B6 · Voltaic cells

Completed notes | Notes 1/3

Explain how a voltaic cell works, label its parts, write its notation and half-reactions, predict observations and calculate E°cell.

1. Separate the halves

From direct contact to a cell

Zinc in copper(II) solution passes electrons **directly** at the metal surface, and the energy appears as **heat**. To use that energy, we make the electrons travel along a path we choose.

In a voltaic cell (also called a galvanic cell), each metal sits in its own solution and a **wire** joins them. A metal strip is an electrode. One electrode plus its solution is a half-cell, and the solution is the electrolyte, because its ions conduct charge.

Use the reduction table from B4. The higher value, Cu^{2+}/Cu **+0.34 V**, is the oxidizing agent. The lower value, Zn^{2+}/Zn **−0.76 V**, is the reducing agent.

The anode is where **oxidation** happens and the cathode is where **reduction** happens. Here the zinc electrode is the **anode** and the copper electrode is the **cathode**. Memory aid: AN OX (anode, oxidation) and RED CAT (reduction, cathode).

On the diploma: label the electrodes by their job, because an option with the anode and cathode swapped is a classic wrong choice.

Watch: What makes electricity in a zinc–copper cell (Tyler DeWitt, “Introduction to Electrochemistry”, 4:33)

Watch: Set up the two half-cells (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 1:34)

Where charge moves

Electrons leave the anode, travel through the **wire** and arrive at the cathode. Electrons do not travel through the **solutions**. Moving ions carry the charge there.

Zinc releases electrons, so in a voltaic cell the anode is **negative** and the cathode is **positive**.

On the diploma: describe electron flow as going from the anode through the wire to the cathode.

Watch: Why electrons flow through the wire (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 4:41)

Watch: Anode and cathode (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 10:04)

Watch: A way to remember anode and cathode (Tyler DeWitt, “Introduction to Electrochemistry”, 10:44)

Zn^{2+}/Zn −0.76 V; Cu^{2+}/Cu +0.34 V. Higher value is reduced.

Anode (oxidation): Zn Cathode (reduction): Cu

Electron path: Zn electrode → wire → Cu electrode

Notation: $Zn(s) \mid Zn^{2+}(aq) \parallel Cu^{2+}(aq) \mid Cu(s)$

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2. The salt bridge and cell notation

Keep the charge balanced

At the anode, $Zn \rightarrow Zn^{2+} + 2e^-$ makes the solution gain **positive** charge. At the cathode, Cu^{2+} leaves the solution, which leaves extra **negative** charge on anions, the negative ions such as sulfate.

A salt bridge, a tube of unreactive ions, or a porous barrier lets **ions** move between the solutions. Anions move toward the **anode** beaker and cations, the positive ions, move toward the **cathode** beaker.

Without a bridge, charge builds up and the electron flow **stops**. The bridge does not carry **electrons**.

On the diploma: to explain why a cell stops, say charge builds up in each beaker. Match the ion type to the beaker with the opposite extra charge.

Watch: What the salt bridge does (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 16:48)

Watch: How ions move through the bridge (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 20:00)

Write the cell in one line

Notation: $Zn(s) \mid Zn^{2+}(aq) \parallel Cu^{2+}(aq) \mid Cu(s)$. The **anode** is on the far left and the **cathode** is on the far right, because electrons start at the anode.

A single line | separates **phases**, such as an electrode and its solution. The double line || stands for the **salt bridge**. Always write state symbols.

Read from the left: the half on the left of the double line is **oxidized**. Halves for this cell: $Zn \rightarrow Zn^{2+} + \mathbf{2e^-}$ and $Cu^{2+} + 2e^- \rightarrow \mathbf{Cu}$.

On the diploma: a complete notation has the anode on the left, the double line in the middle and state symbols on every substance.

Watch: Cell notation (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 14:37)

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3. Predict, then calculate

Observations from the half-reactions

Every prediction comes from a half-reaction. Given Cu(s) | Cu^{2+}(aq) || Ag^{+}(aq) | Ag(s). The copper anode **loses** mass as Cu → Cu^{2+} + $2e^{-}$. The copper solution is already blue, and more Cu^{2+} makes it **deeper** blue.

The silver cathode **gains** mass because $2Ag^{+}$ + $2e^{-}$ → **2Ag**. The Ag^{+} concentration **decreases**.

The overall reaction is Cu + $2Ag^{+}$ → **Cu^{2+} + 2Ag**. Copper gives two electrons and each Ag^{+} takes one, so the silver half is multiplied by **2**.

On the diploma: state the change in mass, concentration and colour from the half-reaction, and do not mix up the two electrodes.

Watch: What you would see in each half-cell (Tyler DeWitt, “Galvanic Cells (Voltaic Cells)”, 9:18)

Cell potential

E°cell = E°cathode − E°**anode**. This is the B4 rule, oxidizing agent minus reducing agent, with new names. Zn/Cu: +0.34 − (−0.76) = **+1.10 V**. Cu/Ag: +0.80 − (+0.34) = **+0.46 V**.

Do not multiply a table value when you multiply a half-reaction. A negative E°cell warns that the **electrodes were swapped**.

The notation always puts the **anode** on the left, even when a drawing shows it on the right. Zn/Ag: E°cell = +0.80 − (−0.76) = **+1.56 V**.

On the diploma: keep the table signs, subtract cathode minus anode, and label electrodes from the table values, not from left and right.

Watch: Which metal pulls electrons harder (Tyler DeWitt, “Introduction to Electrochemistry”, 6:06)

B6 · Worked practice

Voltaic cells | 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.

B6-P01 · Easy · Given Zn^{2+}/Zn −0.76 V and Cu^{2+}/Cu +0.34 V. Name the anode and the cathode, and write the half-reaction at each.

1. Cu^{2+}/Cu has the higher table value, so copper(II) is reduced at the cathode. Zinc is oxidized at the anode.

2. Anode: $Zn \rightarrow Zn^{2+} + 2e^-$. Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$.

B6-P02 · Easy · Describe the path of the electrons and the path of the charge in a Zn / Cu cell with a salt bridge.

1. Electrons leave the zinc anode, travel through the wire and arrive at the copper cathode.

2. In the solutions and the salt bridge, the charge is carried by ions. Electrons do not travel through the solutions.

B6 · Worked practice

Voltaic cells | Questions 3-4 of 12

B6-P03 · Easy · Write the cell notation for a cell in which Mg(s) is oxidized and $Cu^{2+}(aq)$ is reduced, with a salt bridge.

1. Mg(s) | $Mg^{2+}(aq)$ || $Cu^{2+}(aq)$ | Cu(s).

2. The anode half is on the far left, the double line is the salt bridge, and the cathode half is on the far right.

B6-P04 · Easy · Explain why a Zn / Cu cell with wires but no salt bridge or porous barrier stops after a moment.

1. Zn^{2+} builds up in the anode beaker, so positive charge builds up there. The cathode beaker is left with extra negative charge.

2. Without a bridge the ions cannot balance the charge, so the electron flow stops.

B6 · Worked practice

Voltaic cells | Questions 5-6 of 12

B6-P05 · Medium · In a cell with a salt bridge containing $NaNO_3(aq)$, toward which beaker do the NO_3^- ions move in the cell Cu(s) | $Cu^{2+}(aq)$ || $Ag^+(aq)$ | Ag(s)? Explain.

1. The NO_3^- ions move toward the copper (anode) beaker.

2. Cu^{2+} ions are made at the anode, so positive charge builds up there. The anions move in to balance it, and the Na^+ ions move toward the silver beaker.

B6-P06 · Medium · Given Cu^{2+}/Cu +0.34 V and Ag^+/Ag +0.80 V. Write the half-reactions and the overall equation for the Cu / Ag cell.

1. Anode: $Cu \rightarrow Cu^{2+} + 2e^-$. Cathode: $2Ag^+ + 2e^- \rightarrow 2Ag$, because each silver ion takes one electron and copper gives two.

2. Overall: $Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$. Copper is 1 on each side, silver is 2 and charge is +2 on each side.

B6 · Worked practice

Voltaic cells | Questions 7-8 of 12

B6-P07 · Medium · Predict what happens to the mass of each electrode and to the colour of the copper solution while the Cu / Ag cell runs.

1. The copper electrode loses mass because $Cu \rightarrow Cu^{2+} + 2e^{-}$ at the anode. The silver electrode gains mass because Ag^{+} becomes Ag at the cathode.

2. Cu^{2+} increases, so the blue colour of the copper solution gets deeper.

B6-P08 · Medium · Calculate E°cell for the Zn / Cu cell and for the Cu / Ag cell. Use Zn^{2+}/Zn −0.76 V, Cu^{2+}/Cu +0.34 V and Ag^{+}/Ag +0.80 V.

1. Zn / Cu: E°cell = E°cathode − E°anode = 0.34 − (−0.76) = +1.10 V.

2. Cu / Ag: E°cell = 0.80 − 0.34 = +0.46 V.

B6 · Worked practice

Voltaic cells | Questions 9-10 of 12

B6-P09 · Challenging · A student calculates E°cell = 0.34 − 0.80 = −0.46 V for the Cu / Ag cell. What was done wrong, and what is the correct value?

1. The values were subtracted the wrong way round. Silver is the cathode, so its value goes first.

2. The correct value is 0.80 − 0.34 = +0.46 V. A negative answer warns that the electrodes were swapped.

B6-P10 · Challenging · Given Zn^{2+}/Zn −0.76 V and Ag^{+}/Ag +0.80 V. A drawing shows the silver half on the left. Name the anode, write the cell notation and calculate E°cell.

1. Silver has the higher table value, so it is the cathode. Zinc is the anode, even though it is drawn on the right.

2. Notation always puts the anode on the left: $Zn(s) \mid Zn^{2+}(aq) \parallel Ag^{+}(aq) \mid Ag(s)$.

3. E°cell = 0.80 − (−0.76) = +1.56 V.

B6 · Worked practice

Voltaic cells | Questions 11-12 of 12

B6-P11 · Challenging · Predict the change in mass of each electrode in the Zn / Ag cell, Zn(s) | Zn^{2+}(aq) || Ag^{+}(aq) | Ag(s), and write the half-reaction that explains each change.

1. The zinc electrode loses mass: $Zn \rightarrow Zn^{2+} + 2e^{-}$ at the anode.

2. The silver electrode gains mass: $Ag^{+} + e^{-} \rightarrow Ag$ at the cathode.

B6-P12 · Challenging · Explain why the double line in a cell notation is needed and what two half-cells it joins.

1. The double line stands for the salt bridge or porous barrier. Without it, the circuit through the solutions is not complete.

2. It separates the anode half on its left from the cathode half on its right. Each single line separates a metal electrode from its solution.