B13 · Batteries, fuel cells and chlorine for water

Completed notes | Notes 1/3

Explain batteries as voltaic cells and write the reactions of lead-acid, alkaline and fuel cells. Explain chlorine production for water and judge a cell using evidence.

1. Batteries

A battery is one or more voltaic cells

A voltaic cell has an anode, a cathode and an electrolyte, which is a liquid with dissolved ions. A battery is one or more of them.

Cells joined in a row **add** their voltages, so more cells means more voltage.

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

During discharge a battery is a **voltaic** cell. The reaction runs by itself and gives electricity.

During recharge a power supply forces the reverse reaction, so it is an **electrolytic** cell (B8). The electrode that was oxidized is now reduced, so the names anode and cathode swap.

On the diploma: to name the anode, ask where oxidation is happening in that direction. A battery can be one cell or several cells in a row.

The lead-acid cell

The booklet has two lead rows: $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$ (+1.69 V) and $PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$ (−0.36 V).

PbO_2 has the higher value, +1.69 V, so it is the **cathode**. The lower row runs backward at the anode: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$. So lead is the **anode**.

E°cell = 1.69 − (−0.36) = **+2.05 V**. One cell is not enough for a car, and voltages add. Six cells in a row give 6 × 2.05 = **12.3 V**.

Both halves move two electrons, so no multiplier is needed. The cell reaction is $PbO_2 + Pb + 2SO_4^{2-} + 4H^+ \rightarrow$ **$2PbSO_4$** $+ 2H_2O$. Atom check: Pb 2, S 2, O 10, H 4, charge 0.

H^+ and SO_4^{2-} are reactants, so they get used up and the acid gets **weaker**. $PbSO_4$ is a solid that forms on both electrodes, so both electrodes **gain** mass.

We cannot use part of a cell. If each cell gives 2.05 V and a battery needs 7.0 V, then 7.0 ÷ 2.05 = 3.41, so round up to **4** cells.

On the diploma: reverse the lower half-reaction but keep its E° as printed, and never multiply E° by a coefficient. Common wrong choices forget the six cells or say the

anode loses mass.

PbO_2 (+1.69 V) and $PbSO_4$/Pb (−0.36 V). Cathode: PbO_2; anode: Pb

$E°cell = 1.69 - (-0.36) = +2.05$ V

Six cells in a row: $6 \times 2.05 = 12.3$ V

Discharge: both electrodes gain mass as $PbSO_4$ forms.

B13 · Batteries, fuel cells and chlorine for water

Completed notes | Notes 2/3

2. Alkaline cells and fuel cells

The alkaline cell

An alkaline cell, like a flashlight cell, is a primary cell. Its half-reactions are given, so we do not need the table.

The anode is **zinc**, which is oxidized because it loses electrons: $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$. The cathode is **$MnO_2$**, which is reduced: $2MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + 2OH^-$.

Add the halves and cancel the electrons, water and hydroxide ions. The overall reaction is $Zn + 2MnO_2 \rightarrow ZnO +$ **Mn_2O_3**. It is a **primary** cell with a given voltage of about 1.5 V.

Used cells contain **metals**, like zinc and manganese compounds. In the garbage they can harm soil and water, so they should be recycled or disposed of properly.

On the diploma: when half-reactions are given, use them and do not search the booklet. An Evaluate item about batteries expects a benefit and a disposal concern.

The hydrogen fuel cell

Hydrogen is **oxidized** at the anode: $2H_2 \rightarrow 4H^+ + 4e^-$. Oxygen is **reduced** at the cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.

The electrons travel through the outside circuit, and that is the current we use. Hydrogen ions cross a **membrane** inside the cell to complete the circuit.

Both halves move four electrons, so they cancel. Overall: $2H_2 + O_2 \rightarrow$ **$2H_2O$**. $E°_{cell} = 1.23 - 0.00 =$ **+1.23 V**, and we do not multiply E° by the 2.

A fuel cell is fed **fuel** all the time, so it keeps running. A battery stores a fixed amount of **reactants** and runs down.

On the diploma: the particle that is oxidized is the one that loses electrons. Do not multiply E° by the coefficient you used to balance electrons.

B13 · Batteries, fuel cells and chlorine for water

Completed notes | Notes 3/3

3. Chlorine for water and judging cells

Chlorine for a pool

A pool system passes current through NaCl(aq). The cathode makes **hydrogen**: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$. The anode makes **chlorine**: $2Cl^- \rightarrow Cl_2 + 2e^-$.

The table says water should be oxidized, but chlorine forms because of the chloride **anomaly** from B9.

The Cl_2 then reacts with hydroxide: $Cl_2 + 2OH^- \rightarrow Cl^- + OCl^- + H_2O$. One chlorine goes from 0 to **−1**, so it is reduced. The other goes from 0 to **+1**, so it is oxidized.

The same element is both oxidized and reduced, which we call a **disproportionation**.

The ion **OCl^-** cleans the water, because it is an oxidizing agent that oxidizes bacteria.

On the diploma: write the oxidation number of chlorine on each side before you name the change. Hydrogen is at the cathode and chlorine at the anode.

Judge a cell

Start with the **job**. Then compare voltage, mass, lifetime, recharging, cost and **disposal** as separate pieces of evidence.

A higher voltage does not prove a **longer** life or a lower **cost**. A primary cell is cheap and keeps its charge in storage, so it suits a flashlight that is used rarely.

A fuel cell runs as long as fuel arrives. But a claim of no emissions only covers the cell itself, so we need evidence about how the **fuel** is made and delivered.

On the diploma: a common wrong choice says the highest-voltage cell is best. Justify your choice with one advantage and one limit.

Extracting metals long ago

Early peoples heated copper ore with charcoal long before anyone knew about electrons: $2CuO + C \rightarrow 2Cu + CO_2$. Copper goes from +2 to 0, so it is **reduced**. Carbon goes from 0 to +4, so it is **oxidized**.

Carbon gave electrons to copper(II), so carbon is the **reducing** agent. It is the one whose oxidation number goes up.

Trial and error came first, and the redox **model** explained it later. The model also showed that metals low on the table, like aluminium, have ions that accept electrons so poorly that carbon cannot reduce them. Those need electrolysis (B12).

On the diploma: for a science and technology question, give one example in each direction.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 1-2 of 12

State symbols: (s) solid, (aq) dissolved in water, (l) liquid, (g) gas. Use the supplied reaction and conditions. B4 values name the Alberta Chemistry 30 Data Booklet table where used.

B13-P01 · Easy · Explain the difference between a primary cell and a secondary cell, and give one example of each from this lesson.

1. A primary cell is used once and then disposed of or recycled. An alkaline flashlight cell is an example.

2. A secondary cell can be recharged. A lead-acid car battery is an example.

B13-P02 · Easy · A lead-acid car battery is recharged. State what kind of cell it is during recharging, and what the power supply does.

1. During recharging the battery is an electrolytic cell.

2. The power supply forces the reaction backward, so $PbSO_4$ changes back to Pb and PbO_2.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 3-4 of 12

B13-P03 · Easy · Given $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$ (+1.69 V) and $PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$ (−0.36 V). Name the cathode and the anode for a discharging lead-acid cell.

1. The higher value, +1.69 V, is reduced at the cathode, so PbO_2 is the cathode.

2. The lead is oxidized at the anode: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$.

B13-P04 · Easy · Write the cell reaction for the discharging lead-acid cell and find E°cell.

1. Both halves move two electrons, so add them without a multiplier.

2. $PbO_2 + Pb + 2SO_4^{2-} + 4H^+ \rightarrow 2PbSO_4 + 2H_2O$. E°cell = 1.69 − (−0.36) = +2.05 V.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 5-6 of 12

B13-P05 · Medium · A car battery has six lead-acid cells in a row. Find its voltage and explain why cells in a row are used.

1. The voltages add: 6 × 2.05 = 12.3 V.

2. One cell gives only 2.05 V, so many cells are joined to get a voltage large enough for the car.

B13-P06 · Medium · Describe what happens to the acid and to the mass of each electrode as a lead-acid battery discharges.

1. Hydrogen ions and sulfate ions are used up, so the acid gets weaker.

2. Solid $PbSO_4$ forms on both electrodes, so each electrode gains mass.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 7-8 of 12

B13-P07 · Medium · Given the alkaline cell half-reactions $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$ and $2MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + 2OH^-$. Add them and write the overall reaction.

1. Each half moves two electrons. Cancel the electrons, water and hydroxide ions.

2. The overall reaction is $Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$.

B13-P08 · Medium · Why should used alkaline cells be recycled or disposed of properly instead of being thrown into the garbage?

1. Used cells contain metals and other chemicals.

2. These can harm the environment if they leak into soil or water, so recycling recovers the metals and reduces the harm.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 9-10 of 12

B13-P09 · Challenging · Given $H_2 \rightarrow 2H^+ + 2e^-$ (0.00 V) and $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (+1.23 V). Write the overall fuel cell reaction and find E°cell.

1. Multiply the hydrogen half by 2 so that four electrons match.

2. $2H_2 + O_2 \rightarrow 2H_2O$. E°cell = 1.23 − 0.00 = +1.23 V.

B13-P10 · Challenging · A company says that its fuel cell makes only water, so its total emissions are zero. Evaluate the claim.

1. The claim is about the cell where it runs. It does not include the making and delivery of the hydrogen.

2. We need evidence about how the hydrogen is made, squeezed into tanks and moved. We cannot accept or reject the claim without it.

B13 · Worked practice

Batteries, fuel cells and chlorine for water | Questions 11-12 of 12

B13-P11 · Challenging · A flashlight is used only now and then. Compare an alkaline cell and a rechargeable cell for this job, and name the evidence that you would use.

1. An alkaline primary cell is cheap and keeps its charge when stored, so it suits a device that is used rarely.

2. A rechargeable cell costs more at the start and pays off only when it is recharged many times. We compare cost, lifetime and use, not voltage alone.

B13-P12 · Challenging · Salt water is electrolyzed in a pool system. Name the product at each electrode, and show with oxidation numbers that $Cl_2 + 2OH^- \rightarrow Cl^- + OCl^- + H_2O$ is a disproportionation.

1. Hydrogen forms at the cathode and chlorine forms at the anode.

2. In Cl_2 the oxidation number is 0. In Cl^- it is -1 and in OCl^- it is $+1$, so chlorine is both reduced and oxidized.