B12 · Industrial applications and corrosion protection

Student notes - follow the slides, fill the blanks, work the questions

Goals: Explain rusting as a redox cell and calculate E°cell for it. Choose and explain barrier, sacrificial and power-supply protection using the table. Describe electroplating, refining, electrowinning and aluminium production, and judge claims with evidence. Identify the electron transfer in cellular respiration and photosynthesis.

Name: _____ Date: _____

Slide 1 of 9 · Rusting is a tiny cell

Corrosion is a metal slowly wearing away by redox. Rusting needs both _____ and _____.

At one spot iron is oxidized: $Fe \rightarrow Fe^{2+} +$ _____. The electrons move through the iron to another spot, where $O_2 + 2H_2O + 4e^- \rightarrow$ _____.

E°cell is the cell voltage at standard conditions: _____ solutions, _____ and 101.325 kPa for gases.

$E°cell = E°cathode - E°anode = 0.40 - (-0.45) =$ _____. A positive value means the reaction is _____.

Example. Iron rusts in damp air. Write the oxidation and reduction half-reactions and the cell reaction, then calculate E°cell. Use $E°(O_2/OH^-) = +0.40$ V and $E°(Fe^{2+}/Fe) = -0.45$ V.

Work:

Answer: _____

Try it. Zinc also corrodes in damp air. Write the cell reaction for zinc and oxygen, then calculate E°cell. Use $E°(O_2/OH^-) = +0.40$ V and $E°(Zn^{2+}/Zn) = -0.76$ V.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 2 of 9 · Barriers and what happens at a scratch

A _____, such as paint, keeps water and oxygen off the iron. A barrier does not supply _____.

A barrier protects only while it is whole. At a scratch, bare iron meets water and oxygen, and rust can creep _____ the paint.

When two metals touch in water, the metal _____ on the table is the stronger reducing agent and is oxidized first.

Tin (−0.14 V) is above iron (−0.45 V), so at a scratch the _____ corrodes. Zinc (−0.76 V) is below iron, so the _____ corrodes and the iron is protected.

Example. A steel can is coated with tin. The scratch exposes the iron. $E°(Sn^{2+}/Sn) = -0.14$ V and $E°(Fe^{2+}/Fe) = -0.45$ V. Which metal corrodes at the scratch, and why?

Work:

Answer: _____

Try it. A steel sheet is coated with zinc. The scratch exposes the iron. $E°(Zn^{2+}/Zn) = -0.76$ V and $E°(Fe^{2+}/Fe) = -0.45$ V. Which metal corrodes at the scratch, and why?

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 3 of 9 · A sacrificial metal

A sacrificial anode is a block of metal that gives up electrons _____ than iron. Choose a metal _____ iron on the table.

The block is the anode and is _____. The iron is the _____, so it is not oxidized.

Protected minus sacrificial: $-0.45 - (-2.37) =$ _____. A positive value means the block is the stronger _____.

In the real cell oxygen is reduced, so $E°cell = 0.40 - (-2.37) =$ _____. The block needs a _____ to the iron and an electrolyte.

Example. A magnesium block ($E°(Mg^{2+}/Mg) = -2.37$ V) is joined to iron ($E°(Fe^{2+}/Fe) = -0.45$ V) in wet soil. Find protected minus sacrificial, and then E°cell using O_2/OH^- at +0.40 V. Which metal is the anode?

Work:

Answer: _____

Try it. An aluminium block ($E°(Al^{3+}/Al) = -1.66$ V) is joined to iron ($E°(Fe^{2+}/Fe) = -0.45$ V) in wet soil. Find protected minus sacrificial, and then E°cell using O_2/OH^- at +0.40 V.

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 4 of 9 · Protection with a power supply

A power supply pushes _____ around a circuit. Join the iron to the _____ terminal.

Electrons are pushed onto the iron, so it is the _____ of an electrolytic cell. Oxidation does not happen at the cathode.

A separate _____ anode is joined to the positive terminal. Oxidation happens there instead of at the iron.

A sacrificial anode uses a _____ cell and needs no electricity. A power supply uses _____.

Example. A buried steel pipeline is protected by a power supply and an inert anode. To which terminal is the pipeline joined, what is it called, and why does it not rust?

Work:

Answer: _____

Try it. Compare a sacrificial anode with a power supply. Which one needs electricity, and which one needs blocks to be replaced?

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 5 of 9 · Method: how to choose a corrosion protection

Step 1. Name the metal to protect and find its _____ in the table.

Step 2. _____ it with each metal you could use.

Step 3. A metal with a _____ E° can be a sacrificial anode. It is oxidized instead.

Step 4. Check what the method needs. A _____ works only while whole. A sacrificial anode needs a connection and an _____.

Step 5. With a power supply, join the protected metal to the _____ terminal.

Check: the protected metal is always the _____.

Example. Use the method on an iron pipe in wet soil. $E°(Mg^{2+}/Mg) = -2.37$ V and $E°(Fe^{2+}/Fe) = -0.45$ V. Is magnesium a good sacrificial anode?

Work:

Answer: _____

Try it. Use the method on a steel hull. To choose from: Zn (−0.76 V) and Cu (+0.34 V). Fe^{2+}/Fe is −0.45 V. Which metal is a sacrificial anode?

Work:

Answer: _____

Slide 6 of 9 · Your turn: protecting a buried tank

A metal protects iron when its E° is _____ than −0.45 V. It is the stronger _____, so it is oxidized first.

Protected minus sacrificial: −0.45 − (−0.76) = _____ for zinc. This is a comparison value, not a _____.

A positive value means the metal _____. A negative value, like −0.32 V for lead, means it _____.

Magnesium (+1.92 V) is the stronger reducing agent but is used up _____. Voltage cannot show cost, life or _____.

Example. A buried steel tank has E°(Fe^{2+}/Fe) = −0.45 V. The metals to choose from for a sacrificial anode are Mg (−2.37 V), Zn (−0.76 V), Pb (−0.13 V) and Cu (+0.34 V). Which could protect it, and which is the best choice?

Work:

Answer: _____

Try it. A steel pipe has E°(Fe^{2+}/Fe) = −0.45 V. The metals to choose from for a sacrificial anode are Al (−1.66 V), Ni (−0.26 V) and Sn (−0.14 V). Which could protect it? Show protected minus sacrificial for each.

Work:

Answer: _____

Slide 7 of 9 · Plating, refining and winning metal

Electroplating coats an object with a thin layer of metal. The object is the _____, where $Ag^+ + e^- \rightarrow$ _____.

Refining makes an impure metal purer. The impure copper is the _____ and dissolves: $Cu \rightarrow Cu^{2+}$ + _____. Pure copper builds up on the cathode.

Electrowinning recovers a metal from a solution of its ions: $Zn^{2+} + 2e^- \rightarrow Zn$. The anode is _____, so the metal comes from the _____.

For each process, name the _____ first, then say which electrode dissolves and which gains metal. The Faraday chain predicts the _____ of metal formed.

Example. A spoon is silver plated in a solution of Ag^+ ions. What is the purpose, which electrode is the spoon, and what are the half-reactions? The anode is a bar of silver.

Work:

Answer: _____

Try it. Impure copper is refined in a copper(II) sulfate solution. What is the purpose, which electrode is the impure copper, and what are the half-reactions?

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 8 of 9 · Aluminium from a melt

In a water solution of Al^{3+}, the cathode choices are Al^{3+} at _____ and water at −0.83 V. The _____ value is reduced first, so water is reduced.

Hydrogen gas forms at the cathode and no _____ forms. So aluminium cannot be made from a water solution.

Instead, aluminium oxide is dissolved in _____, which has no water. Al^{3+} (−1.66 V) is higher than Na^{+} (−2.71 V), so Al^{3+} + _____ → Al.

Oxide ions are oxidized at a _____ anode, and the oxygen reacts with the carbon, so the anode is used up. The process needs a huge amount of _____.

Example. Could aluminium be made by electrolyzing a water solution of Al^{3+} with inert electrodes? The values are Al^{3+} −1.66 V and water −0.83 V. What forms at the cathode, and what is the fix?

Work:

Answer: _____

Try it. Could magnesium be made by electrolyzing a water solution of Mg^{2+} with inert electrodes? The values are Mg^{2+} −2.37 V and water −0.83 V. What is reduced at the cathode?

Work:

Answer: _____

Slide 9 of 9 · Redox in living things

An oxidation number is the charge an atom would have if all shared electrons went to the atom that _____. It helps us follow _____.

In $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$, oxygen falls from 0 to _____, so O_2 is _____.

Carbon averages 0 in glucose and _____ in CO_2. Six carbon atoms each lose 4 electrons, so _____ electrons are lost. Twelve oxygen atoms each gain 2, so 24 are gained.

Photosynthesis is the reverse: CO_2 is _____ and water is _____. It needs _____, as an electrolytic cell needs a power supply.

Example. Cellular respiration is $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. Find the oxidation numbers of carbon and oxygen, say what is oxidized and reduced, and count the electrons lost and gained.

Work:

Answer: _____

Try it. Photosynthesis is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. What is oxidized, what is reduced, and how many electrons do the carbon atoms gain in total?

Work:

Answer: _____

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1. Given that iron rusts in damp air. Write the oxidation and reduction half-reactions and find E°cell (Data Booklet table values: O_2/OH^- +0.40 V; Fe^{2+}/Fe −0.45 V).

Work:

Final answer (with unit): _____

2. Given tin-plated steel with a deep scratch (Data Booklet table values: Sn^{2+}/Sn −0.14 V; Fe^{2+}/Fe −0.45 V). Which metal corrodes at the scratch, and why?

Work:

Final answer (with unit): _____

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3. Given a steel pipe in wet soil joined to a zinc block (Data Booklet table values: Zn^{2+}/Zn −0.76 V; Fe^{2+}/Fe −0.45 V). Find protected minus sacrificial and state the electrode that is the anode.

Work:

Final answer (with unit): _____

4. Given an underground steel pipeline protected by a power supply. State which terminal the pipeline is joined to and why.

Work:

Final answer (with unit): _____

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5. Given a steel hull in sea water. The metals to choose from are Cu (+0.34 V), Zn (−0.76 V) and Sn (−0.14 V), and Fe^{2+}/Fe is −0.45 V. All four values are from the Data Booklet table. Choose a sacrificial anode and give protected minus sacrificial.

Work:

Final answer (with unit): _____

6. Given the refining of copper. State which electrode is the impure copper and write both half-reactions.

Work:

Final answer (with unit): _____

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7. Given cellular respiration $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. State what is oxidized, what is reduced, and the oxidizing and reducing agents.

Work:

Final answer (with unit): _____

8. Challenge: Given an aluminium production cell that runs at a steady 1.60×10^5 A. The cathode half-reaction is $Al^{3+} + 3e^- \rightarrow Al$ (M = 26.98 g/mol). Use the Faraday chain from B10. Find the mass of aluminium made in 1.00 hour, in kilograms. Use $F = 9.65 \times 10^4$ C/mol e^-.

Work:

Final answer (with unit): _____