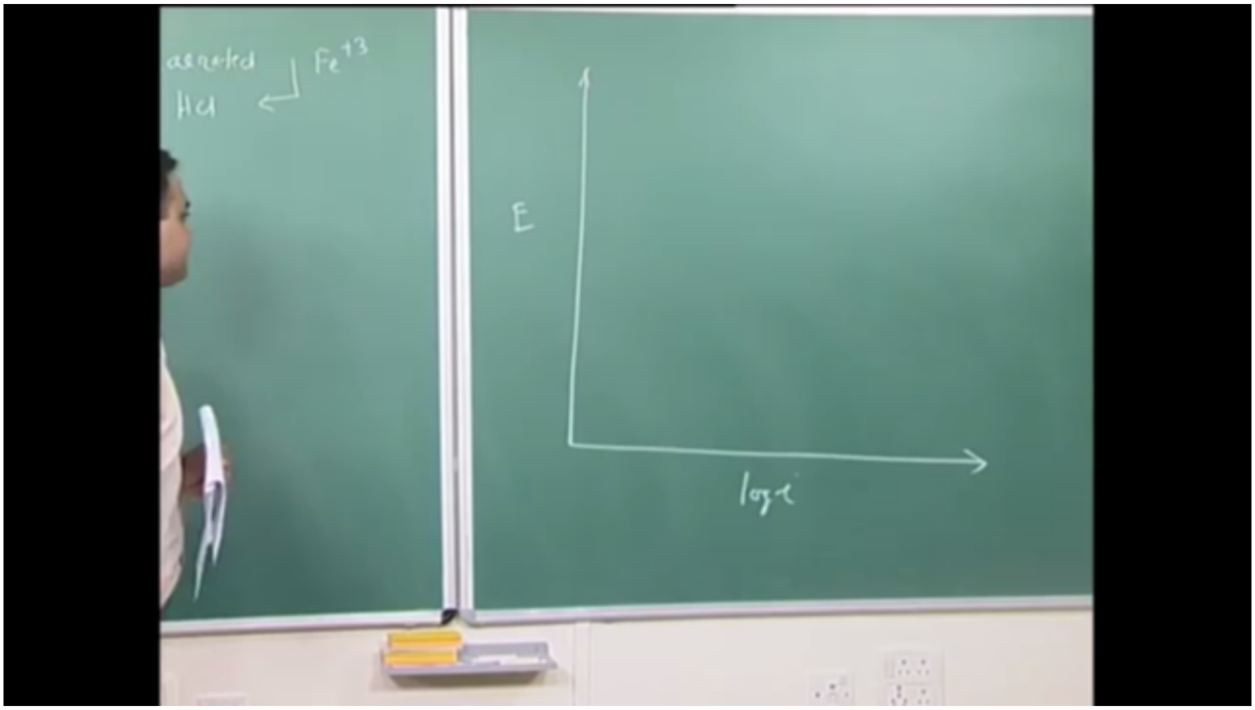

Now let me see where we have $E^0$ for $zinc^{++}/zinc$ and it should be if you are taking standard condition, then it would be -0.76 volt. Now in this case the cathodic reaction would be hydrogen evolution reaction, so hydrogen evolution reaction corresponding potential $E^0$ of $H^+/H_2$. So now let me -- this is my $i_0$ on surface. This is my point and $E^0$ for hydrogen on zinc would be around this.

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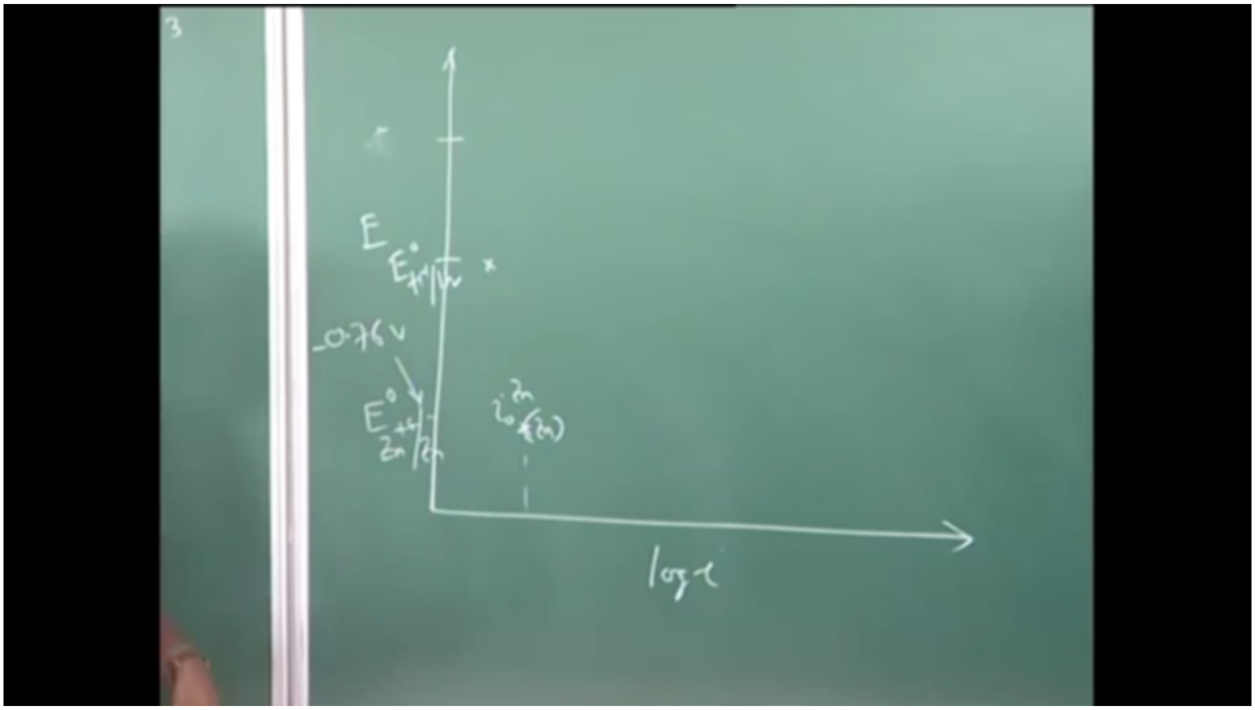

So now we would like to see where -- where is my equilibrium point? Now equilibrium point where the charge transfer rate would be same. It means that the rate at which electrons will get consumed would be equal to the rate at which electron will be generated. So now you have seen that you have this situation. Now this is the point where which is nothing but $i_{corr}$ for zinc, and here $i_c$ would be equal to $i_a$. That means the cathodic current density would be equal to anodic current density and this would be equal to $i_{corr}$, and the reaction what is happening here is $H^+$ plus e, H and in this case it is zinc going to $zinc^{++}$ plus 2e. So at this point, the rate at which electron is -- electrons are getting consumed would be equal to the rate at which electrons are getting generated because of this anodic reaction.

Now this is the case, what is happening in this case. In this case, in the case of pure HCl where you don't have any other cathodic reaction, only one cathodic reaction, which is hydrogen evolution reaction, you can put it like this, hydrogen evolution reaction. You put 2 here. So now you have the equilibrium point at this point and the corrosion potential, this would be my corrosion potential, which is nothing but $e_{corr}$.

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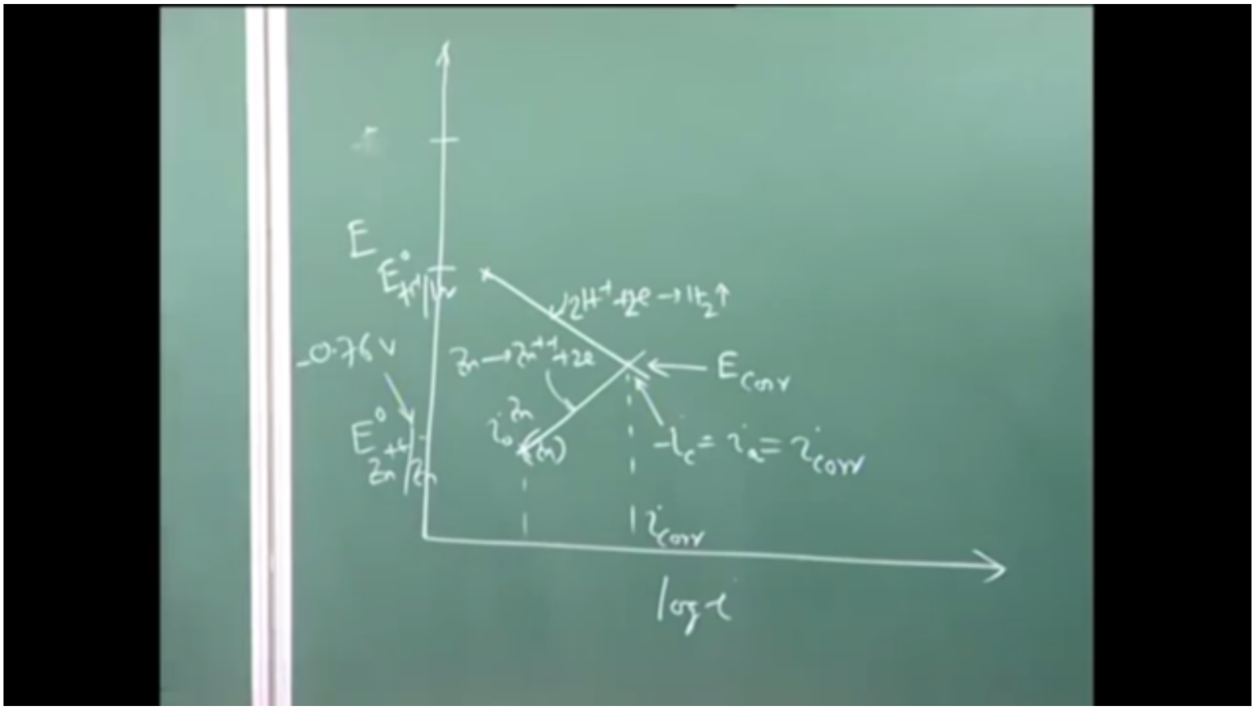

Now let's see what happens here. Now in this case, we have $H^+$ ion. Now $H^+$ ion can get reduced and it will go to H or $H_2$ gas, $2H^+$ ion when this $2H^+$ ions will be reduced, it will form 1 mole of $H_2$ gas.

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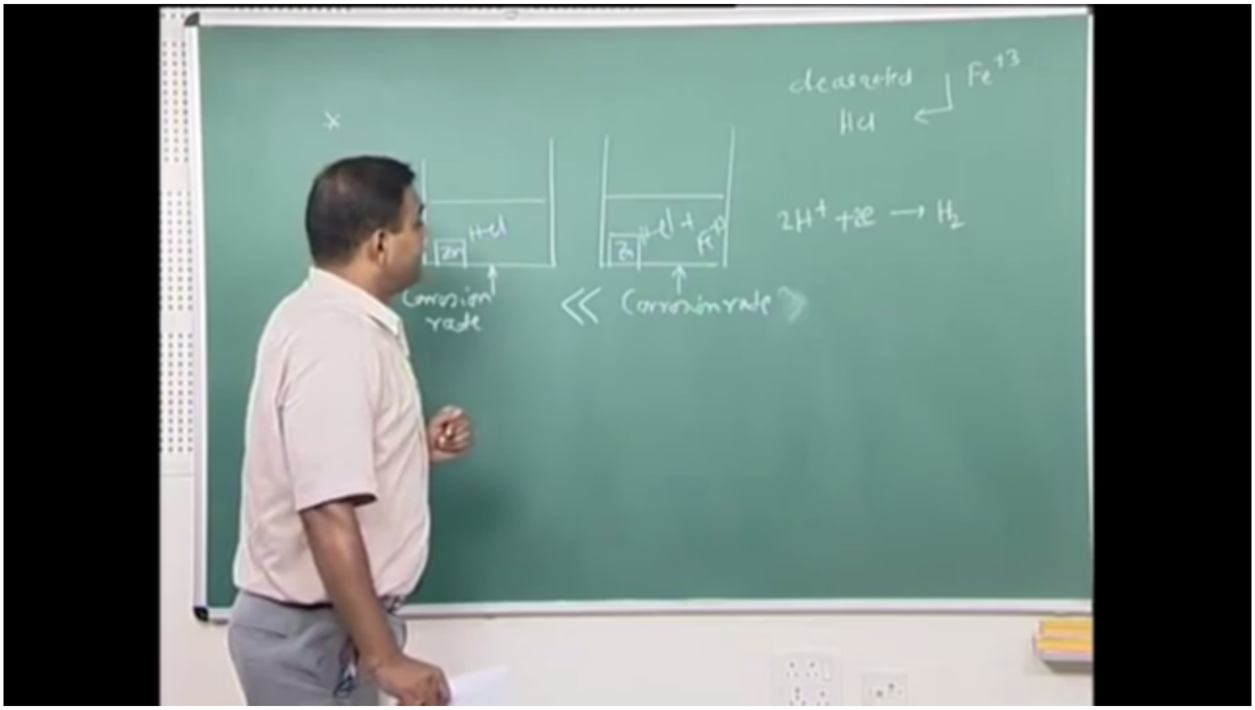

Now there is one more species available in the solution which also leads to occur cathodic reaction. That cathodic reaction is nothing but $Fe^{+3}$ plus e going to $Fe^{+2}$. This is also a cathodic reaction. Now this reaction the potential is nothing but $E^0$ $Fe^{+3}/Fe^{+2}$ is around +2, +3, +3 going to +2, it's around 0.77 most probably. This is volt with respect to Hydrogen, standard hydrogen electrode. Now this is plus and here $E^0$ is basically zero, 0 volt with respect to standard hydrogen electrode.

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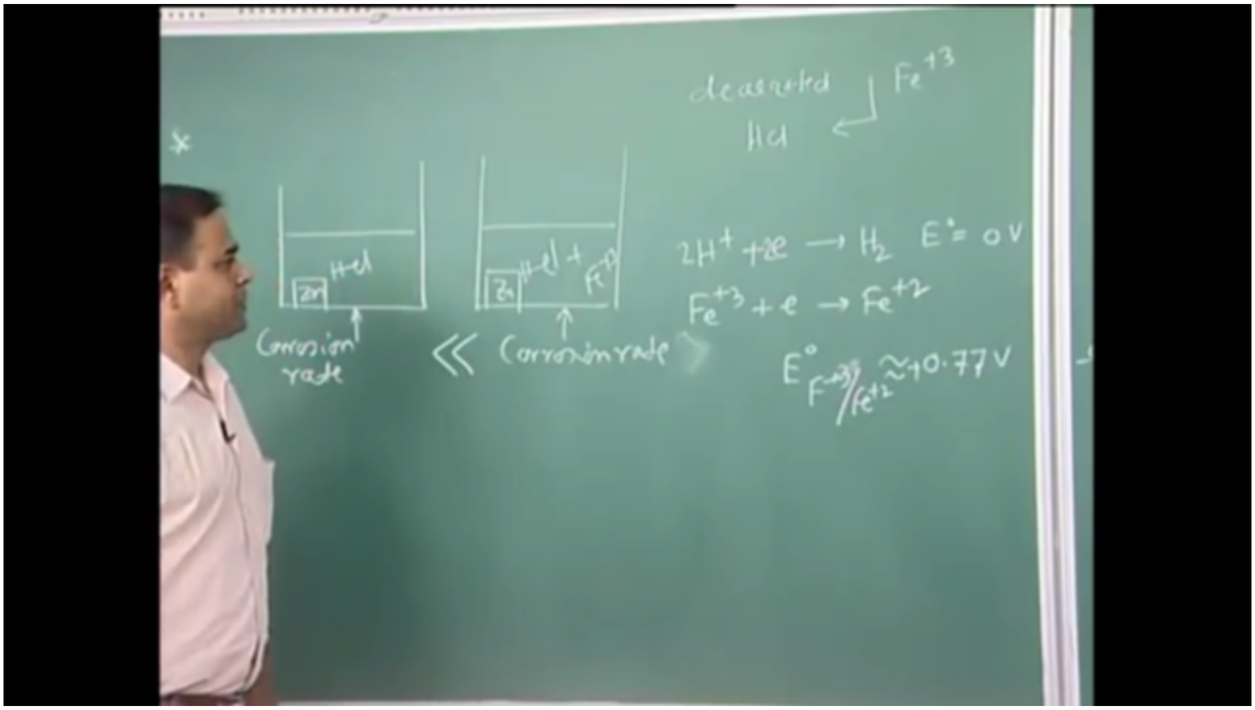

Now since we have one more cathodic reaction, so it also should happen in the same system, and let's say this is my 0.77 volt and from that point, we have to see that how this reaction is happening. So let's say this is my point, which is $i_0$ of $Fe^{+3}/Fe^{+2}$ and this $i_0$ for this reaction is happening on top of zinc surface, so I have to mention zinc in the bracket. I have to include zinc. So that means this reaction the exchange current density of this reaction or of this reaction happening on zinc surface.

Now let's see the activation polarization for this reaction. So this line gives you the cathodic activation polarization for this cathodic reaction. So I write this equation as $Fe^{+3}$ plus e going to $Fe^{+2}$.

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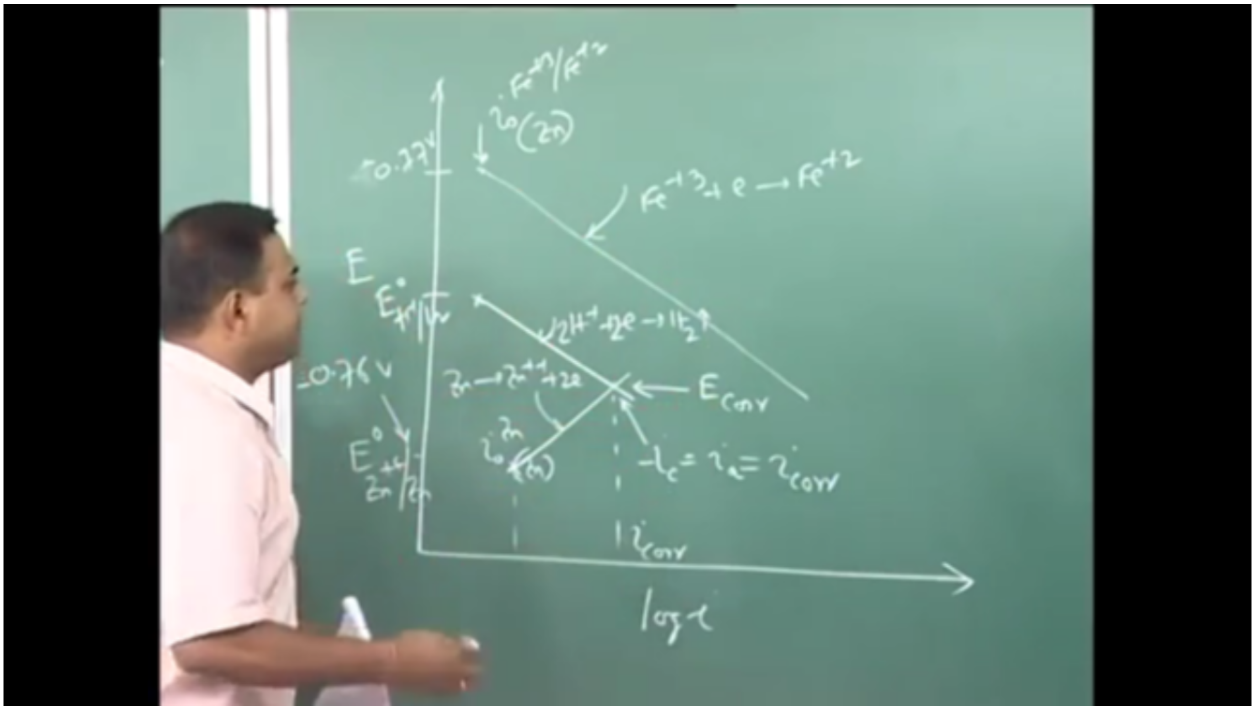

Now the line is coming. If this is not happening, so this line will go, and this will cut at this point. So this is the -- if this hydrogen evolution reaction is not happening, so in that situation, this should be the point where I would get the equilibrium between the rate at which electron is getting consumed and the rate at which electron is getting generated. So this would be the new point.

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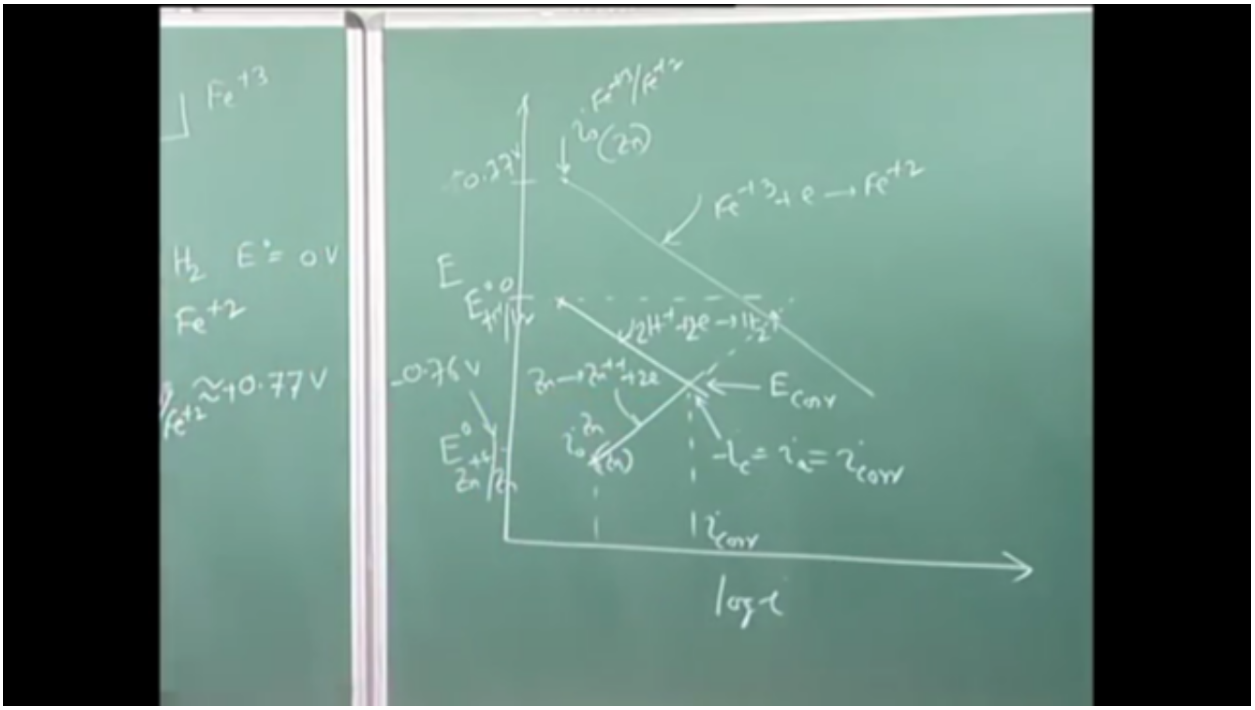

But now when it reaches to this level, this level of potential, which is zero potential, let's say this is zero potential, which is standard hydrogen electrode potential, now at this point when it reaches, now it experiences one more cathodic reaction. So that cathodic reaction is nothing but the hydrogen evolution reaction. So we have to -- as we have seen in case of galvanization of zinc on iron surface, same thing would happen here. So we have to add up all that cathodic currents.

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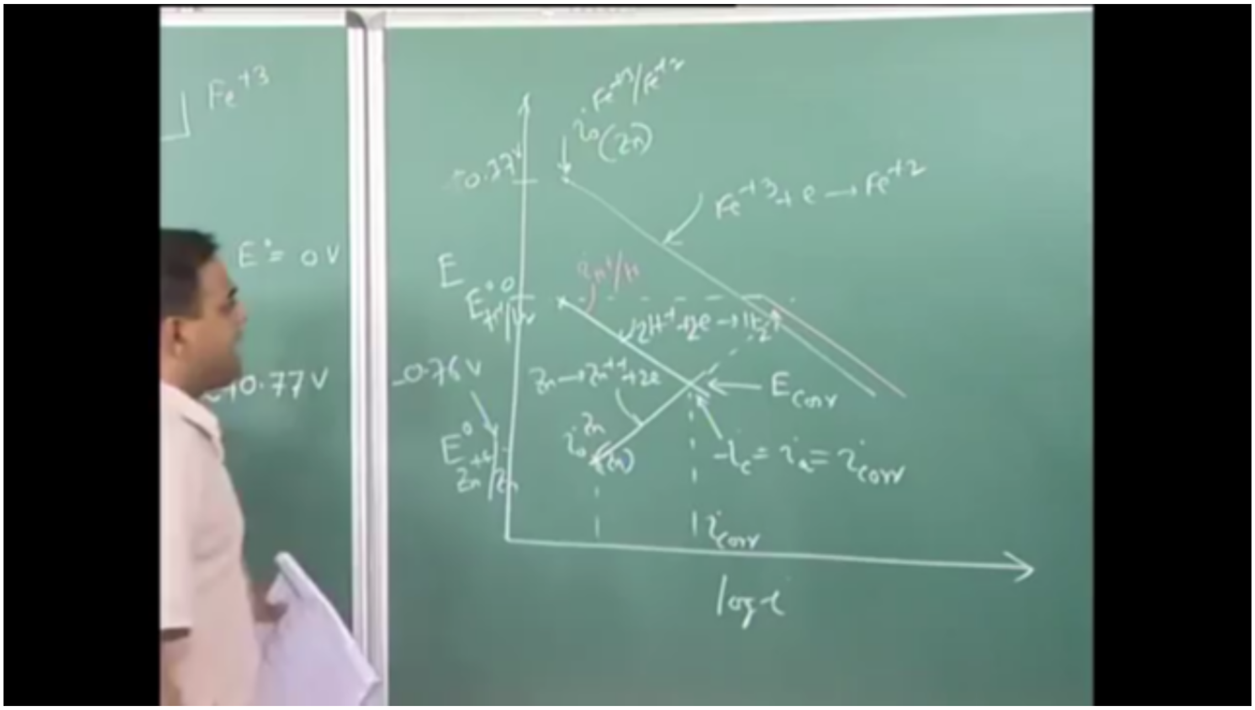

Now if we add up the cathodic current, so you just add it up and it will be along this line. It will be along this line because now this is nothing but I for $H^+/H$, the cathodic current for $H^+$ going to H, that cathodic reaction, and this is for i of $Fe^{+3}$ going to $Fe^{+2}$ and what is the red line? The red line is basically not but $i_c$ which is total. Let me mention total. The total cathodic current density would be equal to i of $H^+/H$ plus $i_{Fe+3/Fe}$ and this is in the straight line because it's in log, log i scale.

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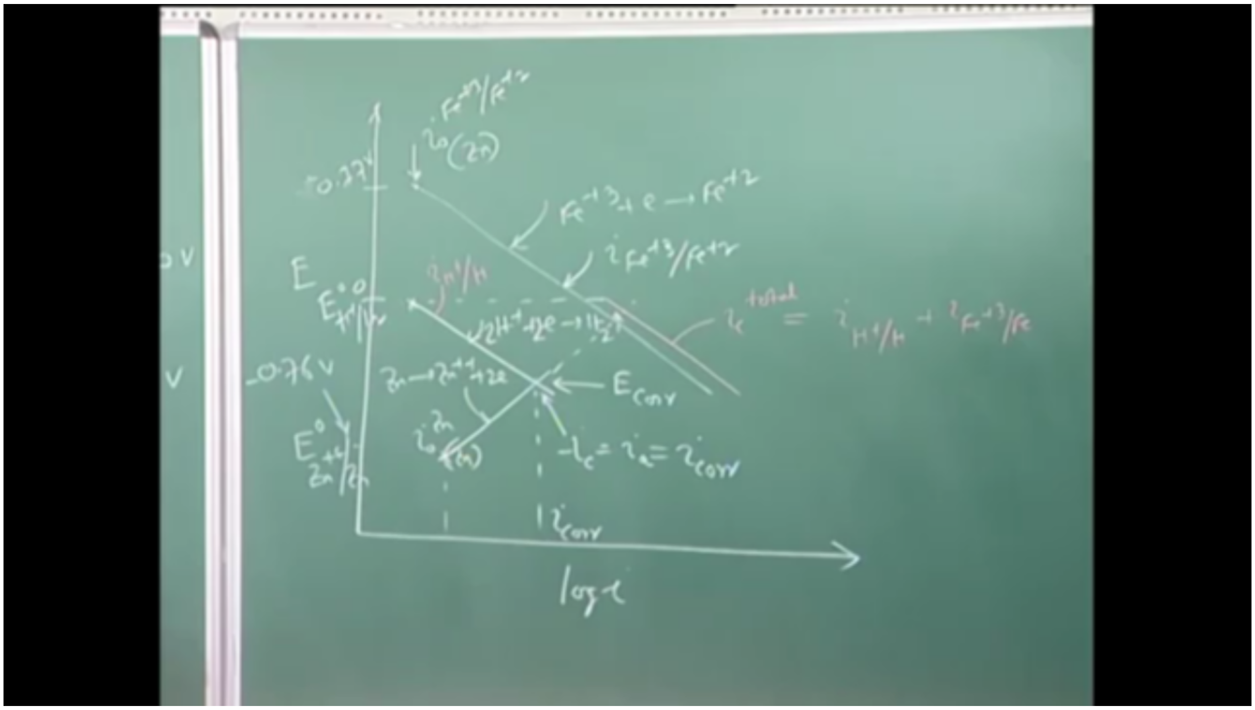

Now what would be my point where I would see the rate at which the evolution or the generation of electron would be equal to the consumption of electron? Now if you see that at this if you extend this, this line if you extend, this line is cutting at this point, at this point. So what would be my -- this is my new $i_a$ for zinc going to zinc$^{+2}$ plus 2e. This is my anodic current density along this line for zinc corrosion and what would be my total cathodic current? Total cathodic current would be this.

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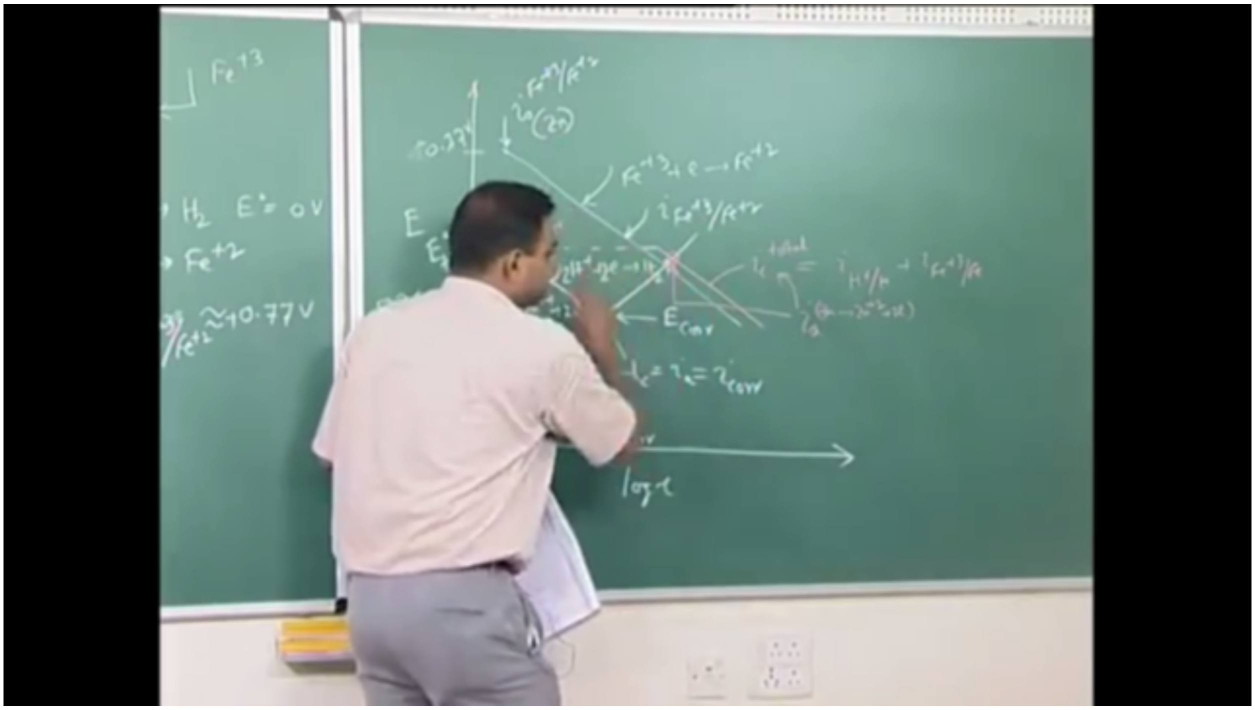

So at this point we see the rate at which electrons are produced from this anodic reaction would be equal to $i_c$ total because $i_c$ total means electrons part of this electrons which are getting generated because of this anodic reaction will be consumed by hydrogen reduction, hydrogen plus reduction, and part of those electrons will be consumed by for the $Fe^{+3}$ reduction to $Fe^{++}$, $Fe^{+2}$. So now we see that this should be my new corrosion current, corrosion current density which is equal to $i_{corr}$, $i_{corr}$. So this is my $i_{corr}$ and it's in log scale.

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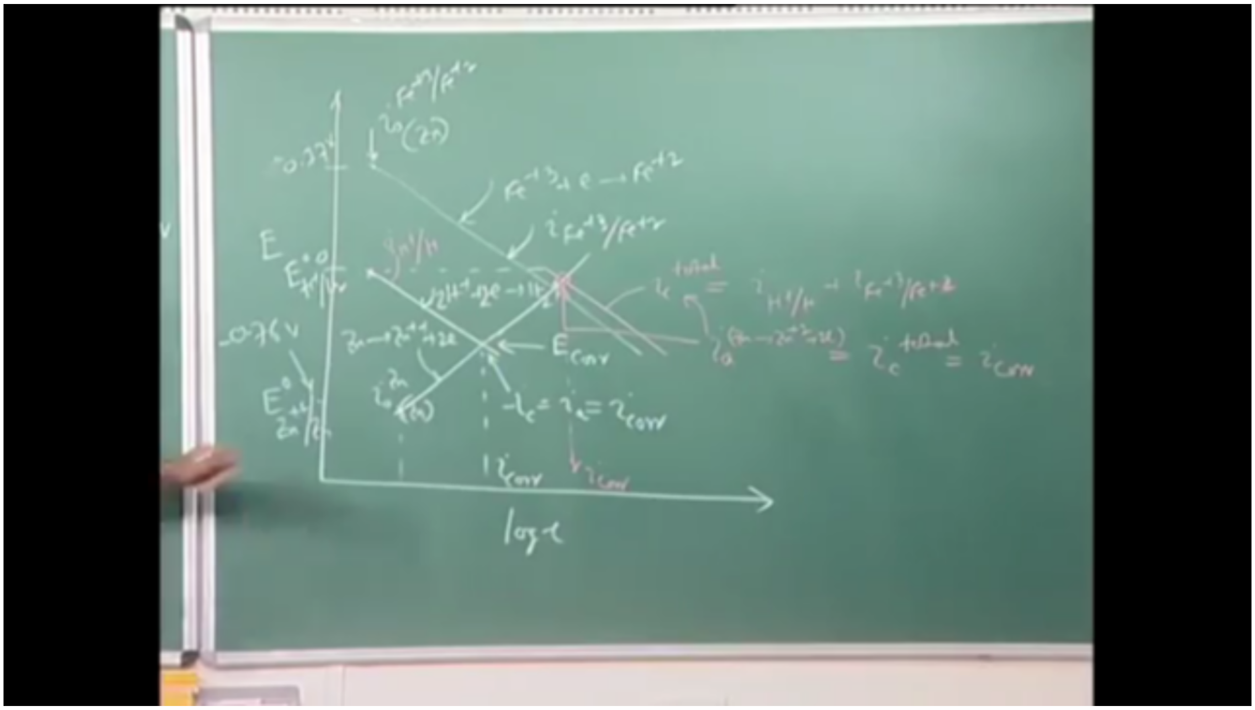

So if ferric ion is not there, so my current density, corrosion current density is this much. If ferric ion is there, my corrosion current density is this much, and since this is in log scale, so it would be of the order of 10 -- tenth -- some orders of 10. So let's say if this value is $10^2$, this value could be $10^5$. So I am just giving you the rough estimation. So now the corrosion rate has increased to a great extent because of this $Fe^{+3}$ presence and the phenomena is happening like that.

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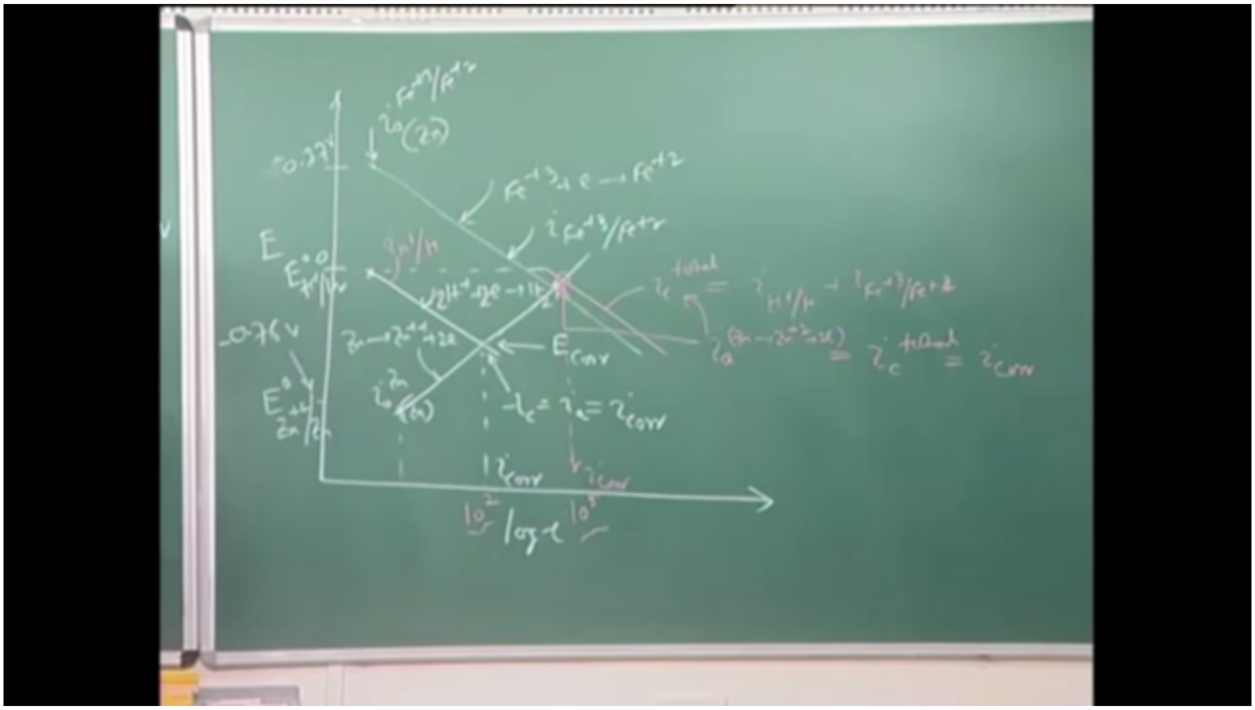

Now there is one another interesting phenomena that is going on parallel. What is that? Let's say with a yellow line let me put what is my corrosion potential, E potential, a corrosion potential $E_{corr}$? So $E_{corr}$ would be the corresponding point. This is my the yellow line tells you the $E_{corr}$, $E_{corr}$. Now what -- what would be my $i_a$ here? $I_a$ is this one. So let me put some points. Let's say this is my A, this point is B and this point is C where this line, parallel line along $E_{corr}$ cuts this hydrogen reaction and $Fe^{+3}$ going to Fe2 reaction.

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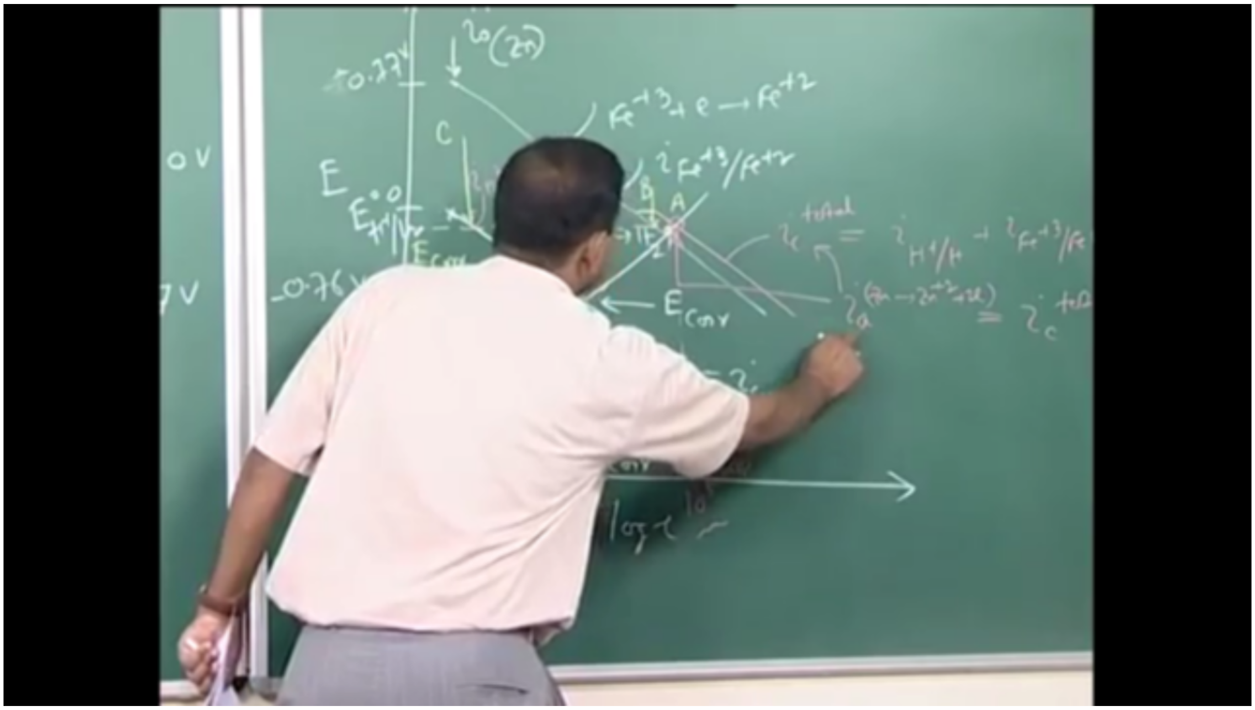

So that means this equal this is basically nothing but $i_{corr}$ or the dissolution rate, anodic reaction rate and which point corresponds to $i_{corr}$, $i_{corr}$ of hydrogen, so I can write it as $i_{corr}$ $i_{H+/H}$ plus $i_{Fe+3/Fe+2}$. This point is nothing but A point and what is this point which corresponds to the current density along the $C_{corr}$, which is nothing but the C. So this is C point and which one is B point? B point is this. So this is my B point.

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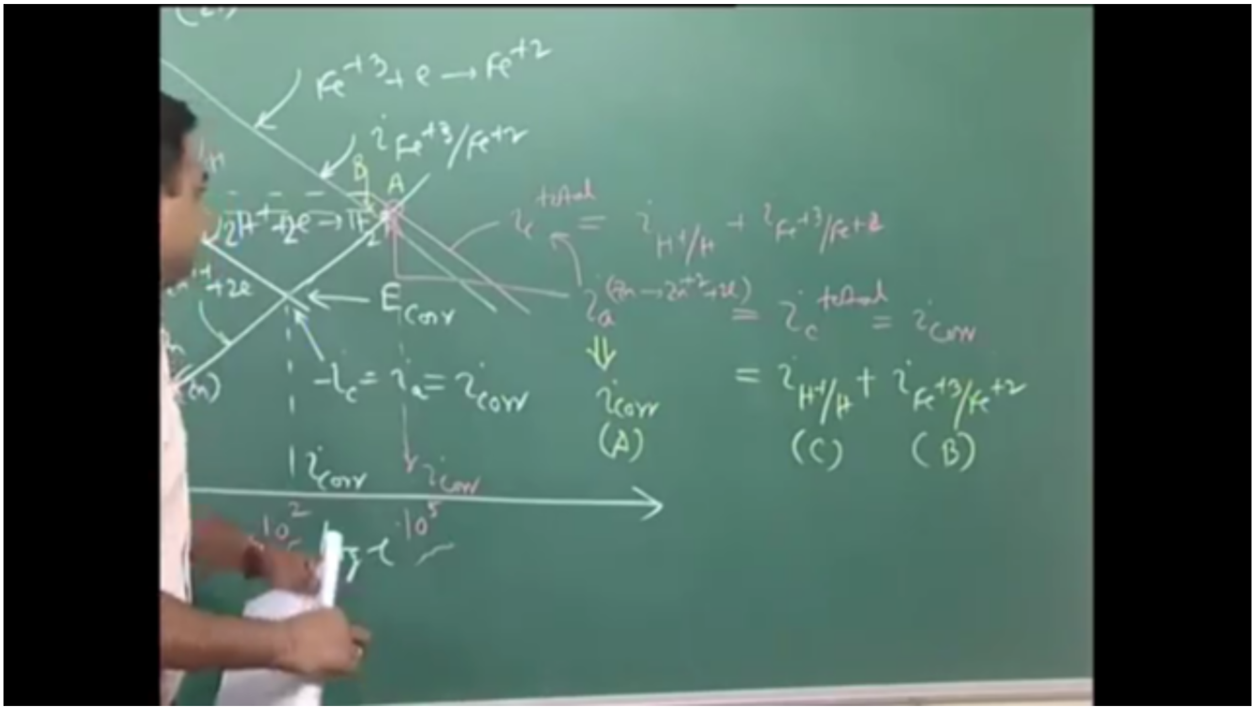

The current density corresponds to B point, which is nothing but the current density of that iron reduction. C point corresponds to the current density of hydrogen ion reduction and A point corresponds to the zinc dissolution rate or anodic current density of which is nothing but at this point or it's nothing but the $i_{corr}$.

Now, interestingly, if you see, if $Fe^{+3}$ is not there, what is my hydrogen evolution rate if this one is not present? So that means before drawing this curve, this top curve, I -- I have drawn this one fast. So if $Fe^{+3}$ is not there, which one is my current density, equilibrium current density, which is equal to the anodic current density, equilibrium current density for cathodic reaction? This is my cathodic reaction rate if $Fe^{+3}$ is not there in the solution.

So now you see without having $Fe^{+3}$, I have this much of hydrogen evolution rate, but if I have $Fe^{+3}$ in the solution, my hydrogen evolution rate is nothing but this one. So if I -- this is let me say D point, now if you compare the current density corresponds to D point as well as C point, then I see that $i_{H+/H}$ is at C is less than less than current density of $H^+/H$ at D point.

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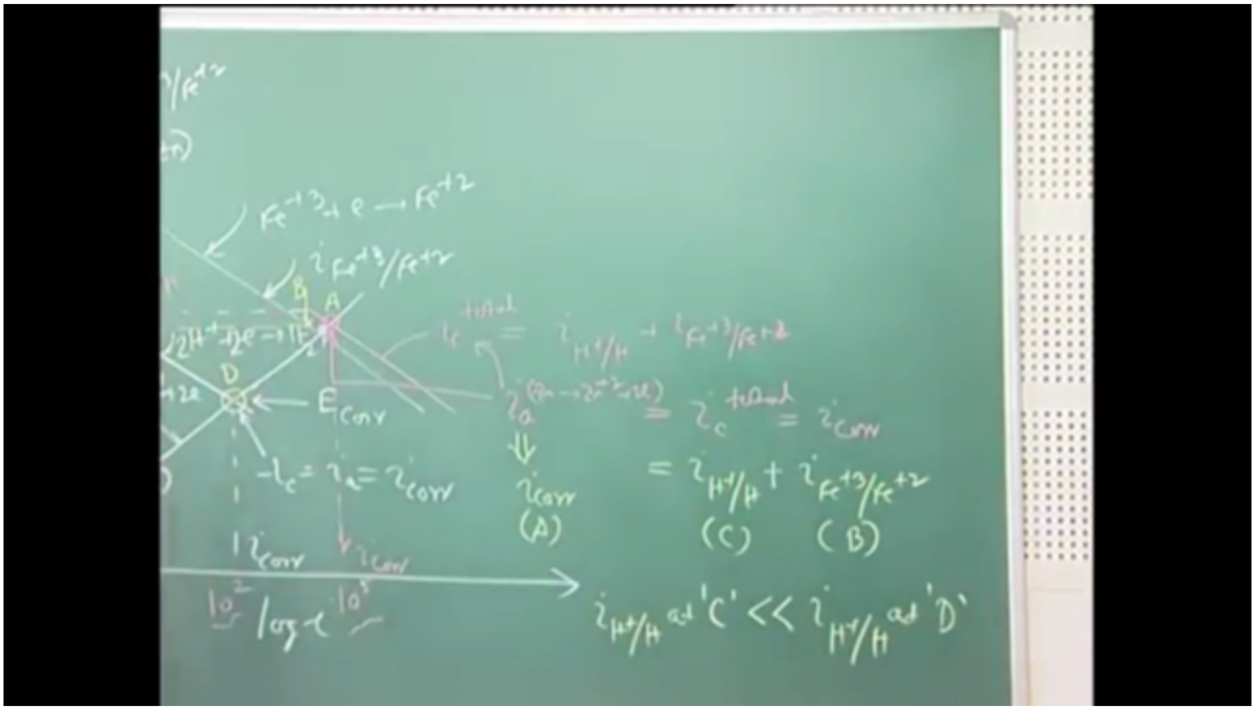

So that means if you don't have this, my hydrogen evolution rate on zinc surface would be much larger than that the case where $Fe^{+3}$ ion is present. So if you have $Fe^{+3}$ ion in the HCl solution, my hydrogen evolution rate will be reduced. Now what is happening? Because of polarization, if you consider the polarization effect, so let's say I am considering the polarization. Polarization means let's say I am considering the cathodic polarization. Cathodic polarization means if this is my polarization and this is my zero, which is basically corresponds to the exchange current density, now that point if you start the polarization, cathodic polarization, it will move along this and this is nothing but log I, and if you have more and more polarization, which is nothing but the more and more value of over voltage, you see the rate of the cathodic reaction is increasing.

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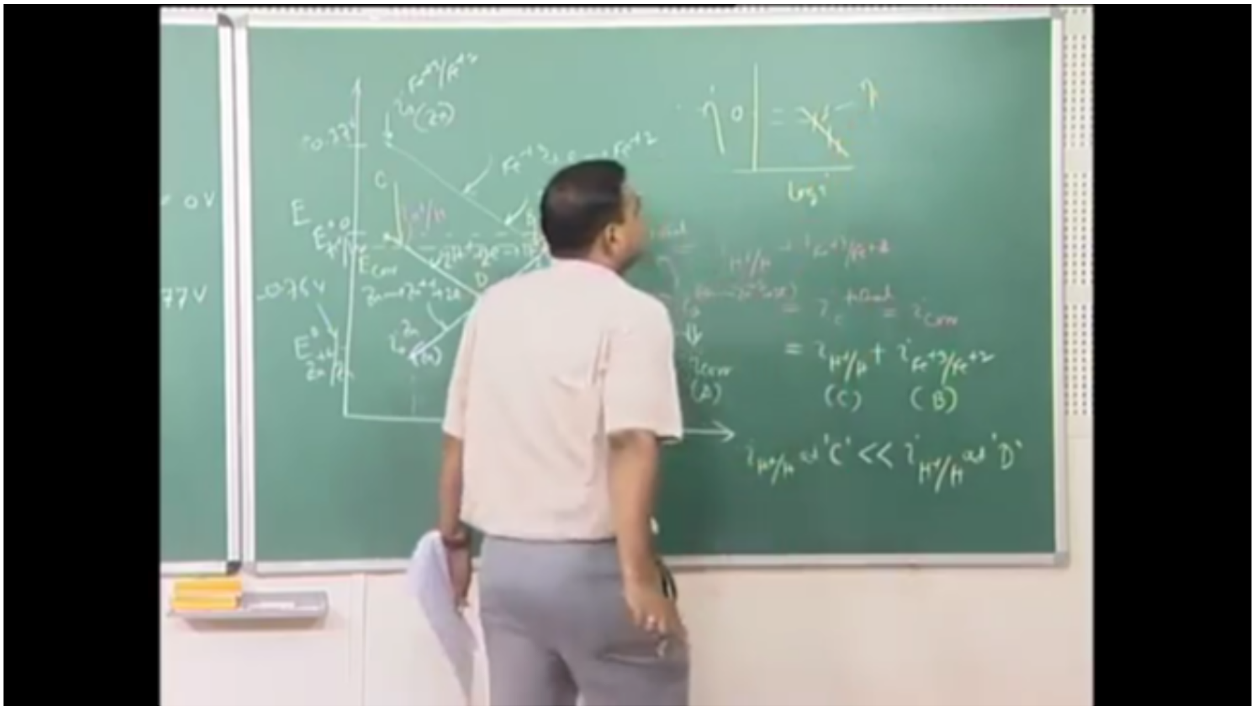

Let's say I am here, which is my this much is my polarization $\eta_1$. Let's say I'm here. So this much would be my polarization $\eta_2$, $\eta_2$ and this is I'm here, which is the polarization is this much, which is $\eta_3$, and you see as $\eta_1$ less greater than $\eta_2$ greater than $\eta_3$, so that means as you are increasing polarization, you are also increasing the rate at which cathodic reaction is happening. So $i^1$, $i_c^1$ would be less than $i_c^2$ would be less than $i_c^3$. $I_c$ is nothing but the cathodic current density.

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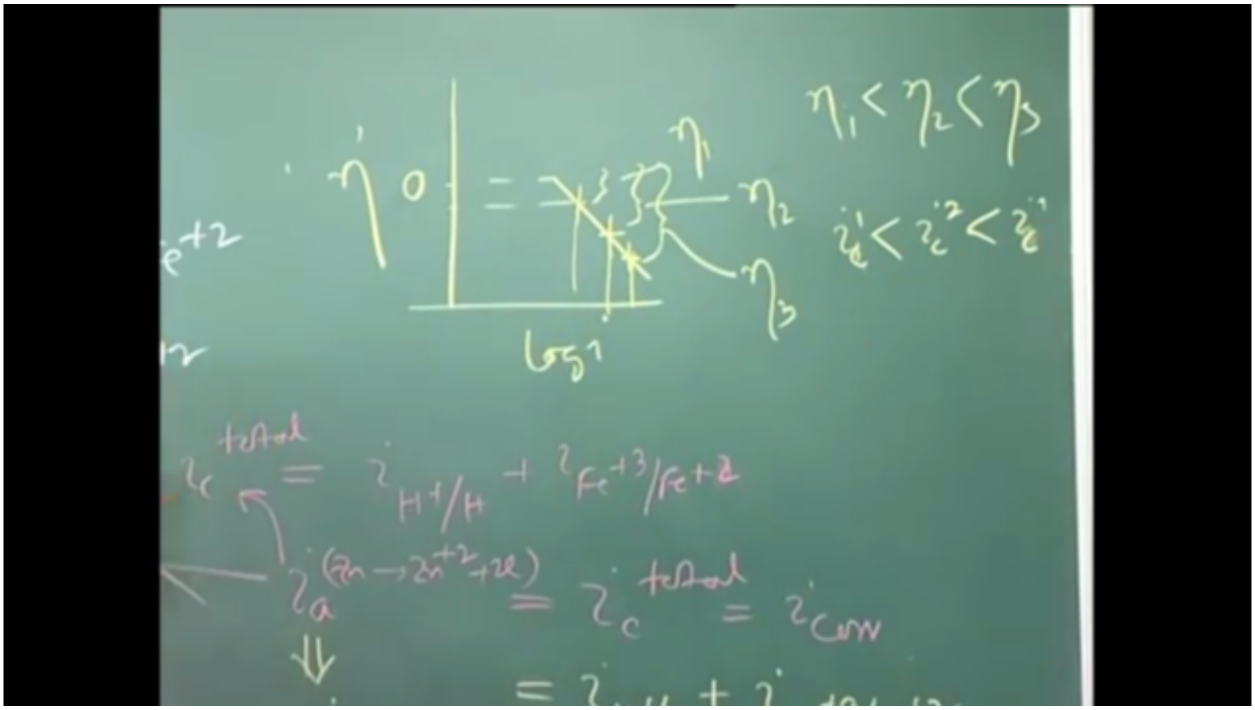

So that means as you go along the polarization line or as you increase the polarization, degree of polarization, you are going to increase the rate at which the cathodic reaction would happen. But here you see without this presence, I can reach to this level of polarization. I can reach to this level of polarization, this level of polarization, but in case of hydrogen, but if you have this, then I can only reach up to this.

That means instead of having polarization up to this or instead of having this much polarization, I am getting a much smaller polarization or a much smaller overvoltage. That suggests that this is acting as a depolarizer for hydrogen evolution reaction. So iron, ferric ion, ferric ion is acting as depolarizer for hydrogen evolution reaction, and Fe$^{+3}$ is also called hydrogen depolarizer, hydrogen depolarizer.

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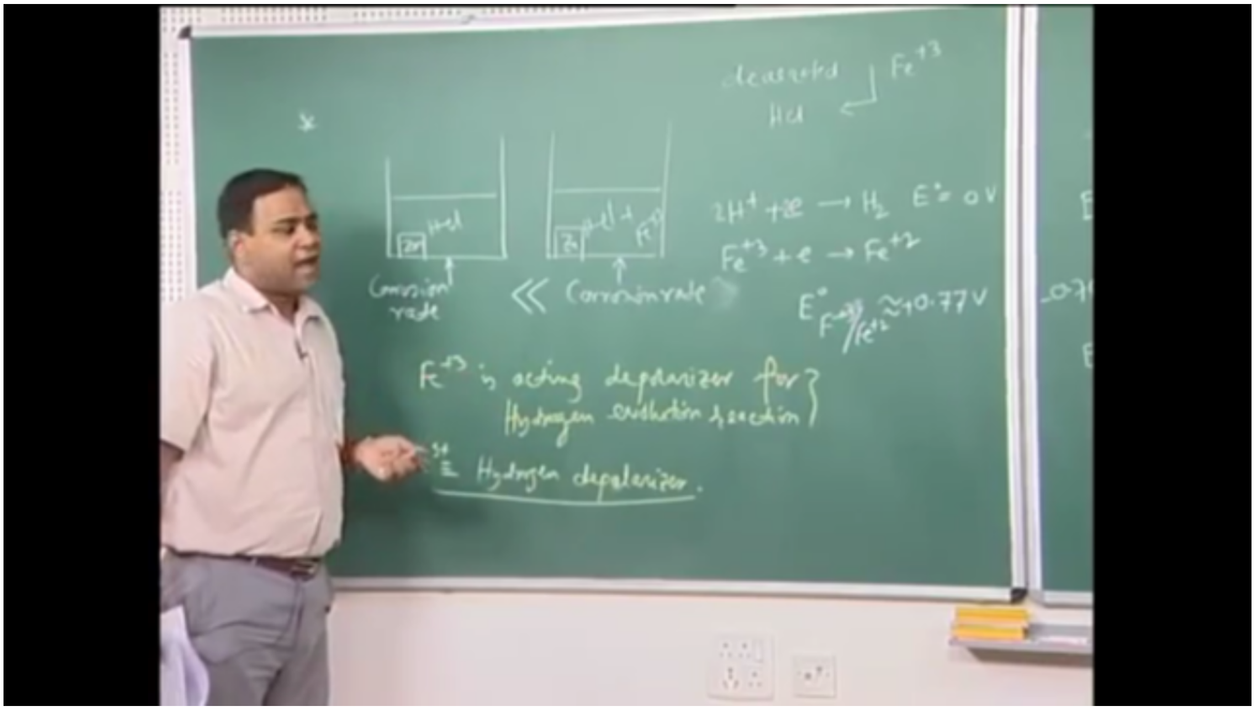

So now we have two distinct effect. One is, if you have impurity like ferric ion, I would -- the corrosion rate of zinc is will be increased in HCl solution. At the same time the -- you will see the hydrogen evolution rate on the zinc surface will be reduced. So if you have this and this, you will see the bubbling would be more here. You will see the bubbling would be less because here the hydrogen evolution reaction is -- reaction rate is this much and here the hydrogen evolution reaction rate is this much. So this is one example.

Now let us also find out some more example. Let's say we have considered the galvanizing effect of zinc on iron surface. Zinc corrodes and in a way it protects iron, but it doesn't mean that iron corrosion is stopped. It means that iron corrosion rate has reduced because of the zinc corrosion and more zinc corrosion.

So let us have second example. Let us have second example. The second example would be let's see what happens, we have seen if you combine iron and zinc and put it in HCl solution, you will see that rate at which the $I_{corr}$ would be less than of iron would be less than $I_{corr}$ zinc and this is nothing but the effect of galvanization. That's why evaluation is done with zinc on iron surface.

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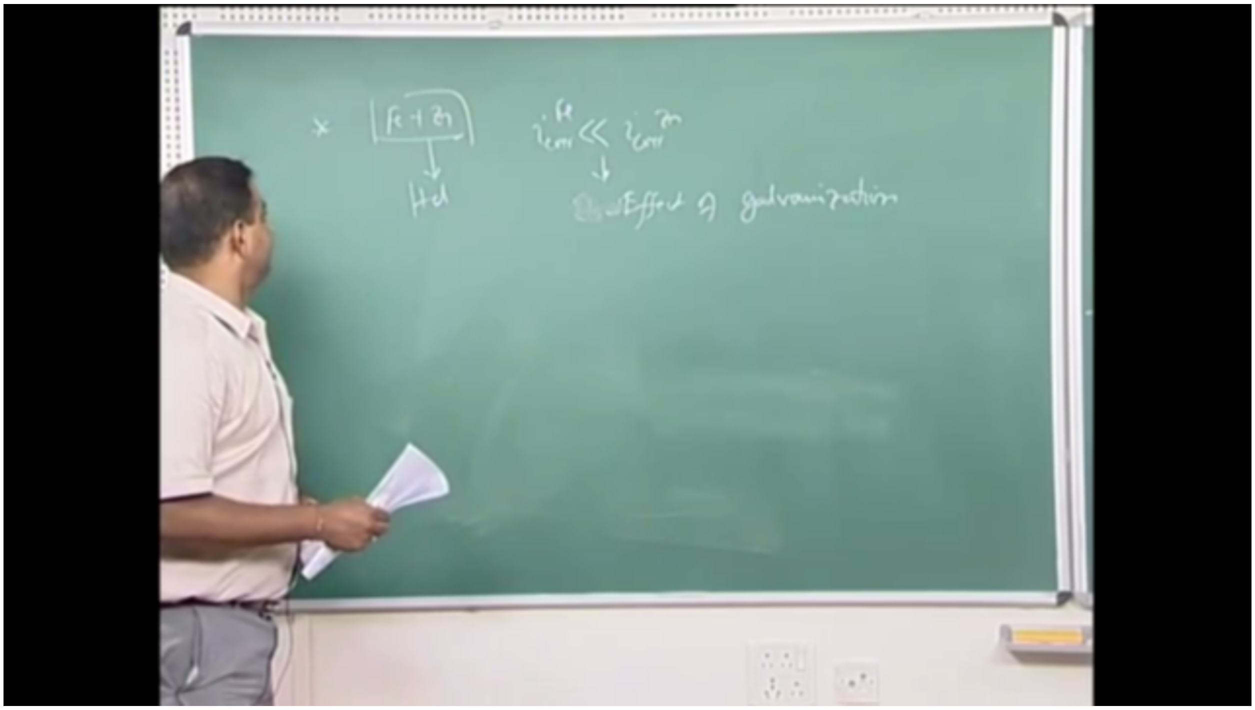

But if we combine platinum with zinc in one case, this is case 1, and if we combine gold with zinc, this is case 2, now what would happen? Let's see what happens here. This also can be explained quite -- quite naturally from mixed potential theory or from this graph. The same kind of graph, we will draw a different curve now.

Now in this case, let's say I will have the cathodic reaction. Let us consider only one single cathodic reaction, which is nothing but $H^+$ plus e going to $H_2$ gas, so hydrogen reduction reaction. Let us consider that only. We are not considering any other cathodic reaction.

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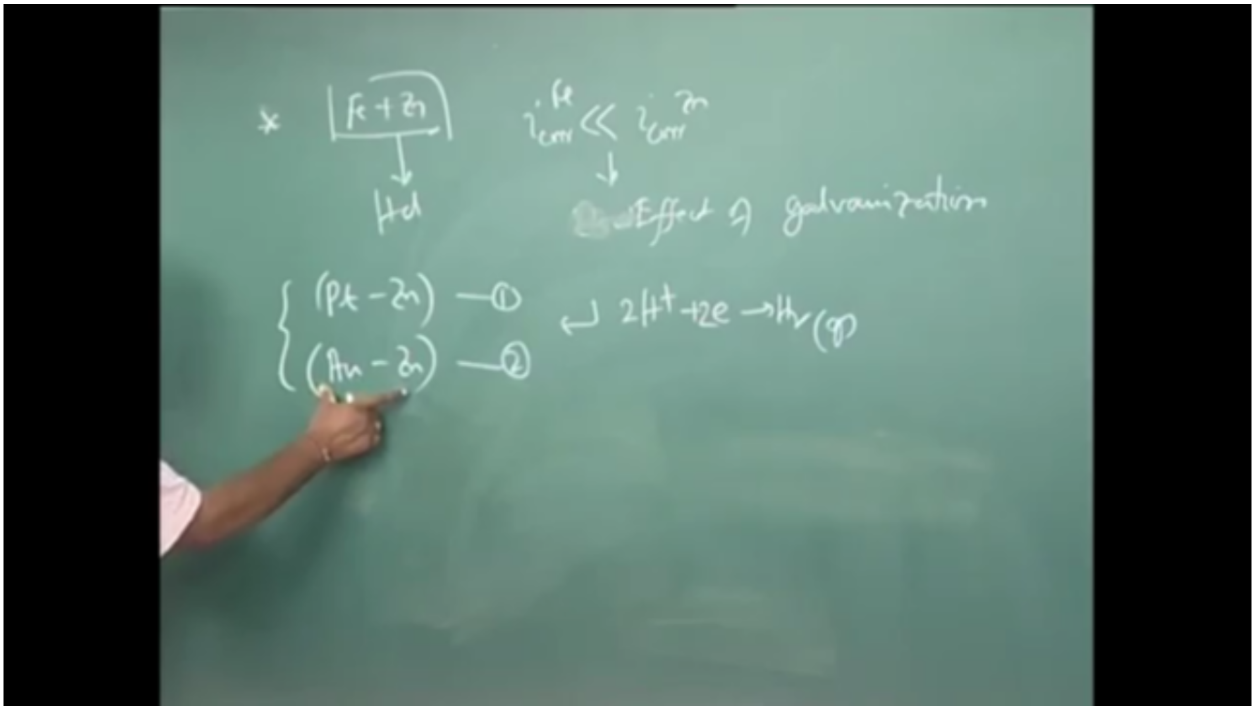

Now when you have these two couples, let me first consider one important aspect. We have seen that the exchange current density has a great effect on the actual corrosion phenomena. That we have seen in case of galvanization effect in this case. Similar sort of effect would come here. Let us find out. You can see that if you consider -- if you consider log of current density I, log of current density and if you like to plot the exchange current density on this scale, now this is my potential. Let's say this is my 0 volt for hydrogen evolution reaction, and the hydrogen, let's say these are two coupled.

Now you have platinum surface. You have zinc surface, and hydrogen is going to get evolved, going to be evolved on this surface as well as on this surface. So what would be my -- that means on this surface, this reaction is happening and in -- on this surface also, this reaction is happening. Let me see what would be the value of $i_0$ of this -- $i_0$ for this reaction or exchange current density on -- this reaction.

So on the zinc surface, this value is about $10^{-11}$. So it's around -- just a minute. Let me have a look at it. Okay. It's around $10^{-11}$ ampere centimeter square. This is $i_0$ of hydrogel on zinc surface.

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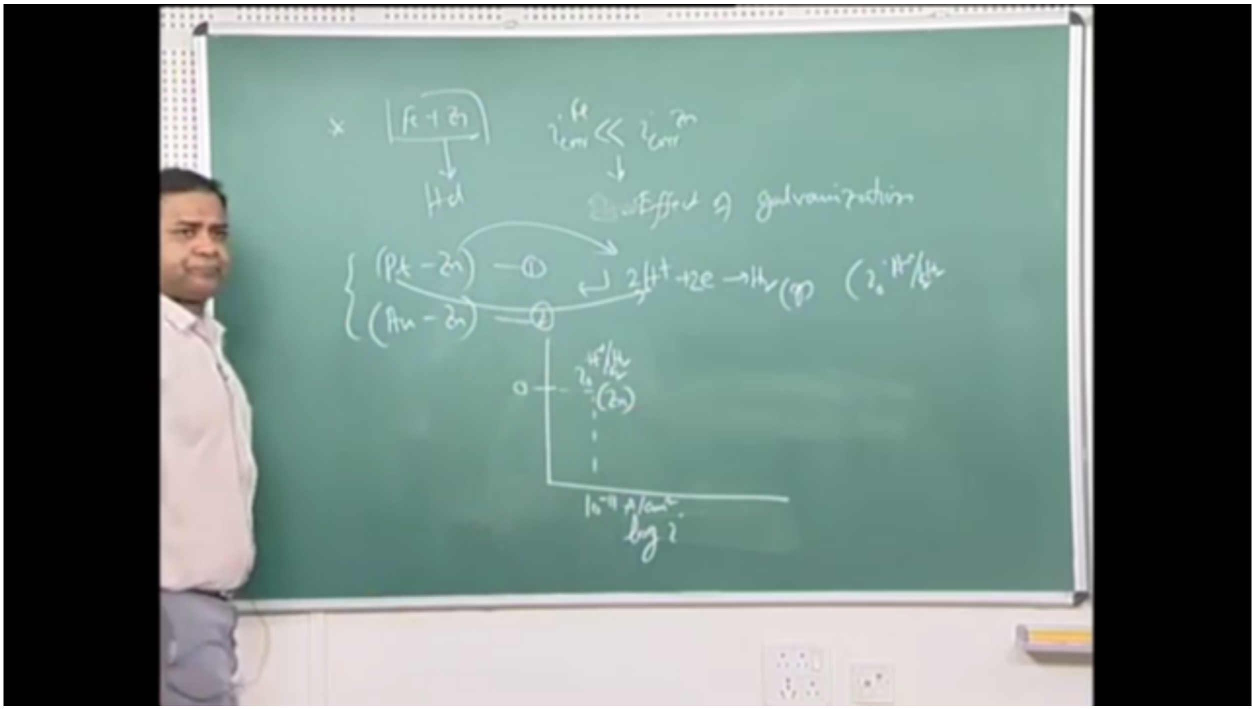

Now let me also find out what should be the $i_0$ on gold surface for the same reaction. Gold surface would be around -- would be around -- around here, so which would be around 10 to the power -- which is -- which would be around -- let me just find out the value. This is 10 to the power minus 2, minus 3. It would be around 10 to the power $i_0$ of $H^+/H_2$ on gold would be equal to around $10^{-6}$, around $10^{-6}$ ampere per centimeter square. But it will lie on the same line along the zero volt. This is -- this is zero volt. This is potential. This is potential and this is log i.

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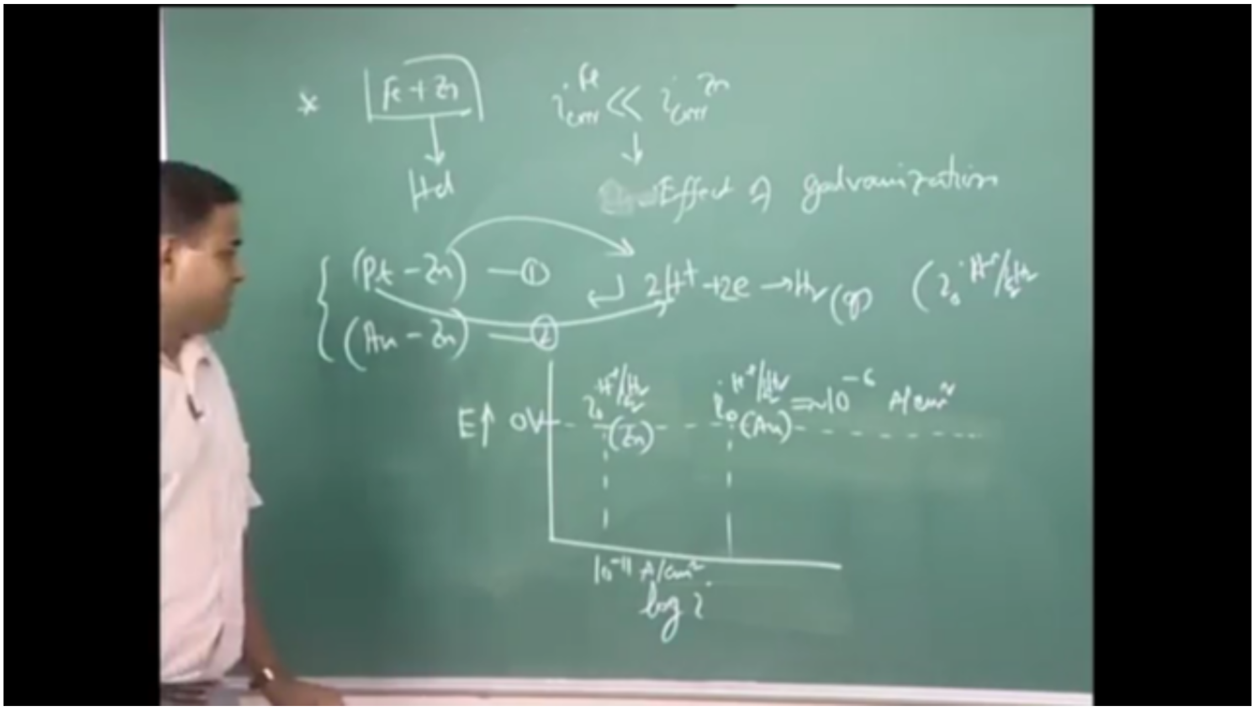

Now the similar way, the value of this reaction, value of exchange current density for this reaction on platinum surface will be around this is $i_0$ $H^+/(1/2)H_2$ on platinum is around $10^{-2}$ ampere per centimeter square.

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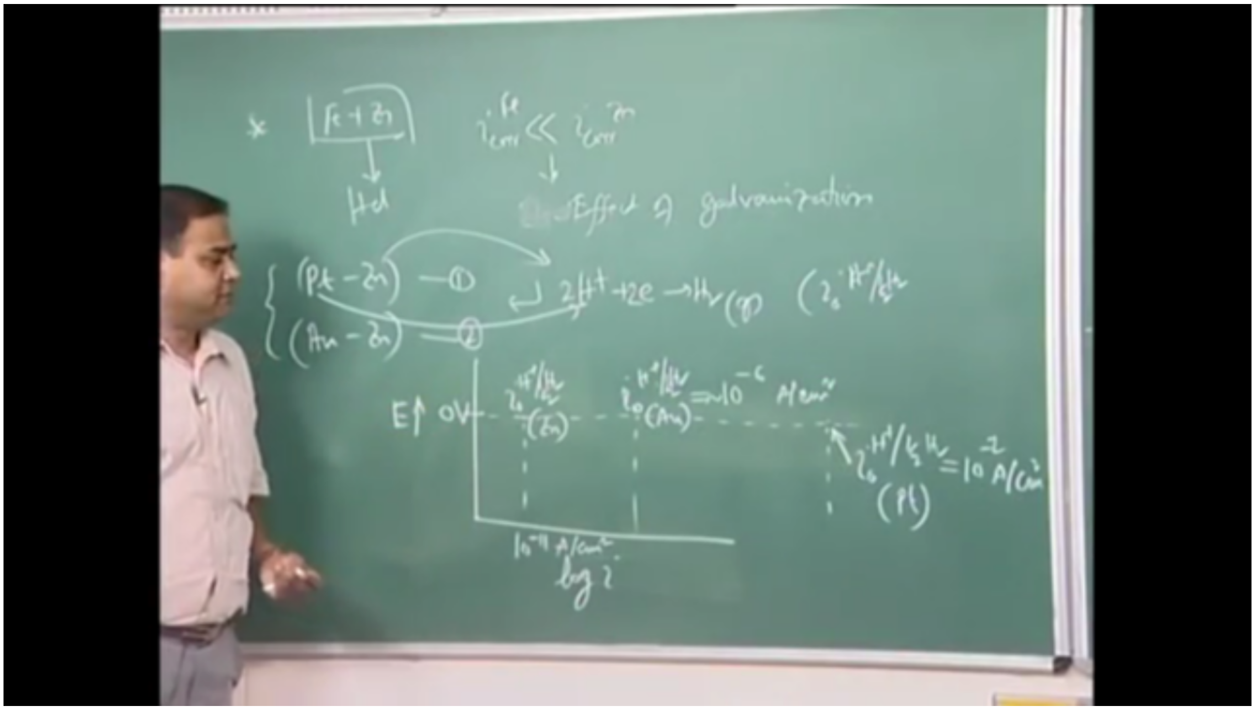

So this is the sort of data we have. Now this data will decide what would be the actual corrosion rate and what would be the effect of this noble metal -- noble metal attachment to zinc.

Now in this case, again, let me draw E versus log I, and this is E, and let's say this is my $E^0$ of zinc, zinc and this is let's say this is my $i_0$ of zinc$^{++}$/zinc on zinc surface, and let us also see the anodic polarization line. The anodic polarization line, it gives you zinc$^{++}$ plus 2e.

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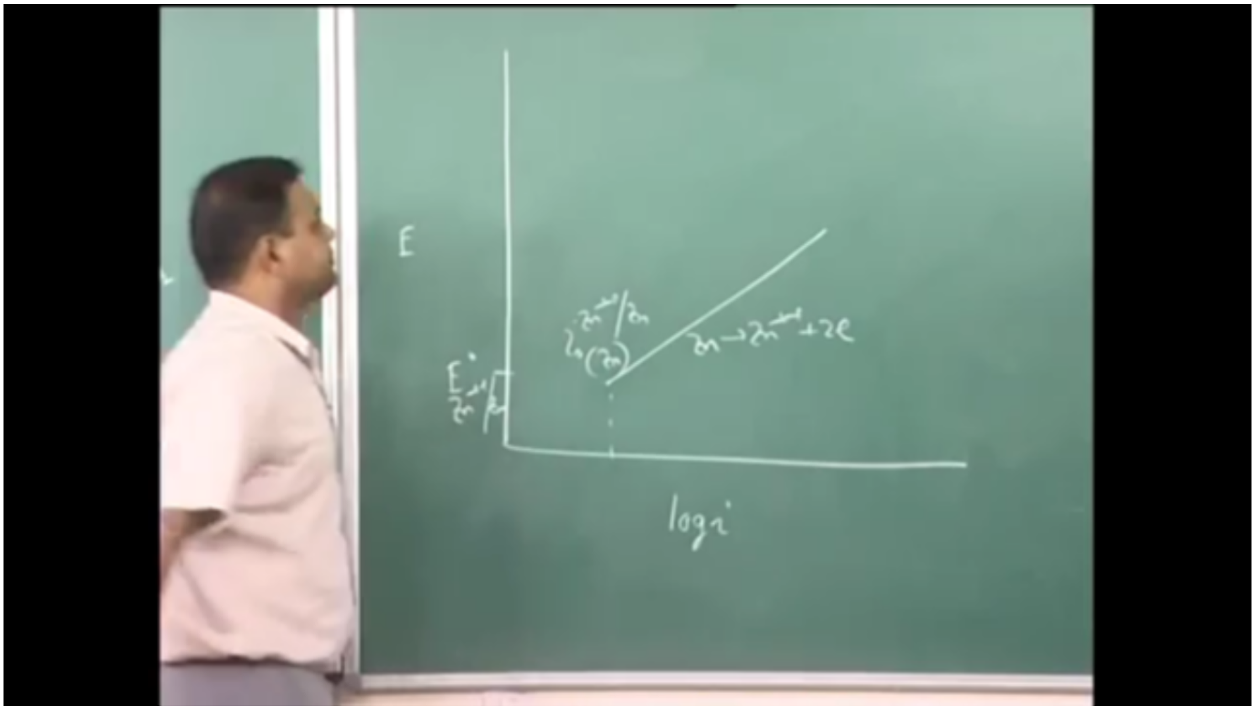

Now if there is no coupling, if there is no coupling, then we have this situation. Let's say this is my zero volt, which is nothing but the hydrogen evolution reaction, standard reduction potential. So that value is around this. So I have to see the cathodic polarization also. So this is nothing but $H^+$ plus e going to $H_2$ gas, and this is my point where this is nothing but $i_{corr}$, which is nothing but $i_c$, which is nothing but $H^+/(1/2)H_2$ minus, I would put a minus here because just to indicate that $i_c$ is flowing opposite direction than that $i_a$. this is nothing but $i_a$. This is $i_c$.

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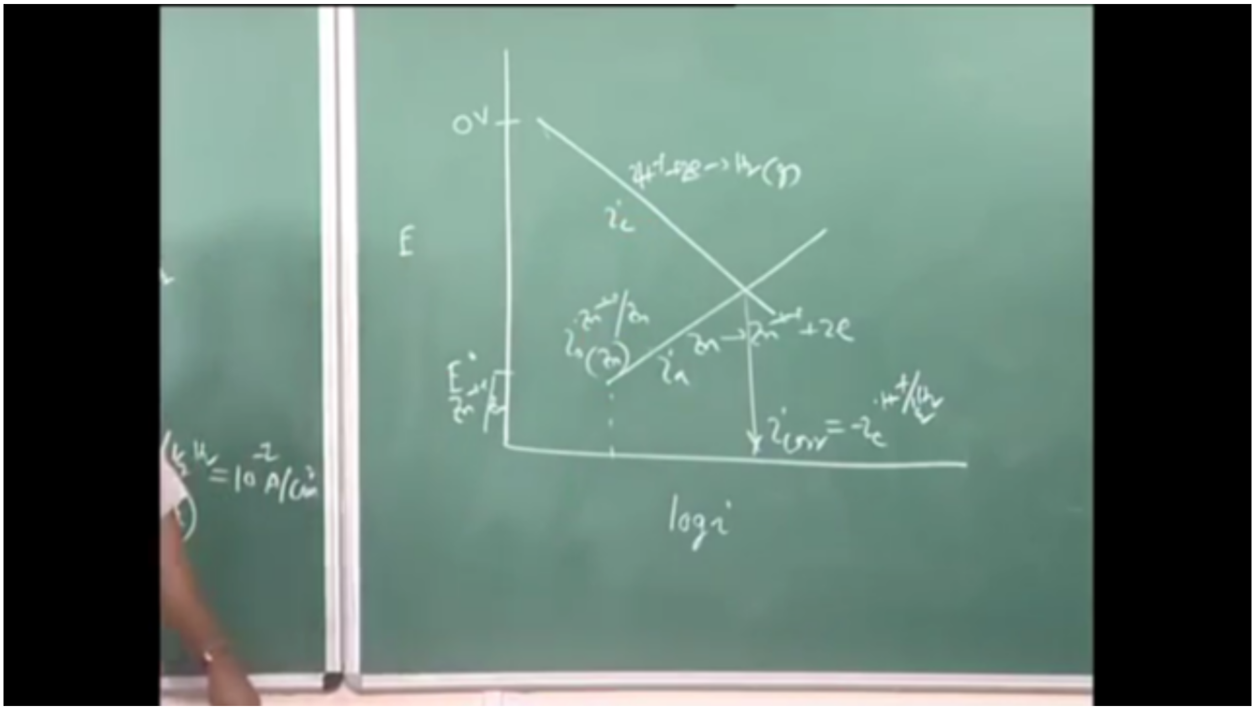

Now this is before coupling with a noble metal with platinum or gold. Let's see if I club it with gold, then this reaction is also taking place because this is $i_0$ of $H^+/(1/2)H_2$ on zinc surface. Now I have to consider this value, the relative value. It's on the right side. So let me see this -- this is my point, which is nothing but $i_0$ on gold -- on gold surface $H^+/(1/2)H_2$. So we have this also as well as this. So this is my hydrogen reduction line, each line for those hydrogen reaction which are happening only on the gold surface.

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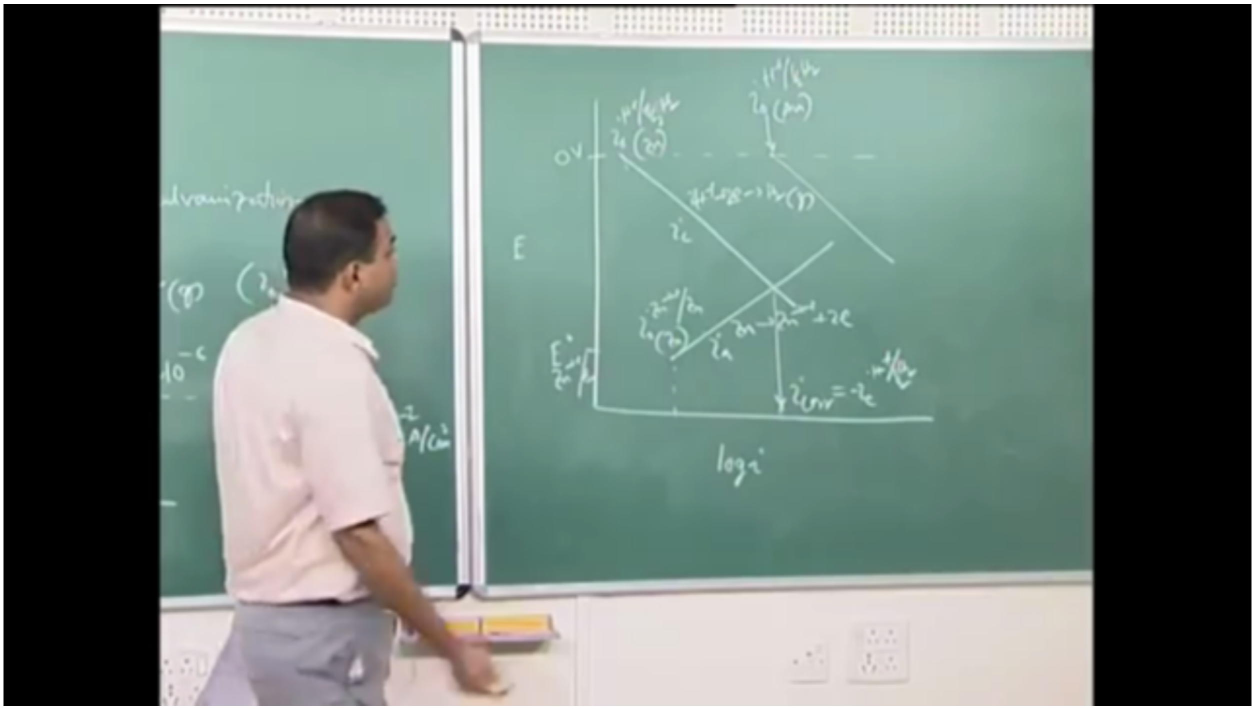

So now you have two cathodic currents. One is cathodic current for the hydrogen evolution on zinc surface and cathodic current density on gold surface for the same hydrogen evolution reaction. So if there are two cathodic reactions, which are parallel going on, so we have to add these two things, two current densities to find out the total cathodic reaction rate or total reduction rate. So the total reduction rate again will be following you have to add these two currents, and then it will follow this line, this red line, and then where do you think that the total reduction rate would be equal to total oxidation rate or the total anodic reaction -- total current density for anodic reaction would be equal to total current density for cathodic reaction?

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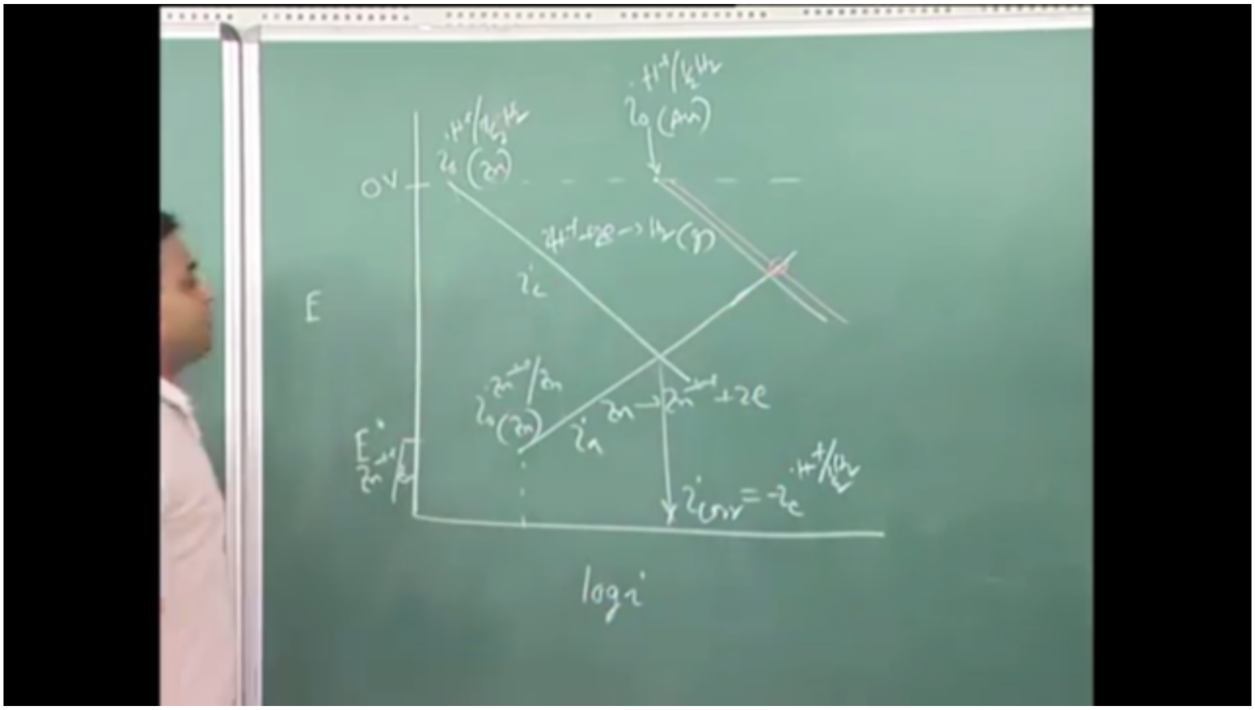

The point would be this one would be my new point. This one would be my new point where you see the current density, anodic current density, the anodic current density $i_a$, which is nothing but zinc$^{++}$ going to -- zinc going to zinc$^{++}$ plus 2e would be equal to $i_c$ total with a negative sign because I am just putting negative sign even if you take the mod value, then this negative value will go. This negative value is nothing but the direction, but magnitude wise both are same, and this would be equal to two contributions. One contribution would come because we have to see where is my $E_{core}$. $E_{core}$ would be my this point. So this is my $E_{core}$ and this is my $i_c$ for hydrogen evolution on zinc surface, and this is my point which tells you the $i_0$, $i_c$ for hydrogen evolution on gold surface.

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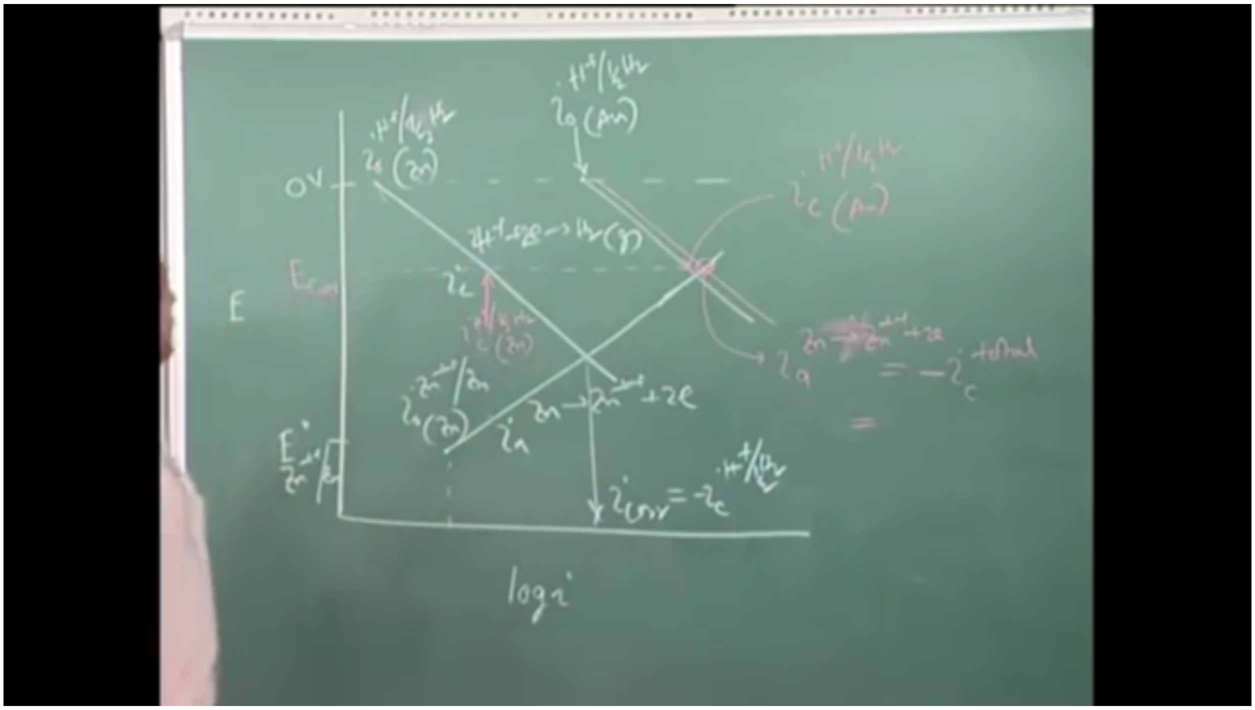

Fine. So this Plus this equal to this. So this would be equal to $i_c$ of this. So let me put the points. This is A point, this is B point, and this is C point, so would be equal to A+B+C or you can write it as $i_c$ on zinc plus $i_c$ on gold, and there would be negative sign because we are taking direction also into consideration. So then now you see if you have this noble metal coupling, the zinc corrosion rate increases quite largely. So here you see in the log scale value the zinc corrosion rate with gold coupling is this one, and zinc corrosion rate without gold coupling is this one, and this is in log scale, so you have a many times increase in the corrosion rate if you couple the zinc with the gold -- with gold. So this is one example how -- why with the noble metal addition to zinc, it increases the corrosion rate of zinc.

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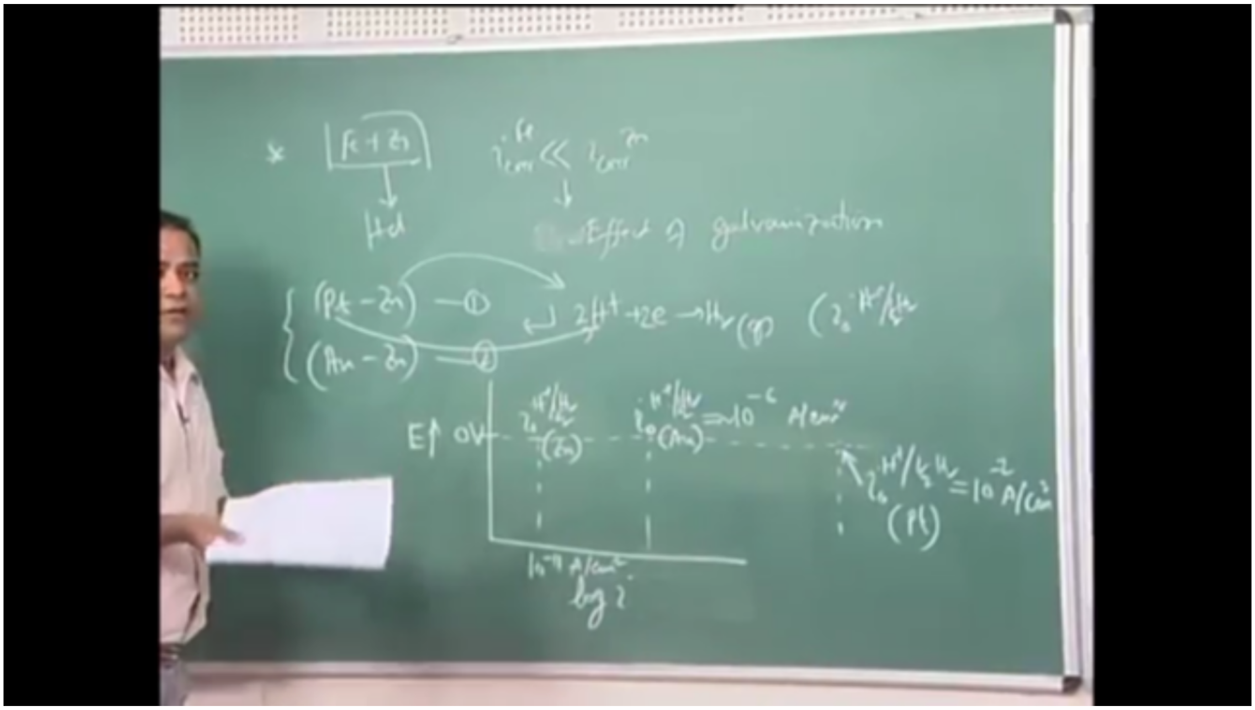

Generally, we have that notion that if we add gold -- pure noble metal into an active metal, the corrosion rate improves. Corrosion -- corrosion resistance, but it actually is reverse. If you add gold into zinc, corrosion rate of zinc increases and this is the beauty of mixed potential theory which and this phenomenon can easily be explained from this. So we see the effect of noble metal addition in an active metal like zinc and we see the zinc corrosion rate increases to a great extinct.

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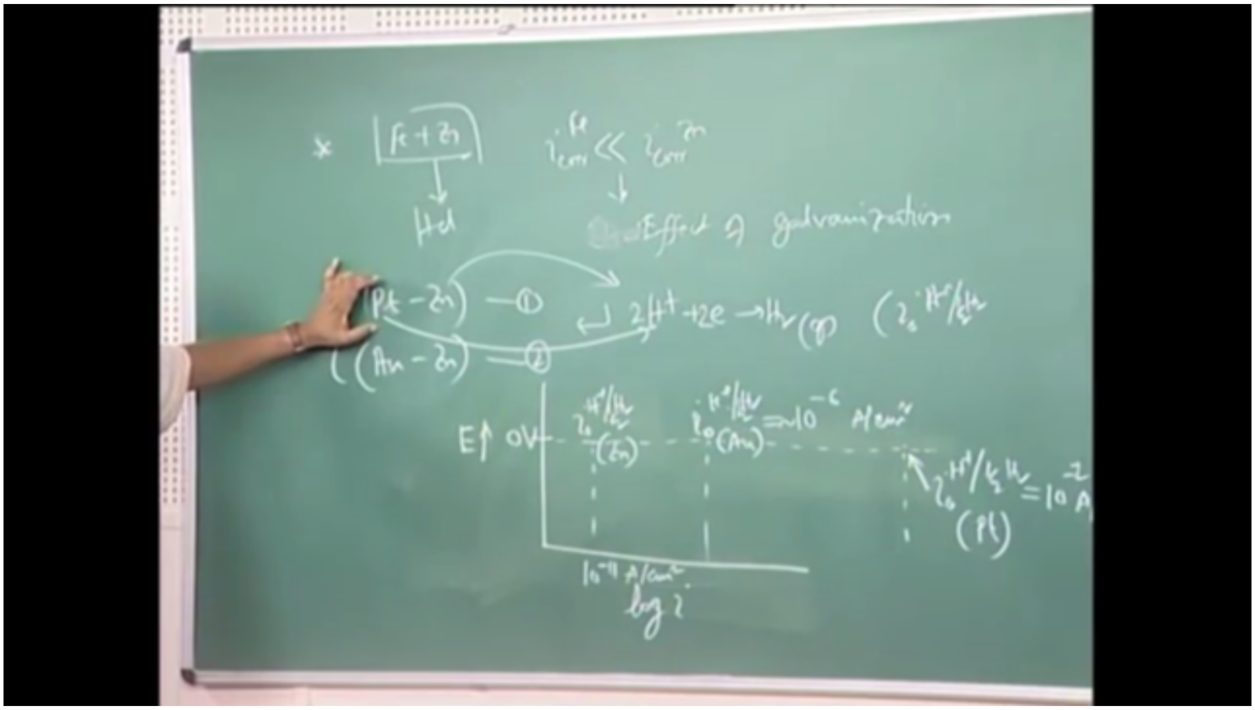

Now, similarly, if you have this couple, and in this couple and in this couple, the main difference is same hydrogen evolution reaction is happening, but here the exchange current density on gold surface for this reaction is less than the exchange current density of this reaction on platinum surface. So what would be that effect?

So in that case I am not removing the gold part. This couple is -- is a separate couple so I am just putting this what happens with respect to platinum on the same curve, but it should not be mixed up like that that gold and platinum both are added to zinc. So this is a separate situation and the case of platinum will be another situation as a different situation. So that case let us find out what happens in case of platinum.

Now let me put the $i_0$ on platinum surface. So this is my $i_0$ of $H^+/H_2$ on platinum surface. Now that means you have hydrogen evolution and reaction, and the same way you can have polarization reaction of hydrogen evolution, polarization effect for this reaction on platinum surface, so my polarization of hydrogen evolution reaction on platinum surface. Now you have two reactions. One is happening. One you have basically same reaction happening on two surfaces. This is one. This is one -- one situation where you have hydrogen evaluation reaction on the zinc surface when it is coupled together and this is my hydrogen evolution reaction on platinum surface.

So you have two cathodic currents coming from same reaction. So this is one cathodic current and this is another cathodic current. So what would be my total cathodic current? Total cathodic current would be this plus this. So I have to indicate that total cathodic current on the same plot and that would be you have to just add it. That would be this one.

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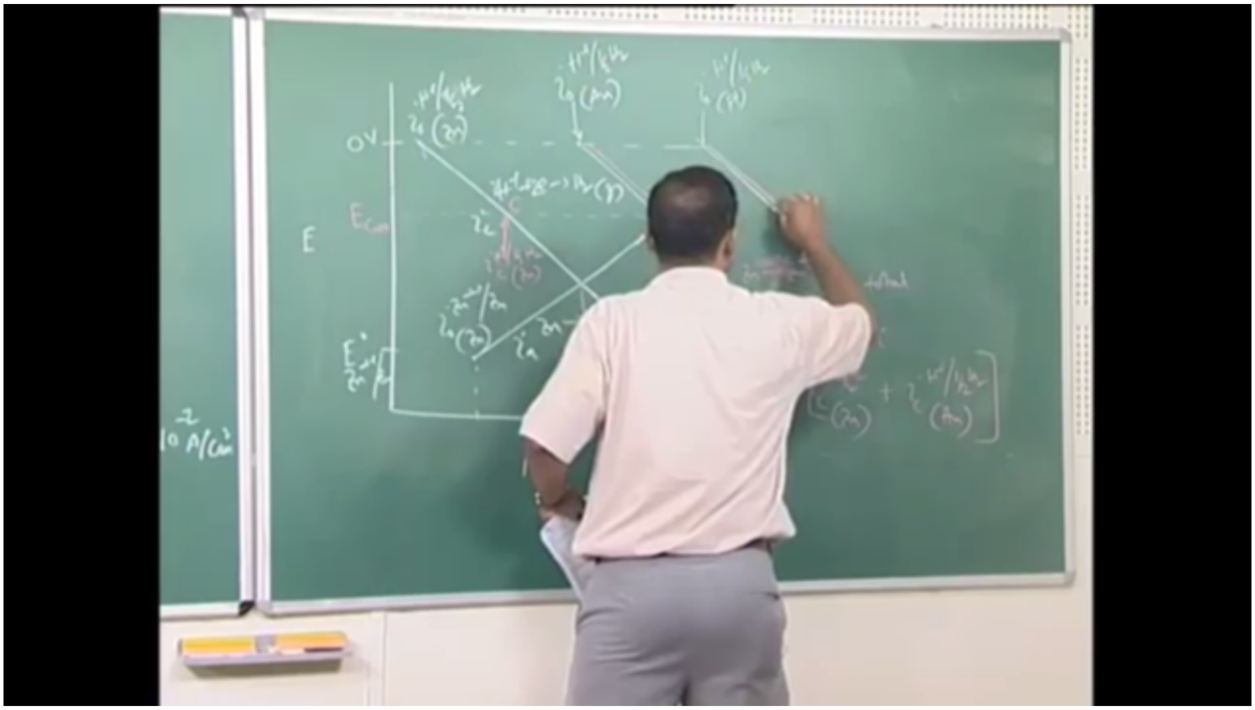

Now you see there is one small difference. You see the gap between these two lines when you are considering on the -- in the case of gold is more than the gap between these two lines, which is the total and platinum, total cathodic current and the current density corresponding to the cathodic reaction on platinum surface. Why it should be? Because here we are adding in the log scale. So if you are adding in log scale, so this would be much closer to this line because since it is on the right -- it is on the increasing side.

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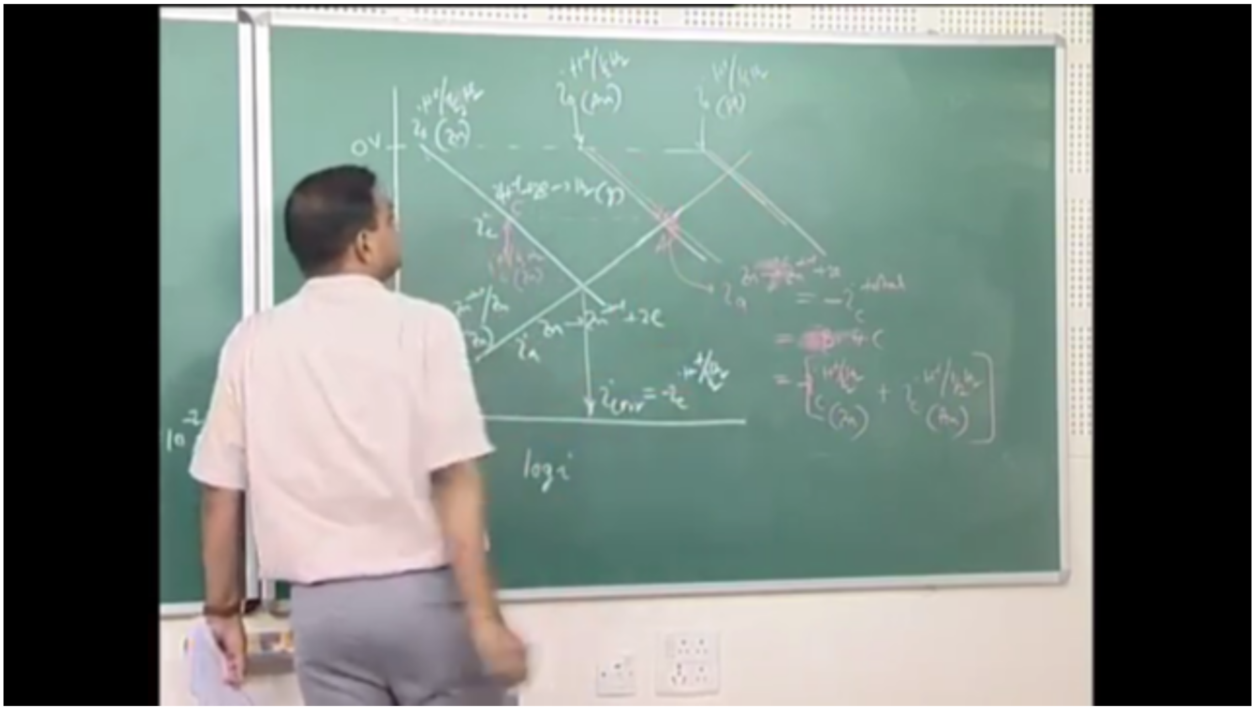

So now what would be my new point where I have the total rate of cathodic reaction would be equal to the total rate of anodic reaction? Here only one anodic reaction is taking place. So let me extend this line. Let me extend this anodic line and it -- let us see where it cuts to the total cathodic reaction rate line and total cathodic reaction rate line is nothing but two cathodic current densities corresponding to the single reaction which is nothing but the hydrogen evolution reaction.

So this is my new point and this is nothing but $i_{corr}$, and let me put bracket platinum because this $i_{corr}$ of zinc when zinc is coupled with platinum. Now you see my $i_{corr}$ on platinum in the case of platinum coupling is much higher than that -- than the case where you have coupling with gold. So you see main point is this increase in corrosion rate of zinc because of galvanic coupling with noble metal is happening because of this situation, because of increased exchange current density for hydrogen evolution reaction.

So you see the importance of exchange current density. It actually tells you the actual kinetics of the reaction, corrosion reaction. So this is my, again, with respect to -- if you couple zinc with platinum, its corrosion rate of zinc will again further increase -- will again increase to a great extent. So this is the effect of noble metal coupling and on the way the effect of exchange current density on the corrosion rate of active metal. So this is one another example.

So let me consider one more example. This is an interesting issue. This is area effect. What would be my area effect? Now let me first tell you the actual -- what happens in actual situation. If you have iron plates, two iron plates, and if you join these two iron plates with a copper rivet, this is situation one. This is copper rivet and this is iron plate and another situation is you have two copper plates -- two copper plates. This is copper, made of copper and you have iron rivet.

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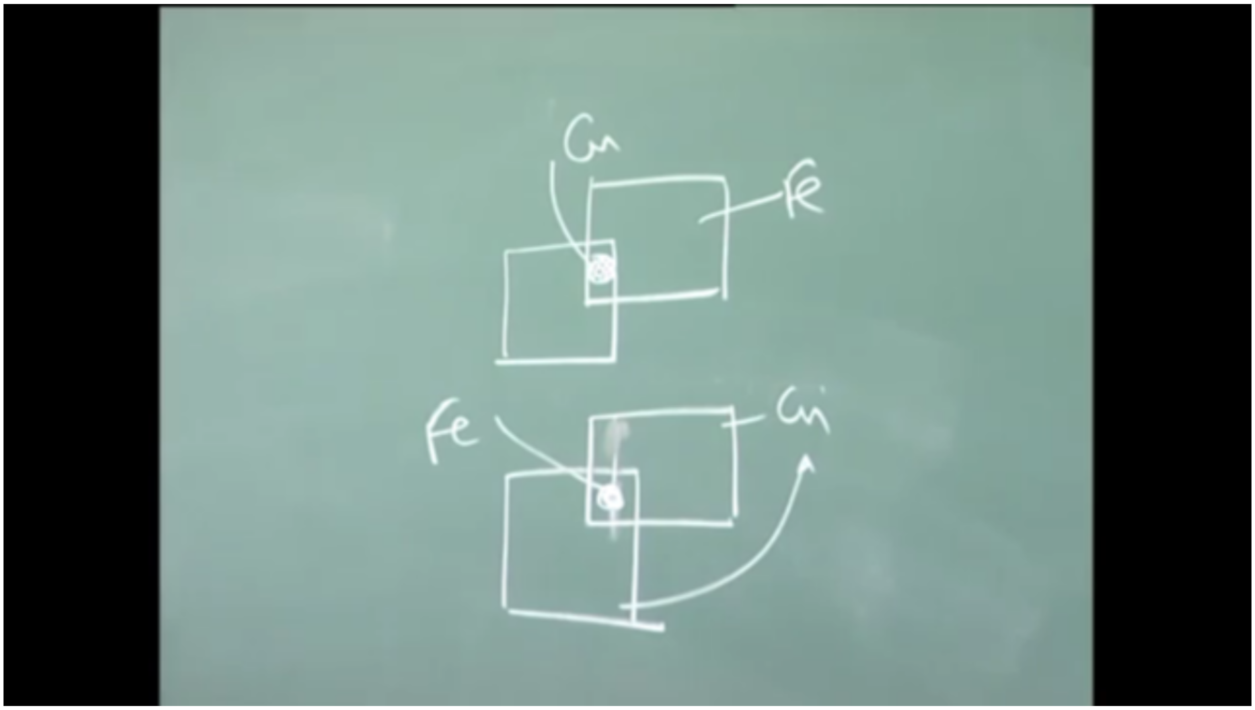

And these two things if you dip it in seawater, you will see the situation, the actual observation would be after some months, this joint will be loose, very loose, but this joint still it maintains some sort of strength. This joint is will be strong, but this one would be really loose. So what is actually happening there? So the main reason is here you have -- here the cathodic reaction is nothing but this is my cathodic reaction which is happening in both the situation and another -- and cathodic reaction would be -- anodic reaction would be Fe going to $Fe^{++}$ plus 2e.

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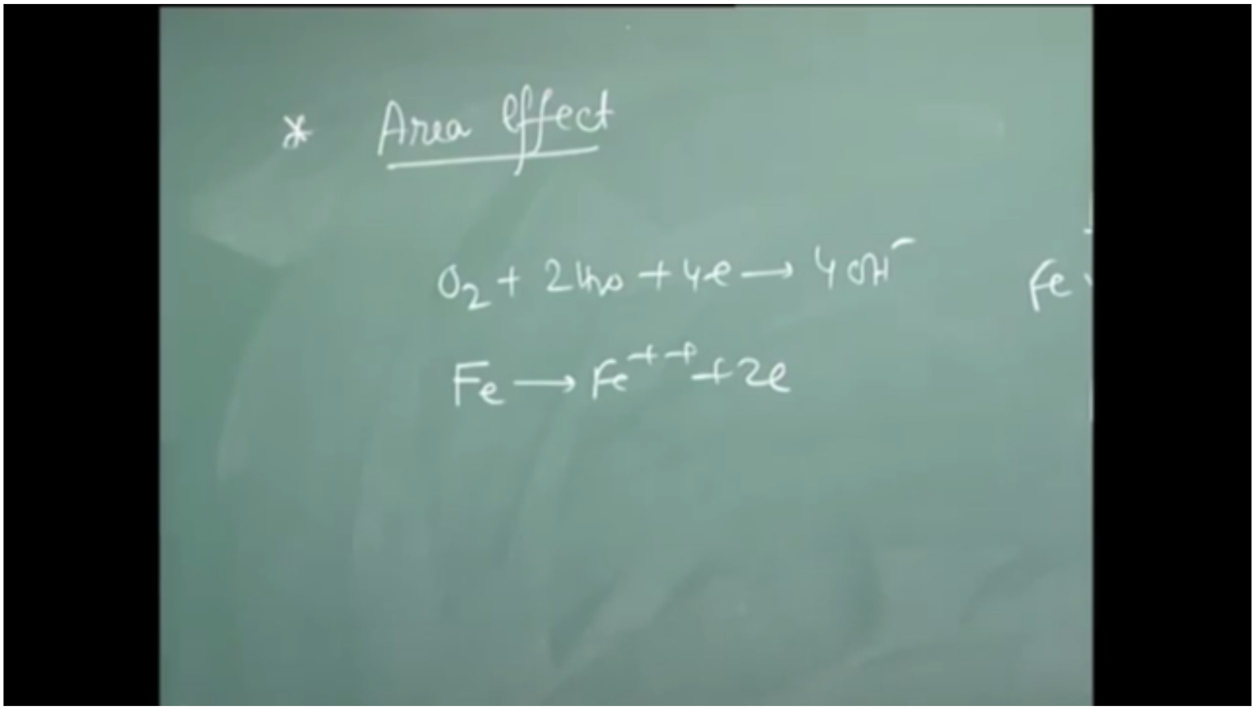

* Area effect

$O_2 + 2H_2O + 4e \rightarrow 4OH^-$

Fe

$Fe \rightarrow Fe^{++} + 2e$

Now in the galvanic series, copper is on top of iron. So galvanic series, it doesn't give you any potential value. It gives you only the relative position with respect to solution. Now if copper is placed above iron in the galvanic series, then copper is noble and iron is active in seawater. In seawater copper is placed on top of iron. It means that the cathodic reaction happens on the noble metal surface. An anodic reaction would be the reaction of that metal which is staying below that noble metal.

So in these two -- in this situation copper is noble. So this reaction would happen on copper -- on copper surface and this is active, so anodic reaction would be nothing but the iron dissolution. This is my anodic reaction and it is happening on iron and then iron is nothing but the active site -- active site and copper is a noble site and this noble reaction is happening when the cathodic reaction is happening.

If cathodic reaction happens on a particular metal surface, so you are not getting the electron discharge reaction. If electron discharge reaction is not happening, it means that it's a protection. Cathodic reaction happens on surface -- on some surface. That surface is getting protected because of this cathodic reaction, but here you have iron reaction.

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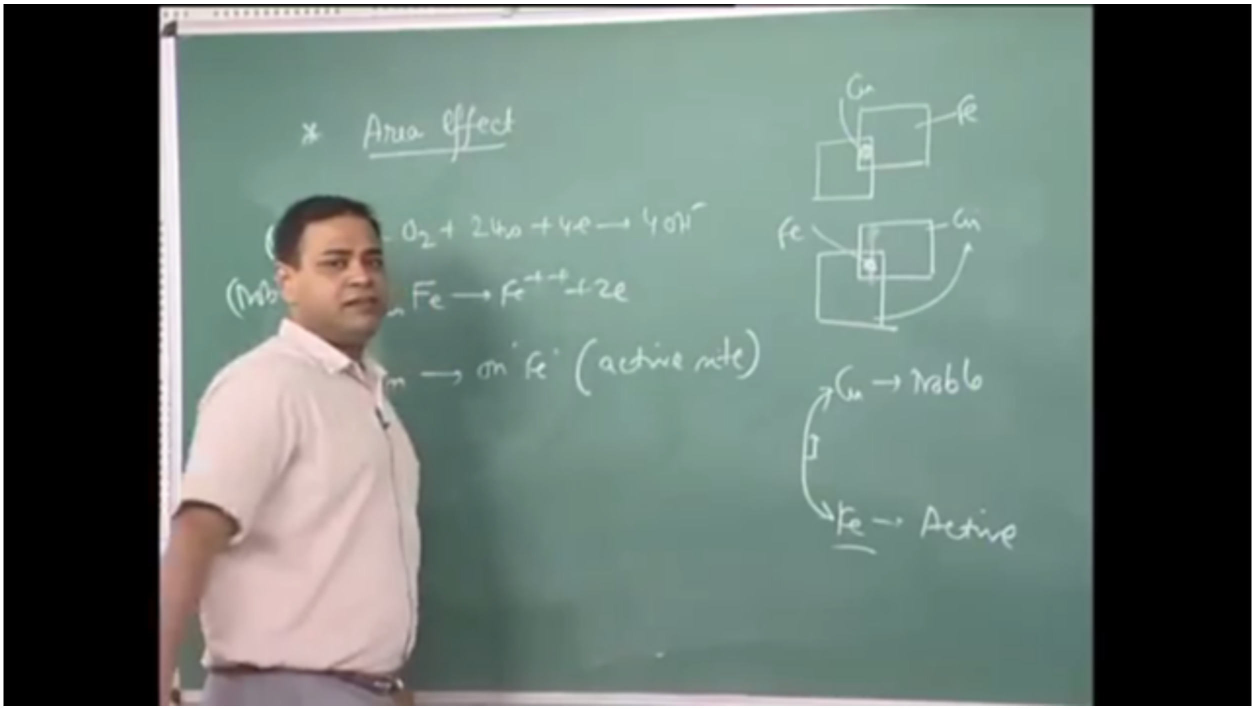

Now in this case, so this couple if you connect it, there would be current flow. There would be some current flow, and if you would like to measure the current density in this case, iron surface it would be $i_a$, copper surface it would be $i_c$. The current which will flow in the system will be decided by the amount of cathodic and anodic reactions. Here the surface area which is available for this cathodic reaction is very small.

So accordingly, the current value would also be small and accordingly, if you consider the value of $i_a$ because that current value, if 'I' value if you consider and the total amount of cathodic reaction if you consider, this 'I' would be small, small. So correspondingly, $i_a$ which is nothing but I divided by $A_{anodic}$, A of anodic surface. So here A of anodic surface is which because you have a huge iron surface, so this is very small and $i_a$ is nothing but the corrosion. So if $i_a$, which is the current density for anodic reaction is small, so the corrosion rate of iron would also be small.

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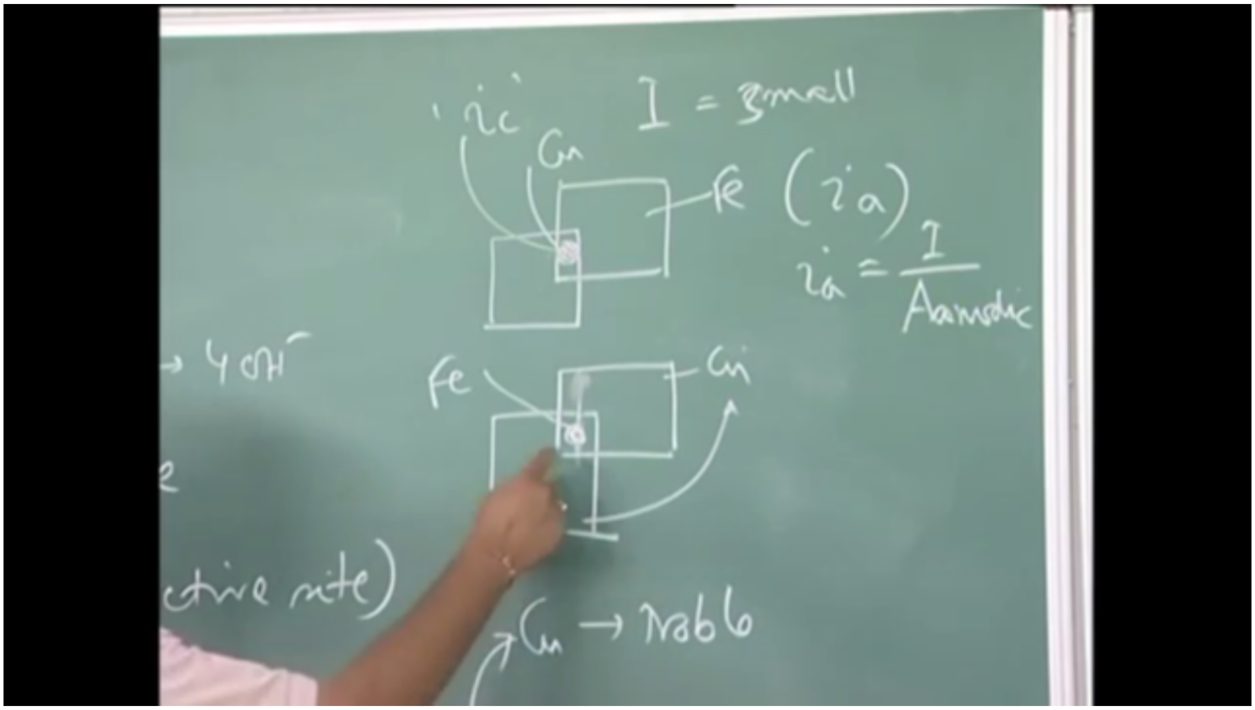

But here the situation is reverse. Here you have iron rivet. If, for example, let me continue, complete this. If iron corrosion rate is small, so the rate at which iron will dissolve around this rivet position would be very small. So, gradually, it goes away, iron goes away from the rivet region, but the rate at which iron dissolves is small. So this joint strength can remain for a longer period.

But here the situation is different because you have huge copper surface available for this reaction. So if we have more and more of this reaction because you have a huge cathodic area, so your current will also be very large. If current is very large, the same current is flowing through this iron region, and here the iron region is very small. So what would be my $I_a$ in this case? $I_a$ would be very, very large because $i_a$ is nothing but I divided by -- capital I divided by $A_{anodic}$. Fine.

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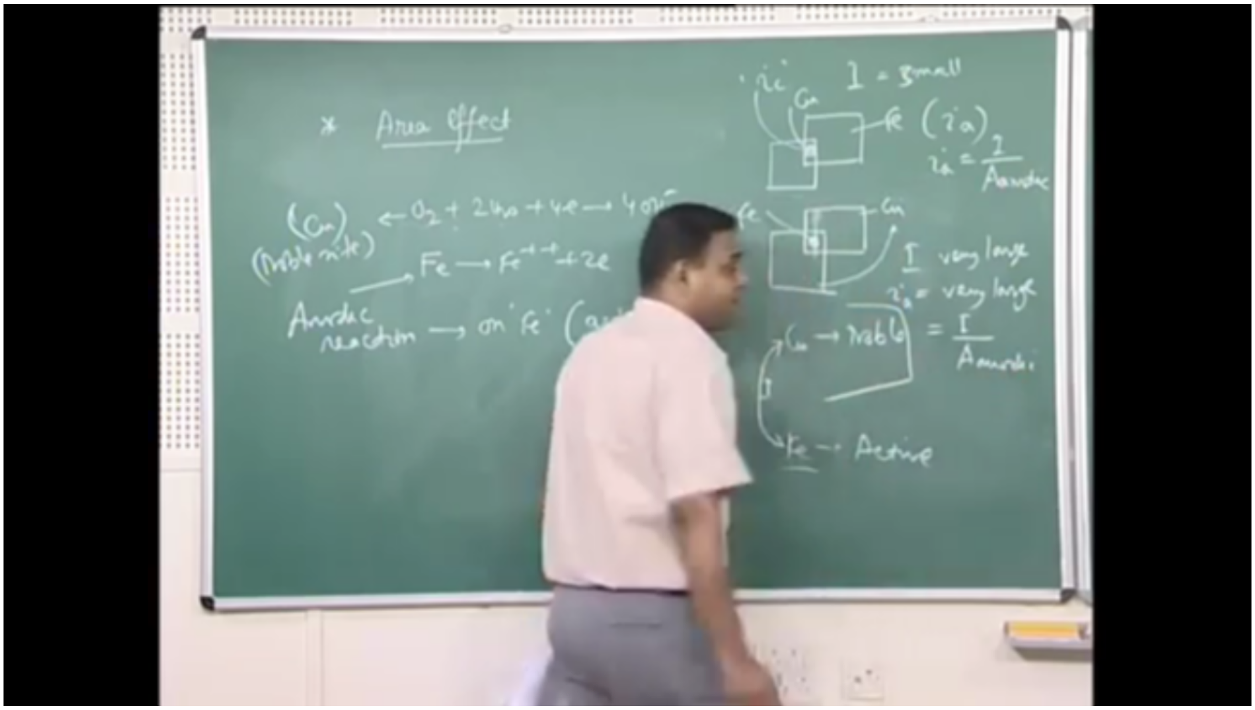

So you have huge current and a very small anodic area, and the consequence of it would be very, very high current density for anodic reaction, but in this case total current would be less. The anodic area is very large. So $i_a$ would be very, very small. So in this case, if $i_a$ is very large, so the rate at which this iron rivet goes into the solution is very, very large. So, gradually, since the rate at which iron dissolves from the rivet portion, the rivet will actually go away. There will not be a very small tiny part will remain in this region. So if rivet is not there, so you don't have strength in the joint. So this will be loose, but this will still maintain its strength because of this small $i_a$.

So the same thing can you explain from this? We can definitely explain this. Let us find out what could be the possible explanation from this exchange -- from this mixed potential theory.

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