B10 · Faraday's law

Student notes - complete the underlined spaces | Notes 1/3

Find the charge from current and time, change it to moles of electrons, use a half-reaction to find moles of metal, and find a mass or a time.

Name: _____ Date: _____

1. Charge and moles of electrons

Current is charge per second

Electric charge is the amount of electricity that moves. We measure it in _____, C. Current is how much charge passes a point each second.

Current is measured in amperes, A. One ampere is one _____ each second. So charge equals current times time: q = _____.

An ampere already has seconds built in, so the time must be in _____. For 2.50 A for 10.0 min, the time is 10.0 × 60 = _____ s.

Then q = 2.50 × 600 = _____. On the diploma: leaving the time in minutes or hours is one of the most common wrong options.

Watch: Current is coulombs per second (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 3:32)

Watch: Change hours and minutes to seconds (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 4:16)

The Faraday constant

Chemistry counts in moles, so we need a number that links coulombs to moles. One mole of electrons carries _____ C.

This is the Faraday constant, F. Look it up in the _____. Think of it as a molar mass for charge.

To change coulombs into moles of electrons, divide: $n(e^-) = q \div$ _____. The coulombs cancel and moles are left.

For 1500 C, $n(e^-) = 1500 \div (9.65 \times 10^4)$ = _____. That is a small piece of one mole, so a small answer makes sense.

On the diploma: a common wrong option multiplies by F when it should divide.

Watch: Faraday’s constant: the charge on one mole of electrons (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 4:59)

Watch: Moles of electrons = current × time ÷ F (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 6:22)

Given 2.50 A for 10.0 min. Time in seconds: _____; q = _____

$n(e^-) = q \div F = 1500 \div (9.65 \times 10^4)$ = _____

$Cu^{2+} + 2e^- \rightarrow Cu$, so n(Cu) = _____

$m = n \times M = 0.00777 \times 63.55$ = _____

B10 · Faraday's law

Student notes - complete the underlined spaces | Notes 2/3

2. Moles of metal and mass

Use the half-reaction as the ratio

Moles of electrons are not yet moles of metal. The reduction half-reaction at the cathode gives the ratio, because it shows how many electrons one atom needs.

In $Cu^{2+} + 2e^- \rightarrow Cu$, _____ mol of electrons make 1 mol of copper. In $Ag^+ + e^- \rightarrow Ag$, 1 mol of electrons makes _____ mol of silver.

In $Al^{3+} + 3e^- \rightarrow Al$, three electrons make one atom, so divide the moles of electrons by _____. The ion charge sets the ratio.

Always write the half-reaction first. On the diploma: a wrong option often uses the wrong ratio, like 1 to 1 for copper.

Watch: Use the half-reaction, not the whole equation (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 1:24)

Watch: The coefficients give electrons to metal (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 12:31)

The full chain

Let’s put the links together. Zinc is plated by 3.00 A for 25.0 min. The time is 25.0 × 60 = _____ s, so q = 3.00 × 1500 = _____ C.

Then $n(e^-) = 4500 \div (9.65 \times 10^4)$ = _____ mol. In $Zn^{2+} + 2e^- \rightarrow Zn$, each zinc atom needs two electrons, so n(Zn) = _____ mol.

Mass is moles times molar mass: m = 0.0233 × 65.41 = _____. The path is charge, moles of electrons, moles of metal, then mass.

As one formula, m = _____ ÷ (zF). M is the molar mass and z is the number of electrons for one _____.

On the diploma: if a formula is given, check that t is in seconds and that z matches the half-reaction.

Watch: Example: zinc plated on a nail (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 7:45)

Watch: Change minutes to seconds (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 10:27)

Watch: Moles to mass (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 13:51)

Watch: Second example: copper on nickel (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 15:55)

B10 · Faraday's law

Student notes - complete the underlined spaces | Notes 3/3

3. Running the chain backward

Find a time

Now run the chain backward. We want 1.00 g of aluminium at 5.00 A. Start at the given, the mass, and find the moles first.

n(Al) = 1.00 ÷ 26.98 = _____ mol. In $Al^{3+} + 3e^- \rightarrow Al$, each atom needs three electrons. Going backward we multiply: $n(e^-)$ = _____ mol.

Moles of electrons to coulombs means multiply by F: $q = 0.1112 \times (9.65 \times 10^4)$ = _____ C.

Since q = It, the time is $t = q \div I = 1.073 \times 10^4 \div 5.00$ = _____ s. Divide by 60 to get _____ min.

On the diploma: check which unit the question wants for time. A wrong option divides by three where you should multiply.

What the calculation assumes

The calculation assumes all the _____ makes the product in the half-reaction. Real cells can lose some charge to _____ reactions, which are other unwanted reactions.

Mass deposited is the _____ in mass of the cathode, not its _____ mass. The cathode already had some mass before the current started.

On the diploma: if a question gives two weighings of the cathode, use the difference, not the final reading.

B10 · Practice

Faraday's law | Questions 1-3 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.

B10-P01 · Easy · A current of 3.50 A flows for 12.0 minutes. Find the charge that moves.

B10-P02 · Easy · A student calculates the charge for 2.00 A and 15 minutes as 30 C. Find the correct charge and explain the error.

B10-P03 · Easy · A charge of 2.52×10^3 C passes through a cell. Find the moles of electrons ($F = 9.65 \times 10^4$ C/mol e^-).

B10 · Practice

Faraday's law | Questions 4-6 of 12

B10-P04 · Easy · Explain in one or two sentences what the Faraday constant is and why it works like a molar mass.

B10-P05 · Medium · Given 0.0261 mol of electrons and the half-reaction $Cu^{2+} + 2e^- \rightarrow Cu$. Find the moles of copper and its mass (M = 63.55 g/mol).

B10-P06 · Medium · Given 0.0261 mol of electrons. Find the moles of aluminium formed from $Al^{3+} + 3e^- \rightarrow Al$, and compare with silver from $Ag^+ + e^- \rightarrow Ag$.

B10 · Practice

Faraday's law | Questions 7-9 of 12

B10-P07 · Medium · Given 1.80 A for 40.0 minutes and $Ag^{+} + e^{-} \rightarrow Ag$ (M = 107.87 g/mol). Find the mass of silver deposited.

B10-P08 · Medium · Given 2.40 A for 50.0 minutes and $Zn^{2+} + 2e^{-} \rightarrow Zn$ (M = 65.41 g/mol). Find the mass of zinc deposited.

B10-P09 · Challenging · Given $Ni^{2+} + 2e^{-} \rightarrow Ni$. Use $m = ItM \div (zF)$ to find the mass of nickel from 1.20 A for 50.0 minutes (M = 58.69 g/mol).

B10 · Practice

Faraday's law | Questions 10-12 of 12

B10-P10 · Challenging · Given that 2.00 g of copper must form from Cu^{2+} at a steady 4.00 A (M = 63.55 g/mol). Find the time needed in minutes.

B10-P11 · Challenging · Given that 1.00 g of aluminium must form from $Al^{3+} + 3e^- \rightarrow Al$ at 2.50 A. Find the time in minutes (M = 26.98 g/mol).

B10-P12 · Challenging · A cathode has a mass of 18.40 g before plating and 19.10 g after. Find the mass deposited, and say why we use it and not 19.10 g.

B11 · Faraday's law with the unknown chosen

Student notes - complete the underlined spaces | Notes 1/3

Start the Faraday chain from the given quantities to find a current, a time, an ion charge or a mass, and use the same charge in cells in series.

Name: _____ Date: _____

1. One chain, any unknown

Choose the direction

In B10 we built one chain: current and time give _____, charge gives moles of electrons, the half-reaction gives moles of _____, and the molar mass gives the _____.

Every Faraday problem uses this same chain. Only the given end and the asked end change.

So write the _____ and the question first. Then start at a given and walk toward the _____.

If the mass is given, go _____. Multiply by the coefficient of the electrons and then by _____. Going forward, you divide, because each step reverses.

On the diploma: many wrong options divide when they should multiply, or the other way round.

Watch: Two kinds of question (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 2:04)

Watch: Working backward from the mass (Alberta Chemistry Teacher, “Chemistry 30 - Cell stoichiometry theory and examples”, 20:02)

Find a current

A copper cathode gains 1.25 g in 40.0 min from Cu^{2+}. The mass is given, so start there: n(Cu) = 1.25 ÷ 63.55 = _____ mol.

$Cu^{2+} + 2e^- \rightarrow Cu$, so multiply by 2: $n(e^-)$ = _____ mol. Moles to coulombs means multiply by F.

q = 0.03934 × (9.65 × 10^4) = _____ C. The time is 40.0 × 60 = 2400 s, so I = q ÷ t = 3796 ÷ 2400 = _____.

Leaving the time in minutes would make the current 60 times too big. On the diploma: write givens with units, like t = 40.0 min, so you see what to convert.

Zn/Cu cell, 0.500 A for 30.0 min. q = _____

$n(e^-) = 900 \div (9.65 \times 10^4)$ = _____

$Zn \rightarrow Zn^{2+} + 2e^-$, so zinc lost = _____

$Cu^{2+} + 2e^- \rightarrow Cu$, so copper gained = _____

B11 · Faraday's law with the unknown chosen

Student notes - complete the underlined spaces | Notes 2/3

2. Ion charge and the voltaic cell

Find the ion charge

Sometimes the ion is the mystery. Let z be the number of electrons each ion gains. Given 2.00 A for 20.0 min and 0.790 g of a metal with M = 63.55 g/mol.

The time is 1200 s, so q = _____ C and n(e^-) = 2400 ÷ (9.65×10^4) = _____ mol.

n(metal) = 0.790 ÷ 63.55 = _____ mol. Dividing electrons by atoms gives electrons per atom: z = _____, so the ion is M^{2+}.

z must be a _____ number, because ion charges are whole numbers. Round to the nearest integer. On the diploma: do not report 2.0007.

The chain in a voltaic cell

An electrode is a piece of metal where a half-reaction happens. In a voltaic cell, the electrons in the wire come from the _____ and go to the _____.

So the same chain links the charge to the mass at both electrodes. A Zn/Cu cell gives 0.500 A for 30.0 min: q = 0.500 × 1800 = _____ C.

Then n(e^-) = 900 ÷ (9.65×10^4) = _____ mol. Both half-reactions use 2 electrons per atom, so n(Zn) = n(Cu) = _____ mol.

The zinc anode loses 0.004663 × 65.41 = _____ g. The copper cathode gains 0.004663 × 63.55 = _____ g. The moles are equal, but the molar _____ are different.

On the diploma: say which electrode loses mass and which gains mass.

B11 · Faraday's law with the unknown chosen

Student notes - complete the underlined spaces | Notes 3/3

3. Gases, mass gained and the anode

Gases from water

$Na_2SO_4(aq)$ is electrolyzed with inert electrodes, which carry electrons but do not react. At 2.00 A for 30.0 min, q = _____ C and $n(e^-)$ = _____ mol.

Reduction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$. It makes one H_2 for two electrons, so $n(H_2)$ = 0.0373 ÷ 2 = _____ mol.

Oxidation: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$. It makes one O_2 for four electrons, so $n(O_2)$ = 0.0373 ÷ 4 = _____ mol.

The same electrons pass through the whole circuit. Hydrogen forms in a ratio of _____ to _____ with oxygen, as in $2H_2O \rightarrow 2H_2 + O_2$.

On the diploma: a wrong option divides by 2 for oxygen. Use the 4 from the oxidation half-reaction.

Mass gained and mass lost

Use the mass _____ by the cathode. A cathode that goes from 14.20 g to 14.85 g gained _____ g.

With 1.50 A, n(Cu) = 0.65 ÷ 63.55 = 0.01023 mol and $n(e^-)$ = 0.02046 mol. Then q = 1974 C and t = 1974 ÷ 1.50 = _____ s, or 21.9 min.

In copper refining, the anode loses mass: $Cu \rightarrow Cu^{2+} + 2e^-$. For 10.0 A for 2.00 h, the time is 7200 s and q = _____ C.

Then $n(e^-)$ = 0.746 mol and n(Cu) = 0.373 mol, so the anode loses _____ g of copper. If no electrons go to side reactions, the pure cathode gains the same amount.

B11 · Practice

Faraday's law with the unknown chosen | Questions 1-3 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.

B11-P01 · Easy · A cathode gains 0.850 g of silver in 15.0 minutes from $Ag^+ + e^- \rightarrow Ag$ (M = 107.87 g/mol). Find the constant current.

B11-P02 · Easy · A cathode gains 2.50 g of nickel in 30.0 minutes from $Ni^{2+} + 2e^- \rightarrow Ni$ (M = 58.69 g/mol). Find the current.

B11-P03 · Easy · A student finds the current by dividing the charge by the time in minutes. Explain the error and the fix.

B11 · Practice

Faraday's law with the unknown chosen | Questions 4-6 of 12

B11-P04 · Easy · Given 1.50 A for 30.0 minutes and 0.485 g of a metal deposited (M = 52.00 g/mol). Find the charge on the metal ion.

B11-P05 · Medium · A calculation of z gives 2.96. Explain why we state z = 3 and what the small difference tells us.

B11-P06 · Medium · A zinc and copper voltaic cell gives 0.800 A for 45.0 minutes. Find the mass of zinc lost from the anode (M = 65.41 g/mol).

B11 · Practice

Faraday's law with the unknown chosen | Questions 7-9 of 12

B11-P07 · Medium · For the same cell, find the mass of copper gained at the cathode (M = 63.55 g/mol), and explain why the two masses are different.

B11-P08 · Medium · $Na_2SO_4(aq)$ is electrolyzed with inert electrodes at 3.00 A for 20.0 minutes. Find the moles of hydrogen and oxygen formed.

B11-P09 · Challenging · For the same electrolysis, find the mass of hydrogen formed (M = 2.02 g/mol) and state the ratio of hydrogen to oxygen by moles.

B11 · Practice

Faraday's law with the unknown chosen | Questions 10-12 of 12

B11-P10 · Challenging · A cathode of 20.00 g has a mass of 21.20 g after copper plating at 2.00 A. Find the time in minutes (M = 63.55 g/mol).

B11-P11 · Challenging · A copper anode in a refining cell runs at 5.00 A for 90.0 minutes. Find the mass lost by the anode (M = 63.55 g/mol).

B11-P12 · Challenging · A student uses the final mass of a cathode, 21.20 g, to find a plating time. Explain the error and say whether the time is too large or too small.

B12 · Industrial applications and corrosion protection

Student notes - complete the underlined spaces | Notes 1/3

Explain rusting as a redox cell, choose a method to protect iron using the reduction table, describe plating, refining, electrowinning and aluminium production, and judge claims with evidence.

Name: _____ Date: _____

1. Rusting and barriers

Rusting is a tiny cell

Rusting is just redox, like B1. Corrosion is the slow wearing away of a metal by a _____ reaction. At one spot, iron loses electrons: $Fe \rightarrow Fe^{2+} + 2e^-$.

The electrons travel through the iron to another spot. There, oxygen and water gain them: $O_2 + 2H_2O + 4e^- \rightarrow$ _____. So iron needs both _____ and _____ to rust.

The higher table value is the cathode, so oxygen (+0.40 V) is reduced. E°cell = cathode − anode = 0.40 − (−0.45) = _____.

A positive value says rusting is _____, so it happens by itself. It does not say how _____ rusting is. Salt water speeds it up because its ions carry charge.

On the diploma: to find what is oxidized, look for the particle that loses electrons. A wrong option flips the sign or adds the numbers.

Barriers

A barrier is a coating that keeps water and oxygen off the iron. Paint, oil and plastic are barriers. A barrier does not take part in the redox reaction.

It works only while whole. A deep _____ lets water and oxygen reach the iron again, and rusting can creep under the paint.

A metal coating is a barrier too. At a scratch, the metal lower on the table is oxidized first, because it gives up electrons more easily.

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 protects the iron.

On the diploma: predict by comparing the two table values and naming the lower one. The wrong option picks the higher value.

Rusting: $E°_{cell} = 0.40 - (-0.45) =$ _____

Tin-plated steel, scratched (Sn −0.14 V). Corrodes: _____

Zinc-plated steel, scratched (Zn −0.76 V). Corrodes: _____

Mg block on iron: $-0.45 - (-2.37) =$ _____; anode is _____

B12 · Industrial applications and corrosion protection

Student notes - complete the underlined spaces | Notes 2/3

2. Sacrificial anodes and power supplies

Choose a sacrificial metal

A sacrificial anode is a block of metal that gives up electrons more easily than iron. Join it to the iron, and the block is oxidized instead.

So the block must be _____ iron on the table. That makes it the stronger reducing agent, which means it loses electrons more easily. It is the _____ and the iron is the cathode.

Compare the metals with protected minus sacrificial. For Mg: $-0.45 - (-2.37) =$ _____. For Zn: $-0.45 - (-0.76) =$ _____. Positive means the metal works.

These are comparison numbers, not the real cell voltage. In the real cell, oxygen (+0.40 V) is reduced at the iron. With magnesium that is $0.40 - (-2.37) = +2.77$ V.

Copper (+0.34 V) is above iron, so it _____. The iron would become the anode and corrode faster. On the diploma: the wrong options are the metals above iron.

The block needs an electrical _____ to the iron. It also needs an electrolyte, a liquid with dissolved ions such as wet soil or sea water. It is used up, so it must be _____.

A larger number like +1.92 V shows magnesium is the stronger reducing agent. It does not prove lower cost or a longer _____.

Use a power supply

A power supply pushes electrons around a circuit. A terminal is a connection point on it. Join the pipeline to the _____ terminal.

Electrons are pushed onto the pipeline, so it is the _____ of an electrolytic cell. That is a cell that uses electrical energy to force a reaction.

A separate inert anode goes on the positive terminal. Inert means it does not react or dissolve. Oxidation happens there, not at the iron.

Both methods keep the protected metal as the cathode, so it is not oxidized. A sacrificial anode needs new blocks. A power supply needs _____.

On the diploma: the protected metal always goes on the negative terminal. The wrong option is the positive one.

B12 · Industrial applications and corrosion protection

Student notes - complete the underlined spaces | Notes 3/3

3. Making, cleaning and coating metals

Electrolytic processes

Electroplating coats an object with a thin layer of metal. The object is the _____, because metal ions are reduced onto it: $Ag^+ + e^- \rightarrow$ _____.

Refining purifies a metal. The impure metal is the _____ and dissolves: $Cu \rightarrow Cu^{2+} + 2e^-$. Pure metal forms at the cathode.

Electrowinning recovers a metal from a solution of its ions. The anode is _____ and does not dissolve, so the metal comes from the solution.

The Faraday chain works for all three processes. On the diploma: a common wrong choice says the anode dissolves in electrowinning.

Watch: Plating a copper ring with silver (Tyler DeWitt, “Electroplating”, 1:30)

Watch: The whole plating cell in one picture (Tyler DeWitt, “Electroplating Part 2”, 7:22)

Aluminium

Al^{3+}/Al is −1.66 V, very low on the table. In a water solution, the higher value is reduced first. Water is −0.83 V, so _____ forms at the cathode, not aluminium.

The fix is to remove the water. Aluminium oxide is dissolved in _____ cryolite, a melted mineral with no water. Then Al^{3+} (−1.66 V) beats Na^+ (−2.71 V): $Al^{3+} + 3e^- \rightarrow$ _____.

The oxide ions are oxidized at a carbon anode. The oxygen reacts with the carbon, so the anode is _____.

A table value shows that a method _____. It does not prove lower cost or a longer life.

Redox in living things

Oxidation numbers help us follow electrons. In cellular respiration, $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$, the average oxidation number of carbon rises from 0 to _____. So glucose is _____.

Six carbons each lose 4 electrons, so 24 are lost. Oxygen falls from 0 to −2, so O_2 is _____ and gains the same 24 electrons.

Oxygen is the oxidizing agent and glucose is the _____ agent. Respiration is spontaneous, so it releases energy, like a voltaic cell.

Photosynthesis is the _____. It is not spontaneous by itself, so _____ supplies the energy, like a power supply in an electrolytic cell.

On the diploma: the particle whose oxidation number goes down is the one reduced.

B12 · Practice

Industrial applications and corrosion protection | Questions 1-3 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.

B12-P01 · Easy · Iron rusts in damp air. Write the oxidation and reduction half-reactions and find E°cell (O_2/OH^- +0.40 V; Fe^{2+}/Fe −0.45 V).

B12-P02 · Easy · A student says that a positive E°cell of +0.85 V means iron rusts quickly. Explain what the value shows and what it does not show.

B12-P03 · Easy · Explain how a layer of paint protects iron, and give one way that it can fail.

B12 · Practice

Industrial applications and corrosion protection | Questions 4-6 of 12

B12-P04 · Easy · Tin-plated steel is scratched (Sn^{2+}/Sn −0.14 V; Fe^{2+}/Fe −0.45 V). Which metal corrodes at the scratch, and why?

B12-P05 · Medium · Zinc-plated steel is scratched (Zn^{2+}/Zn −0.76 V; Fe^{2+}/Fe −0.45 V). Which metal corrodes, and why does the iron stay protected?

B12-P06 · Medium · A steel pipe in wet soil is joined to a magnesium block (Mg^{2+}/Mg −2.37 V; Fe^{2+}/Fe −0.45 V). Name the anode and find protected minus sacrificial.

B12 · Practice

Industrial applications and corrosion protection | Questions 7-9 of 12

B12-P07 · Medium · A plan uses copper blocks to protect a steel pipe (Cu^{2+}/Cu +0.34 V). Will the plan work? Explain with the table.

B12-P08 · Medium · The metals to choose from for protecting a steel hull are Cu (+0.34 V), Zn (−0.76 V), Sn (−0.14 V) and Pb (−0.13 V), with Fe^{2+}/Fe at −0.45 V. Choose the metal and give protected minus sacrificial.

B12-P09 · Challenging · A sacrificial block must be replaced from time to time. Explain why, and name one other thing that the block needs to work.

B12 · Practice

Industrial applications and corrosion protection | Questions 10-12 of 12

B12-P10 · Challenging · A buried steel pipeline is protected with a power supply. State the terminal that the pipeline is joined to and the electrode where oxidation happens.

B12-P11 · Challenging · A steel spoon is silver plated. State whether the spoon is the anode or the cathode, and write the half-reaction at the spoon.

B12-P12 · Challenging · A student tries to make aluminium by electrolysis of aqueous Al^{3+} with inert electrodes (Al^{3+}/Al −1.66 V; water −0.83 V). State what forms at the cathode and how aluminium is made in industry.

B13 · Batteries, fuel cells and chlorine for water

Student notes - complete the underlined spaces | 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.

Name: _____ Date: _____

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 _____ their voltages, so more cells means more voltage.

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

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

During recharge a power supply forces the reverse reaction, so it is an _____ 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 _____. The lower row runs backward at the anode: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$. So lead is the _____.

$E°cell = 1.69 - (-0.36) =$ _____. One cell is not enough for a car, and voltages add. Six cells in a row give $6 \times 2.05 =$ _____.

Both halves move two electrons, so no multiplier is needed. The cell reaction is $PbO_2 + Pb + 2SO_4^{2-} + 4H^+ \rightarrow$ _____ $+ 2H_2O$. 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 _____. $PbSO_4$ is a solid that forms on both electrodes, so both electrodes _____ mass.

We cannot use part of a cell. If each cell gives 2.05 V and a battery needs 7.0 V, then $7.0 \div 2.05 = 3.41$, so round up to _____ 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: _____; anode: _____

$E°_{cell}$ = 1.69 − (−0.36) = _____

Six cells in a row: 6 × 2.05 = _____

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

B13 · Batteries, fuel cells and chlorine for water

Student notes - complete the underlined spaces | 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 _____, which is oxidized because it loses electrons: $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$. The cathode is _____, 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 $Zn + 2MnO_2 \rightarrow ZnO +$ _____. It is a _____ cell with a given voltage of about 1.5 V.

Used cells contain _____, 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 _____ at the anode: $2H_2 \rightarrow 4H^+ + 4e^-$. Oxygen is _____ 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 _____ inside the cell to complete the circuit.

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

A fuel cell is fed _____ all the time, so it keeps running. A battery stores a fixed amount of _____ 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

Student notes - complete the underlined spaces | 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 _____: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$. The anode makes _____: $2Cl^- \rightarrow Cl_2 + 2e^-$.

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

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

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

The ion _____ 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 _____. Then compare voltage, mass, lifetime, recharging, cost and _____ as separate pieces of evidence.

A higher voltage does not prove a _____ life or a lower _____. 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 _____ 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 _____. Carbon goes from 0 to +4, so it is _____.

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

Trial and error came first, and the redox _____ 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 · Practice

Batteries, fuel cells and chlorine for water | Questions 1-3 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.

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.

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.

B13 · Practice

Batteries, fuel cells and chlorine for water | Questions 4-6 of 12

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

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.

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

B13 · Practice

Batteries, fuel cells and chlorine for water | Questions 7-9 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.

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

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.

B13 · Practice

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

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

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.

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.

B14 · Investigation: plan and predict

Student notes - complete the underlined spaces | Notes 1/2

Write a testable question, draw a labelled cell design, predict the anode and voltage from the table, plan safe handling and plan a battery.

Name: _____ Date: _____

1. Question, variables and design

A testable question

We have used the table to predict voltages. Now we test the predictions. A testable question links one thing we change to one thing we measure.

The variable you change is the _____ variable. The variable you measure is the _____ variable. Here we change the metal and measure the voltage.

A fair test keeps everything else the same. These are the controlled variables: the _____, temperature, electrode size and salt bridge.

The table values assume _____ solutions at standard conditions. If a control changed, we could not tell what caused a change in voltage.

On the diploma: the independent variable is what you change, and the dependent variable is what you measure.

A labelled design

A half-cell is a metal strip, called an electrode, in a solution of its _____. The second half-cell is always copper in copper(II) sulfate.

A _____ lets ions move between the half-cells. This keeps the charge balanced and completes the circuit. A voltmeter joins the strips through wires.

Label the _____, the cathode, the direction of electron flow and the concentrations. Electrons flow in the wire from the anode to the cathode.

On the diploma: a labelled diagram needs the salt bridge, the solutions with concentrations, the wires and the meter.

Zn/Cu cell, 0.500 A for 30.0 min. q = _____

$n(e^-) = 900 \div (9.65 \times 10^4)$ = _____

$Zn \rightarrow Zn^{2+} + 2e^-$, so zinc lost = _____

$Cu^{2+} + 2e^- \rightarrow Cu$, so copper gained = _____

B14 · Investigation: plan and predict

Student notes - complete the underlined spaces | Notes 2/2

2. Predict, stay safe and plan a battery

Predict before measuring

The metal with the _____ reduction value is the anode, because that metal is oxidized. The higher value is the cathode.

Zn/Cu: zinc (−0.76 V) is lower, so zinc is the anode. E°cell = cathode − anode = 0.34 − (−0.76) = _____. Dropping the minus sign gives a classic wrong answer.

Ag/Cu: silver (+0.80 V) has the higher value, so copper is the _____. E°cell = 0.80 − 0.34 = _____. Copper is not always the cathode.

When you double a half-reaction to balance electrons, you do not _____ its table value. The voltage does not depend on the number of copies.

A prediction is not an _____. Only a measurement shows what the cell does. Ask where a number came from: the table or a meter.

Safety and disposal

Read the _____ and the safety data sheet first. They are part of _____, the system for labelling hazardous materials in workplaces.

Wear goggles, gloves and an apron. Silver nitrate stains skin. Copper(II) compounds harm life in water.

Collect solutions that contain metal _____. Do not pour them down the drain, because they can harm water life.

On the diploma: name the hazard from the label, then a matching precaution, and give a reason for each step.

Plan a battery

Cells in a row _____ their voltages. A device needs at least 3.0 V, and one Zn/Cu cell gives 1.10 V.

So 3.0 ÷ 1.10 = 2.7. We cannot use part of a cell, so round up and use _____ cells. They give 3 × 1.10 = 3.30 V. Two cells give only 2.20 V.

The voltage _____ as the cell works, because the reactants get used up. So the plan must include a test over time.

A bigger table voltage does not always make a better battery. Magnesium gives 2.71 V with copper but reacts with water. On the diploma: name a practical fact such as safety, cost or lifetime.

B14 · Practice

Investigation: plan and predict | Questions 1-3 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.

B14-P01 · Easy · Given the question "How does the metal in one half-cell change the cell voltage?" Name the independent variable and the dependent variable.

B14-P02 · Easy · Name two variables that must be controlled when you compare metals joined to copper, and explain why.

B14-P03 · Easy · List the parts that a labelled diagram of a zinc and copper cell must show.

B14 · Practice

Investigation: plan and predict | Questions 4-6 of 12

B14-P04 · Easy · Explain what the salt bridge does in your design.

B14-P05 · Medium · Given Fe^{2+}/Fe −0.45 V and Cu^{2+}/Cu +0.34 V. Predict the anode, the cell reaction and the voltage.

B14-P06 · Medium · Given Ag^{+}/Ag +0.80 V and Cu^{2+}/Cu +0.34 V. Which metal is the anode and what is the voltage?

B14 · Practice

Investigation: plan and predict | Questions 7-9 of 12

B14-P07 · Medium · Given Ni^{2+}/Ni −0.26 V and Ag^{+}/Ag +0.80 V. Write the cell reaction and find the voltage. Explain why the silver table value is not doubled.

B14-P08 · Medium · A student predicts +0.79 V and says this proves the measured voltage will be 0.79 V. Explain what is wrong.

B14-P09 · Challenging · Name two hazards or precautions for a plan that uses silver nitrate solution, and one disposal step.

B14 · Practice

Investigation: plan and predict | Questions 10-12 of 12

B14-P10 · Challenging · A device needs at least 3.0 V. Using 1.10 V cells in a row, find how many cells are needed and the voltage of the battery.

B14-P11 · Challenging · Explain why a metal with a large cell voltage can still be a poor choice for a battery. Use magnesium as an example.

B14-P12 · Challenging · Given a plan and a prediction only. State what they can show and what they cannot show, and why a real measurement may differ.

B15 · Investigation: analyze and explain

Student notes - complete the underlined spaces | Notes 1/2

Put together given evidence, compare predictions with observations, explain differences, identify products and judge a battery design.

Name: _____ Date: _____

1. Evidence and comparison

Put together the evidence

In B14 we predicted each voltage. Now we look at results. This lesson uses a _____ sample set that we did not measure.

Pairs are predicted/measured: Zn 1.10/1.07 V, Fe 0.79/0.76 V, Ni 0.60/0.57 V, Ag 0.46/0.43 V. Each row is one cell.

A good table has a title, _____ in the headings, the predicted column and the measured column. Note the controlled conditions too.

The measured column holds _____, because those numbers came from a voltmeter. The predicted column holds values from the reduction table.

On the diploma: a common wrong choice mixes up observation and prediction. Ask which column came from a measurement.

Compare

Difference = predicted − _____. Each cell here is _____ V lower than the prediction. That is a pattern with a direction and a size.

The order also matches, with zinc highest and silver lowest. So the data _____ the table. We say support, not prove.

A percent difference compares the gap with the prediction. For zinc, 0.03 ÷ 1.10 × 100 = _____ %. A small gap means close agreement.

On the diploma: describe a pattern with its direction and size, with the unit. Do not just say the numbers are close.

B15 · Investigation: analyze and explain

Student notes - complete the underlined spaces | Notes 2/2

2. Explain, identify and evaluate

Explain a difference

Three possible causes fit a constant gap: the salt bridge adds _____, the strips have _____ coatings, or the concentration is not exactly 1.0 mol/L.

Temperature is another, because the table assumes 25 °C. A good report records the room temperature and the concentration.

To test a cause, change _____ thing and measure again. For example, sand the strips and see if the voltage rises toward the prediction.

Until the test is done, the cause is _____, not proven. On the diploma: never claim a cause that was not tested.

Identify products

In the Zn/Cu cell, the zinc strip loses mass, so zinc is oxidized. The copper strip gains a _____ coating, so copper ions are reduced.

An observation is what we see or measure. An inference is a conclusion drawn from it. Zn^{2+} is colourless, so it is an _____.

In the Ag/Cu cell, copper is the anode. The copper strip loses mass, and the copper solution is already blue, so it gets _____ blue as Cu^{2+} forms.

A conclusion has a _____, the evidence and an explanation. Name a limitation and an _____, such as three trials averaged.

On the diploma: to identify a product, name the observation that supports it.

Battery design and disposal

Three cells of 1.07 V give 3 × 1.07 = _____. Judge voltage, mass, cost, lifetime and _____, because voltage is only one part of the evidence.

Used batteries contain metals that can harm soil and water, so they are collected for _____. Recycling has benefits and costs, like the energy it needs.

A hydrogen fuel cell gives about 1.23 V per cell. A fair presentation gives purpose, reactions, benefits and _____, and states the source of its evidence.

On the diploma: to evaluate a technology, name evidence that supports it and a limit that remains.

B15 · Practice

Investigation: analyze and explain | Questions 1-3 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.

B15-P01 · Easy · Name three things that a good data table includes.

B15-P02 · Easy · Which column of the table holds observations and which holds predictions? Explain.

B15-P03 · Easy · Given a given result for zinc and copper: predicted 1.10 V, measured 1.07 V. Find the difference.

B15 · Practice

Investigation: analyze and explain | Questions 4-6 of 12

B15-P04 · Easy · All four given cells are 0.03 V below the prediction and the order matches. Does the data support the table? Give a reason.

B15-P05 · Medium · Give two possible explanations for a small constant gap and say how to test one of them.

B15-P06 · Medium · Explain why a possible cause should not be stated as proven before a test.

B15 · Practice

Investigation: analyze and explain | Questions 7-9 of 12

B15-P07 · Medium · In a zinc and copper cell the zinc strip loses mass and the copper strip gains a reddish-brown coating. State two observations and the half-reactions they support.

B15-P08 · Medium · $Zn^{2+}(aq)$ is colourless. Is its formation an observation or an inference? Explain.

B15-P09 · Challenging · Given a given nickel and copper result: predicted 0.60 V, measured 0.57 V. Write a short conclusion with a claim, evidence and one possible explanation.

B15 · Practice

Investigation: analyze and explain | Questions 10-12 of 12

B15-P10 · Challenging · A design uses one trial for each cell. Give one limitation and one improvement.

B15-P11 · Challenging · Four cells of 1.07 V are joined in a row. Find the battery voltage and name one disposal step for the used battery.

B15-P12 · Challenging · Name two parts that a short fuel cell presentation must include, and say why the source of evidence should be stated.

B16 · Unit B review: choose the method

Student notes - complete the underlined spaces | Notes 1/2

Sort a problem, choose between the table, Faraday and titration, and apply Unit B ideas to corrosion, plating, refining and batteries.

Name: _____ Date: _____

1. Choose the method

Sort the problem

Choose the method before you touch a calculator. Voltage, spontaneity or the anode: use the _____ table. Mass, current or time at an electrode: use _____'s law.

A concentration from a volume of a reactant: use a redox _____. It finds a concentration by reacting a sample with a solution of known concentration.

A positive E°cell means the reaction runs by itself, so it can be a _____ cell. A negative E°cell needs a power supply, so the cell is _____.

Either way, oxidation happens at the _____. The electrode names follow the reaction, not the cell type.

On the diploma: many wrong options use the right numbers in the wrong method, so name the method first.

Watch: Is this equation redox or not? (Alberta Chemistry Teacher, "Electrochemistry Diploma Prep - Chemistry 30 - Part 1 of 4", 18:39)

Watch: Spotting disproportionation (Alberta Chemistry Teacher, "Electrochemistry Diploma Prep - Chemistry 30 - Part 1 of 4", 20:04)

Methods in order

Table: the anode is the _____ value, E°cell = cathode − anode. Do not _____ E° values by coefficients, because voltage does not depend on the number of copies.

Faraday: q = _____ with the time in seconds, then $n(e^-) = q \div 9.65 \times 10^4$, then the mole _____ from the half-reaction, then the mass.

Titration: balance the _____, find the amount of the known reactant, use the ratio, then divide by the volume in _____. Divide millilitres by 1000.

The endpoint is the moment the reaction is just complete. With permanganate, it is the first lasting pale pink, so no indicator is needed.

On the diploma: a wrong mole ratio is a common wrong option, so read it from the half-reaction or the balanced equation.

Watch: Trends in the reduction table (Alberta Chemistry Teacher, "Electrochemistry Diploma Prep - Chemistry 30 - Part 1 of 4", 23:36)

Watch: Patterns: metals, halogens and multivalent ions (Alberta Chemistry Teacher, "Electrochemistry Diploma Prep - Chemistry 30 - Part 1 of 4", 24:21)

B16 · Unit B review: choose the method

Student notes - complete the underlined spaces | Notes 2/2

2. Apply the ideas

Corrosion and industry

Magnesium (−2.37 V) is below iron (−0.45 V), so it is a stronger reducing agent. It is the _____ anode that is oxidized, and the iron is protected as the cathode.

A power supply protects iron too, by making it the cathode. Both methods stop the iron from being oxidized.

In electroplating the object is the _____. In refining the impure metal is the _____. Oxidation is always at the anode, reduction at the cathode.

Judge a battery by voltage, mass, cost, lifetime and _____. On the diploma: a wrong electrode is a common wrong choice, so label the anode and cathode first.

B16 · Practice

Unit B review: choose the method | Questions 1-3 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.

B16-P01 · Easy · Which method do you use for a question that gives 2.00 A for 30.0 min and asks for a mass of copper? Explain.

B16-P02 · Easy · Given a calculated E°cell of −0.50 V. State the type of cell that can make the reaction happen and what it needs.

B16-P03 · Easy · Given Al^{3+}/Al −1.66 V and Ag^{+}/Ag +0.80 V. Write the cell reaction.

B16 · Practice

Unit B review: choose the method | Questions 4-6 of 12

B16-P04 · Easy · Find the voltage of the aluminium and silver cell, and explain why the silver value is not multiplied by three.

B16-P05 · Medium · A current of 3.00 A runs for 25.0 min with a silver cathode in Ag^+ solution. Find the charge and the amount of electrons.

B16-P06 · Medium · Continue the last question and find the mass of silver deposited. M(Ag) = 107.87 g/mol.

B16 · Practice

Unit B review: choose the method | Questions 7-9 of 12

B16-P07 · Medium · Given 4.00 A for 20.0 min through $Cu^{2+}(aq)$ with a copper cathode. Find the mass of copper deposited. M(Cu) = 63.55 g/mol.

B16-P08 · Medium · Given $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$. If 20.00 mL of 0.0150 mol/L MnO_4^- reacts with 25.00 mL of $Fe^{2+}(aq)$, find $[Fe^{2+}]$.

B16-P09 · Challenging · Describe the end point of the permanganate titration and say why no indicator is added.

B16 · Practice

Unit B review: choose the method | Questions 10-12 of 12

B16-P10 · Challenging · Explain how a magnesium block protects a steel pipe in soil. Name the role of the pipe.

B16-P11 · Challenging · A spoon is plated with silver using a silver nitrate solution. Name the electrode for the spoon, the half-reaction there and the power supply connection.

B16-P12 · Challenging · Choose the method and solve: 2.00 A runs for 30.0 min through molten NaCl. Find the mass of sodium at the cathode. M(Na) = 22.99 g/mol.