B13 · Batteries, fuel cells and chlorine for water

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

Goals: Explain batteries as voltaic cells, and primary and rechargeable cells. Write the reactions and find the voltage of a lead-acid cell, an alkaline cell and a hydrogen fuel cell. Explain how chlorine is made for water, and judge a cell for a purpose using evidence.

Name: _____ Date: _____

Slide 1 of 10 · A battery is a voltaic cell

A battery is _____ voltaic cells. A voltaic cell has an anode, a cathode and an _____, which is a liquid with dissolved ions.

When cells are joined in a row, their voltages _____. So more cells in a row give _____ voltage.

A _____ cell is used once, because its reaction cannot easily be reversed. A _____ cell can be recharged.

Recharging runs the cell reaction _____ with a power supply. During recharge the battery acts as an _____ cell.

Example. A phone, a car and a watch each use stored chemical energy as electricity. What is a battery? How does a primary cell differ from a secondary cell?

Work:

Answer: _____

Try it. A rechargeable battery is being recharged by a power supply. What kind of cell is it acting as? What happens to the electrode that was oxidized during discharge?

Work:

Answer: _____

Slide 2 of 10 · The lead-acid battery

Two lead rows match this cell: E°(PbO_2/$PbSO_4$) = +1.69 V and E°($PbSO_4$/Pb) = _____. In a voltaic cell the _____ value is the cathode.

The higher row runs as written at the _____. The lower row is reversed to Pb + SO_4^{2-} → $PbSO_4$ + $2e^-$ at the _____, but its E° value stays _____.

Both halves move _____ electrons, so the electrons cancel. The cell reaction is PbO_2 + Pb + $2SO_4^{2-}$ + $4H^+$ → _____. The acid gets _____.

E°cell = E°cathode − E°anode = 1.69 − (−0.36) = _____. Six cells in a row give 6 × 2.05 = _____, or 12.3 V to three digits, enough for a car.

Example. A car battery is rechargeable and gives large currents. Given E°(PbO_2/$PbSO_4$) = +1.69 V and E°($PbSO_4$/Pb) = −0.36 V, write the cell reaction, find E°cell for one cell and find the voltage of six cells in a row.

Work:

Answer: _____

Try it. Given E°(PbO_2/$PbSO_4$) = +1.69 V and E°($PbSO_4$/Pb) = −0.36 V. Which row belongs to the anode? What is the voltage of a battery of four of these cells in a row?

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 3 of 10 · A primary cell: the alkaline cell

An alkaline cell is a _____ cell. Its anode is _____ powder and its cathode is manganese(IV) oxide in a basic paste.

When half-reactions are _____, use them and do not look in the Data Booklet. Zinc is oxidized: $Zn + 2OH^- \rightarrow ZnO + H_2O +$ _____.

Manganese is reduced: $2MnO_2 + H_2O + 2e^- \rightarrow$ _____ $+ 2OH^-$. Add the halves and cancel the electrons, water and hydroxide ions: $Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$.

The zinc is used up, and the reaction cannot easily be reversed. Used cells hold metals that harm soil and water, so they should be _____. A diploma answer gives a benefit and a _____ concern.

Example. A flashlight uses an alkaline cell that is not recharged. The given half-reactions are $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$ and $2MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + 2OH^-$. Find the overall reaction and say what happens to the zinc.

Work:

Answer: _____

Try it. In the alkaline cell reaction $Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$, find the oxidation number of zinc and of manganese on each side. What is oxidized and what is reduced?

Work:

Answer: _____

Slide 4 of 10 · Your turn: a lead-acid battery

Cells in a row _____ their voltages. The number of cells is the voltage needed divided by the _____.

You cannot use part of a cell, so the number of cells must be a _____. Follow the rounding rule in the question.

Oxidation happens at the anode. In $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$, the _____ electrode is the anode. Solid $PbSO_4$ stays on it, so its mass goes _____.

At the cathode, PbO_2 is _____ and solid $PbSO_4$ also forms there. So on discharge both electrodes _____ mass, and the acid gets weaker.

Example. Given lead-acid cells in a row, each with $E°_{cell} = +2.05$ V. The discharge half-reactions are $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$ and $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$. A 6.15 V battery is needed. How many cells are needed? Which electrode is the anode, and does its mass rise or fall?

Work:

Answer: _____

Try it. A battery must give 10.25 V from lead-acid cells of 2.05 V each. How many cells are needed? Does the cathode mass rise or fall on discharge, and why?

Work:

Answer: _____

Slide 5 of 10 · Method: how to find how many cells make a battery

Step 1. Find the voltage of _____. Use E°cell.

Step 2. _____ the voltage needed by the voltage of one cell.

Step 3. Round _____ to a whole number of cells, unless the question gives a rule.

Step 4. Multiply _____ to check the total voltage.

Example. Use the method on lead-acid cells of E°cell = +2.05 V. A 6.15 V battery is needed. How many cells?

Work:

Answer: _____

Try it. Use the method on lead-acid cells of 2.05 V each. A battery must give at least 8.2 V. How many cells?

Work:

Answer: _____

Slide 6 of 10 · The hydrogen fuel cell

A fuel cell is a voltaic cell that is _____ its reactants all the time. A battery stores a fixed amount and runs down.

At the anode, hydrogen is oxidized: $2H_2 \rightarrow$ _____ $+ 4e^-$. At the cathode, oxygen is reduced: $O_2 + 4H^+ + 4e^- \rightarrow$ _____.

Both halves move _____ electrons, so the electrons cancel. The overall reaction is _____. $E°cell = 1.23 - 0.00 =$ _____.

Do not multiply E° by a coefficient used to balance electrons. To judge a claim of no emissions, you need _____ about how the hydrogen is made and moved.

Example. A fuel cell makes electricity from hydrogen and oxygen that are fed to it all the time. Given $2H_2 \rightarrow 4H^+ + 4e^-$ and $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$. Also given $E°(O_2/H_2O) = +1.23$ V and $E°(H^+/H_2) = 0.00$ V. Write the overall reaction and find E°cell.

Work:

Answer: _____

Try it. Each cell of a hydrogen fuel cell stack gives $E°cell = +1.23$ V. A stack has three cells in a row. What is the stack voltage? Why does a fuel cell keep running when a battery runs down?

Work:

Answer: _____

Sketch (draw and label the diagram):

Slide 7 of 10 · Chlorine for a swimming pool

In salt water, NaCl(aq), a current makes one gas at each electrode. At the cathode, _____ is reduced: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$.

At the anode, chloride is oxidized: $2Cl^- \rightarrow$ _____ $+ 2e^-$. The +1.23 V water row is for acid, so the table gives only a first _____ that water is oxidized. Chlorine forms in practice. This is the chloride _____.

An oxidation number is the charge an atom would have if all shared electrons went to the atom that attracts them _____. In $Cl_2 + 2OH^- \rightarrow Cl^- + OCl^- + H_2O$, chlorine goes from _____ to −1 and to _____.

The same element is both oxidized and reduced, which is called a _____. Hypochlorite, OCl^-, cleans water because it is an _____ agent.

Example. Salt-water pools make chlorine by electrolysis of NaCl(aq). Name the gas formed at each electrode. Then use oxidation numbers to show that $Cl_2 + 2OH^- \rightarrow Cl^- + OCl^- + H_2O$ is a disproportionation.

Work:

Answer: _____

Try it. Given $Br_2 + 2OH^- \rightarrow Br^- + OBr^- + H_2O$, with oxygen −2 in OBr^-. Find the oxidation number of bromine in each particle that contains it. Is this a disproportionation?

Work:

Answer: _____

Slide 8 of 10 · Choose a cell for a purpose

To choose a cell, start with the _____: what must the cell do? Then compare cells using evidence.

Voltage, mass, how long it runs, recharging, cost and disposal are each _____ evidence. A higher voltage alone does not show a longer _____ or a lower cost.

A primary cell is cheap and keeps its charge for years. A rechargeable cell costs more at the start but can be used _____. A _____ cell runs as long as fuel keeps coming.

There is no best cell for every job. Justify a choice by naming one _____ and one _____ of the type you choose.

Example. A company wants a cell for a flashlight that is used rarely and stored for years. Compare a primary cell, a rechargeable cell and a fuel cell. Which one would you choose? Give one advantage and one limit.

Work:

Answer: _____

Try it. A company wants a cell for a laptop that is used every day. Which type would you choose? Give one advantage and one limit.

Work:

Answer: _____

Slide 9 of 10 · Method: how to choose a cell for a purpose

Step 1. State what the _____ needs.

Step 2. List the _____ about each cell: voltage, mass, life, recharging and cost.

Step 3. Match each need to a fact. Use _____, not the highest voltage alone.

Step 4. Note disposal and safety. Used cells contain _____.

Step 5. Recommend one cell with a _____ and one limit.

Example. Use the method on a flashlight that is used rarely and kept in a drawer for years. Which type of cell suits it?

Work:

Answer: _____

Try it. Use the method on a phone that is used every day. Which type of cell suits it?

Work:

Answer: _____

Slide 10 of 10 · Extracting metals long ago

Redox is much older than batteries. Early peoples heated copper ore with _____ and got copper metal: $2CuO + C \rightarrow 2Cu + CO_2$.

Copper goes from _____ to 0, so copper is reduced. Carbon goes from 0 to _____, so carbon is oxidized.

The reducing agent is the one that is _____. Its oxidation number _____. Here the reducing agent is _____.

Trial and error gave the method first, and the redox model explained _____ it works. Metals low on the table, like _____, need electrolysis instead.

Example. Early peoples heated copper(II) oxide with charcoal and got copper. Given $2CuO + C \rightarrow 2Cu + CO_2$, find the oxidation number of copper and of carbon on each side. Name what is oxidized and reduced, and the reducing agent. Check the atoms and charge.

Work:

Answer: _____

Try it. Iron(III) oxide is heated with carbon monoxide: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$. Find the oxidation number of iron and of carbon on each side. Name what is oxidized and the reducing agent.

Work:

Answer: _____

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1. Explain the difference between a primary cell and a secondary cell, and say what happens during recharging.

Work:

Final answer (with unit): _____

2. Given these Data Booklet table rows for the lead-acid cell: $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$ (+1.69 V) and $PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$ (−0.36 V). Find E°cell for one cell and the voltage of a battery of six cells.

Work:

Final answer (with unit): _____

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3. Given the alkaline cell half-reactions $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$ and $2MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + 2OH^-$. Name what is oxidized and what is reduced. Then write the overall reaction.

Work:

Final answer (with unit): _____

4. Given a battery that must give 8.2 V from lead-acid cells of 2.05 V each. Find the number of cells and say which electrode gains mass on discharge.

Work:

Final answer (with unit): _____

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5. Given a hydrogen fuel cell with the Data Booklet table rows $H_2 \rightarrow 2H^+ + 2e^-$ (0.00 V) and $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (+1.23 V). Write the overall reaction and find E°cell.

Work:

Final answer (with unit): _____

6. Given the electrolysis of NaCl(aq) in a pool system. Name the product at each electrode and show why $Cl_2 + 2OH^- \rightarrow Cl^- + OCl^- + H_2O$ is a disproportionation.

Work:

Final answer (with unit): _____

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7. Given heating of copper(II) oxide with charcoal: $2CuO + C \rightarrow 2Cu + CO_2$. Name what is oxidized and reduced and the reducing agent.

Work:

Final answer (with unit): _____

8. Challenge: Given a hydrogen fuel cell with the anode half-reaction $H_2 \rightarrow 2H^+ + 2e^-$. The cell gives 2.00 A for 1.00 hour. Use the Faraday chain from B10. Find the mass of hydrogen gas used, in grams ($M(H_2) = 2.02$ g/mol). Use $F = 9.65 \times 10^4$ C/mol e^-.

Work:

Final answer (with unit): _____