Electrochemistry

Part Two:
The Electrolysis of Aqueous Salts, Acids and Alkalis

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

What happens during the electrolysis of an aqueous salt using inert electrodes?

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O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- Remember, not all ionic compounds are soluble in water! For example…

→ Barium sulfate, $BaSO_4$ – insoluble!

→ Calcium carbonate, $CaCO_3$ – insoluble!

→ Copper(II) oxide, CuO – insoluble!

→ Lead(II) iodide, PbI_2 – insoluble!

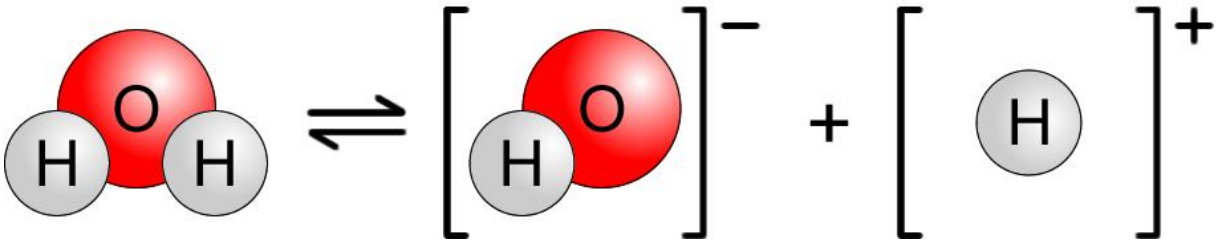
→ Silver chloride, AgC*l* – insoluble!

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

$$H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H^+_{(aq)}$$



- Water molecules spontaneously dissociate (ionize) to form *hydroxide ions* and *hydrogen ions*:

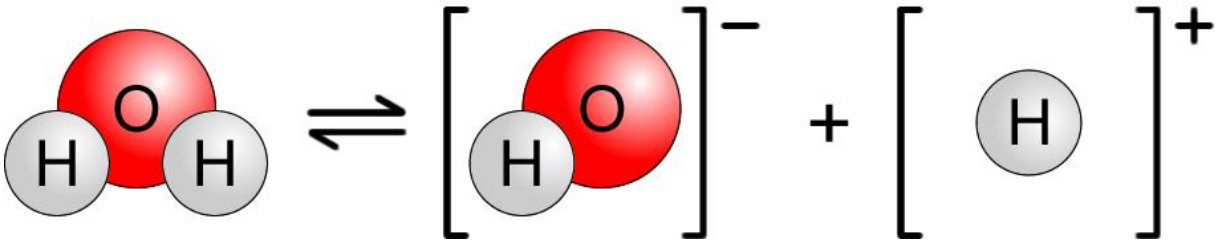
- The concentrations of the hydroxide ions and hydrogen ions are relatively low (1×10^{-7} mol/dm) but their presence in solution still affects the products that are formed during the electrolysis of *aqueous salts*.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

$$H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H^+_{(aq)}$$



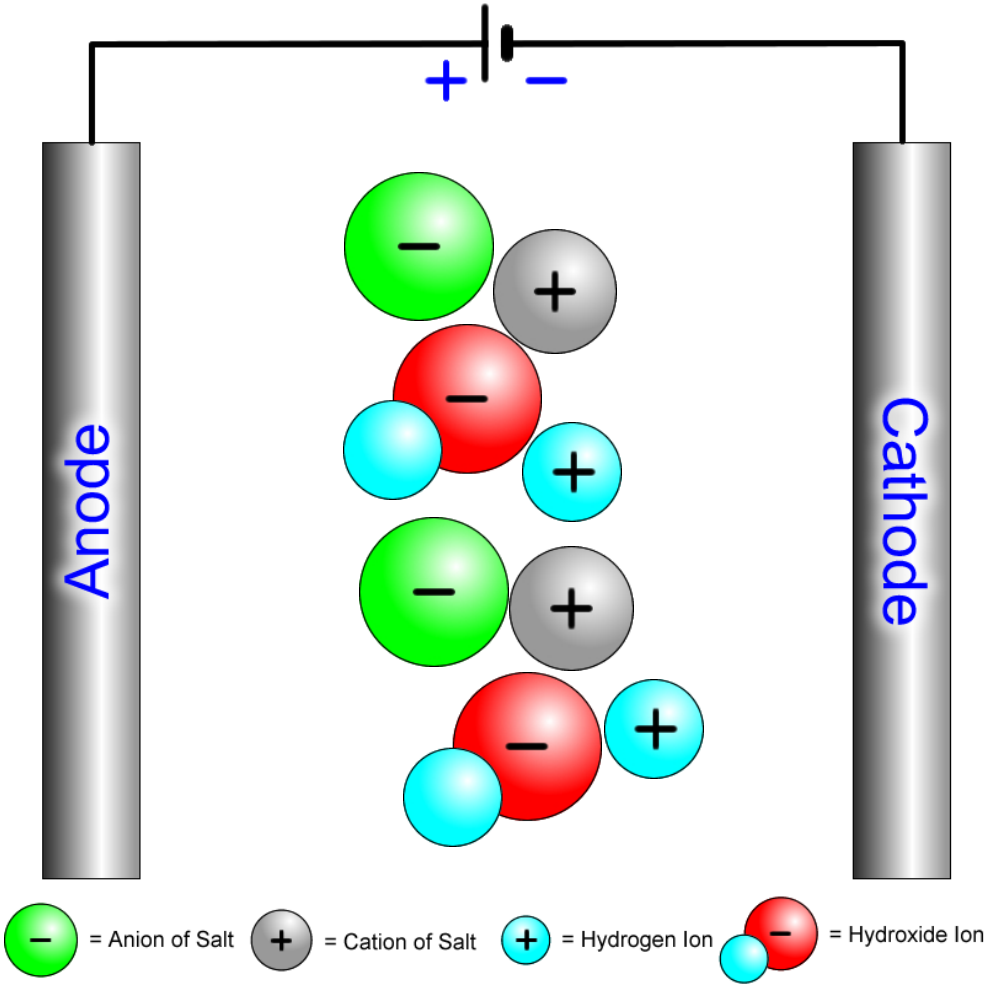
- During the electrolysis of an aqueous salt solution, *hydroxide ions*, as well as anions from the salt itself, will be attracted to the *anode*.

- During the electrolysis of an aqueous salt solution, *hydrogen ions*, as well as cations from the salt itself, will be attracted to the *cathode*.

O' Level

Electrochemistry

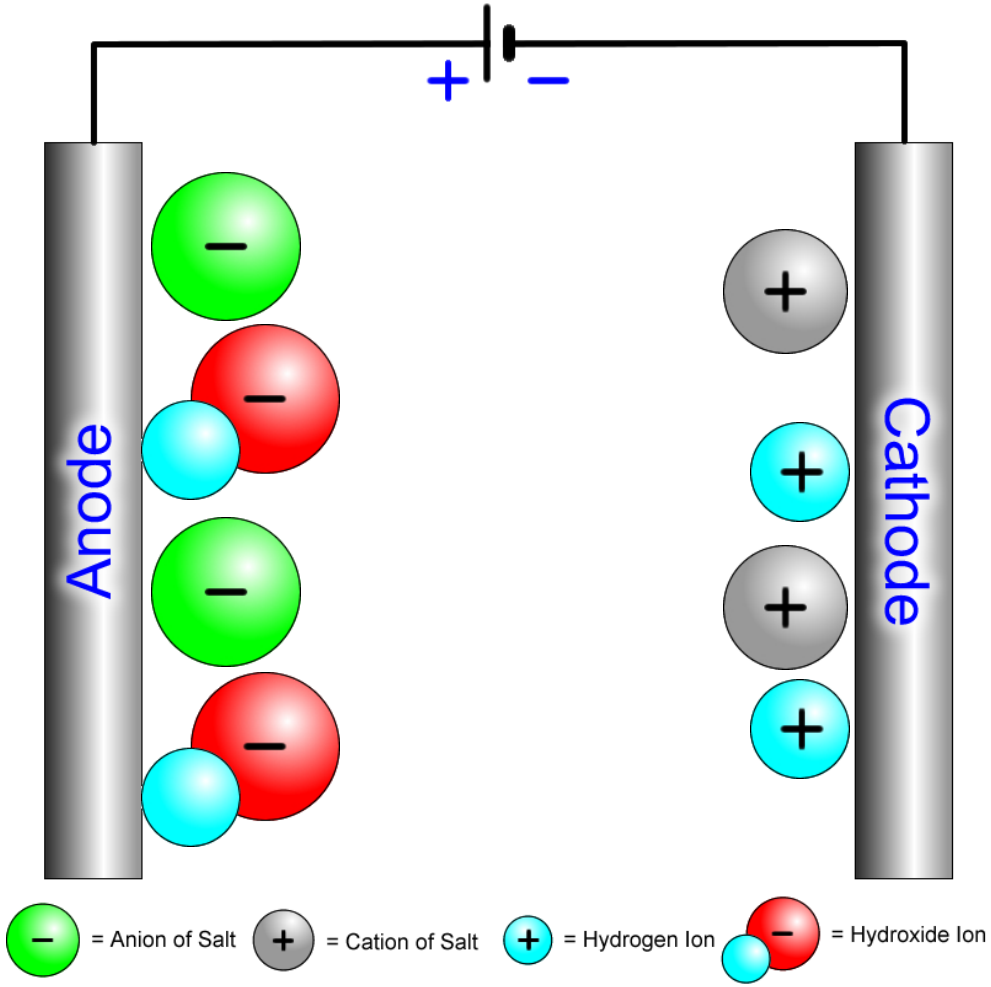
Electrolysis of Aqueous Salts



O' Level

Electrochemistry

Electrolysis of Aqueous Salts



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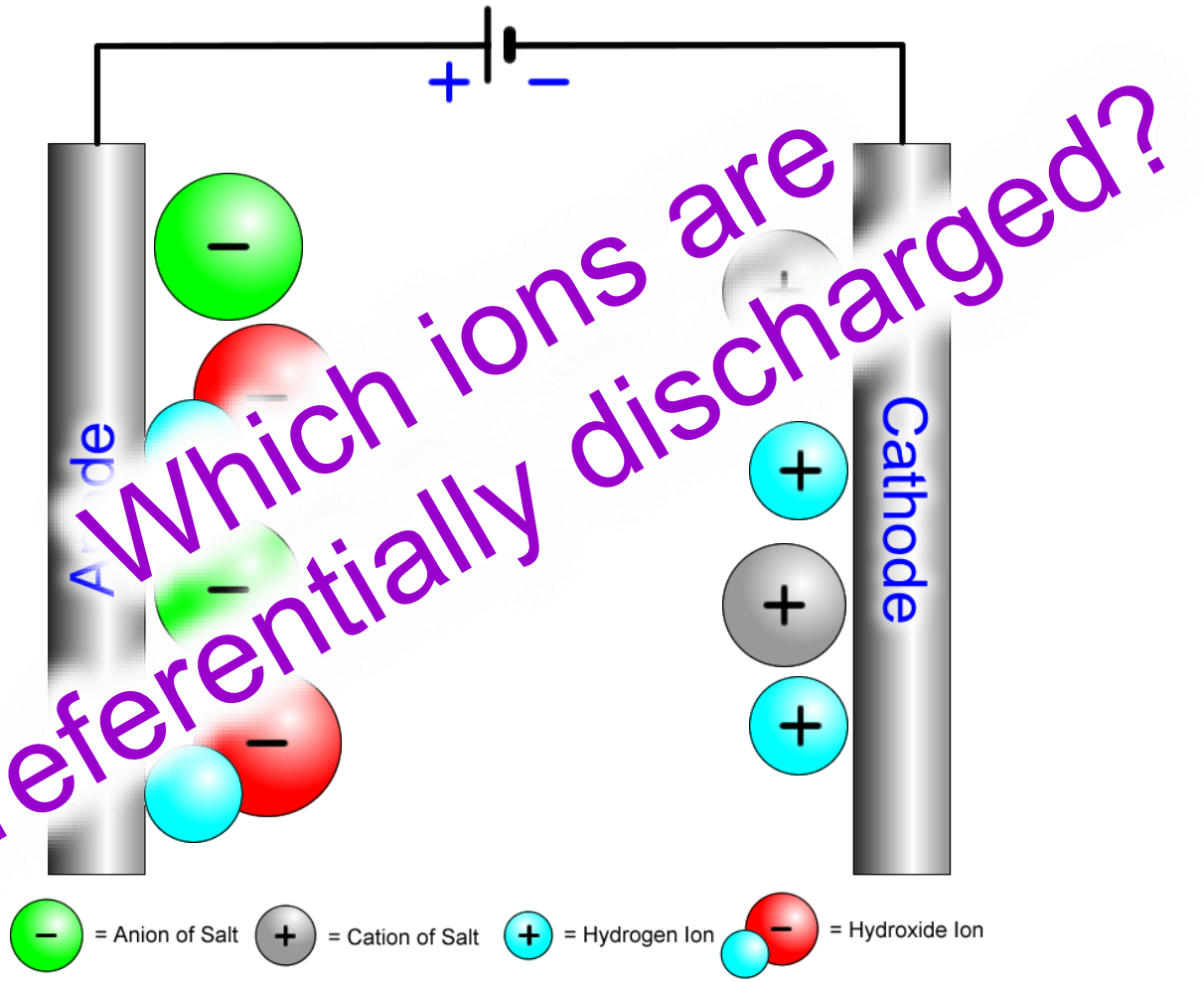
Electrochemistry

Electrolysis of Aqueous Salts



O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- If the aqueous salt solution is *dilute*, hydroxide ions are oxidised at the anode and effervescence is observed as oxygen gas is produced:

$$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$$

(Hydroxide ions are oxidised to form molecular oxygen)

- If the aqueous salt solution is *concentrated*, the anion of the salt is oxidised at the anode.

- **Note**: Regardless of concentration, *carbonate ions*, *nitrate ions* and *sulfate ions* are *not* oxidised during the electrolysis of aqueous salt solutions.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- If the cation of the salt is *above hydrogen* in the electrochemical series, then hydrogen ions are reduced at the cathode and effervescence is observed as hydrogen gas is produced:

$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$

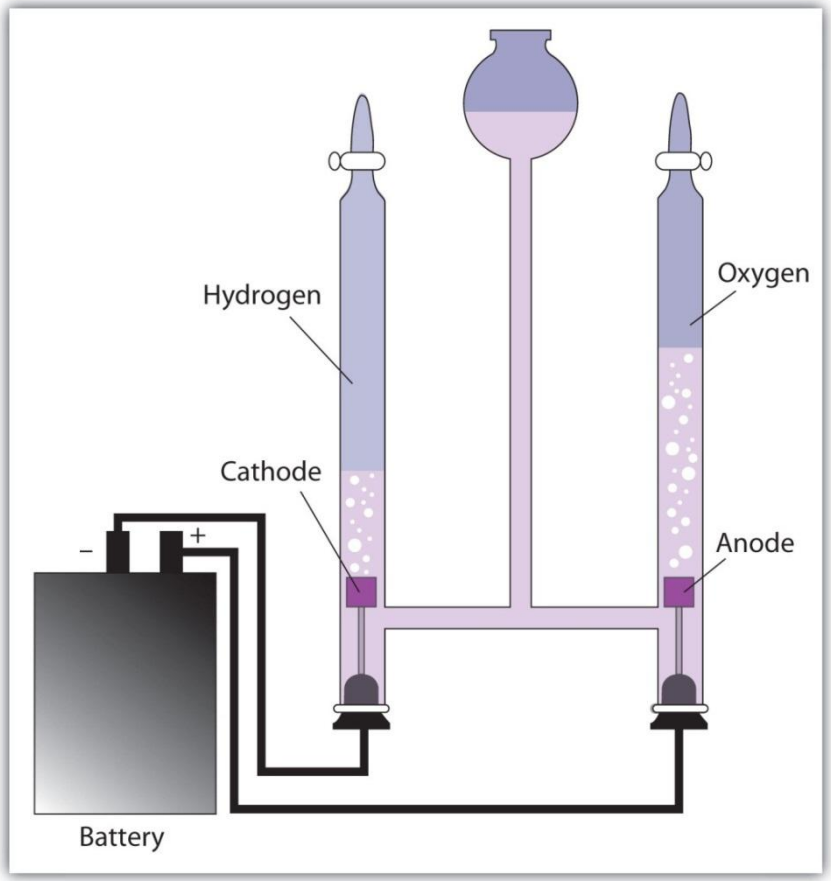
(Hydrogen ions are reduced to form molecular hydrogen)

- If the cation of the salt is *below hydrogen* in the electrochemical series, then the cation of the salt is reduced at the cathode.

O' Level

Electrochemistry

Electrolysis of Water



- Anode: $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$
- Cathode: $2H^+(aq) + 2e^- \; H_2(g)$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

Ions Are More Easily Reduced

- Potassium – K^+
- Sodium – Na^+
- Calcium – Ca^{2+}
- Magnesium – Mg^{2+}
- Aluminium – Al^{3+}
- Zinc – Zn^{2+}
- Iron – Fe^{2+} / $^{3+}$
- Lead – Pb^{2+}
- Hydrogen – H^+
- Copper – Cu^{2+}
- Silver – Ag^+

- During electrolysis of the aqueous salt, *e.g.* $CaCl_2$, hydrogen gas is produced at the cathode, not the metallic element.

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

- These metals can only be extracted from their compounds by electrolysis of the molten salt, not electrolysis of the aqueous salt.

- During electrolysis of the aqueous salt, *e.g.* $CuCl_2$, the metallic element is produced at the cathode, not hydrogen gas.

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Electrochemistry

Electrolysis of Aqueous Salts

Ions Are More Easily Oxidised

- Sulfate – SO_4^{2-}
- Nitrate – NO_3^-

• Not oxidised during electrolysis of the aqueous salt.

- Chloride – Cl^-
- Bromide – Br^-
- Iodide – I^-

• Oxidised only if the aqueous solution is concentrated, *e.g.* a concentrated solution of sodium bromide.

- Hydroxide – OH^-

• The hydroxide ion is readily oxidised at the anode.

$4OH^-(aq) \rightarrow 2H_2O(l) + O_2(g) + 4e^-$

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Electrochemistry

Electrolysis of Aqueous Salts

Could I please have a summary?

Use online software, such as www.mindmeister.com to design your own summary.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- Electrolysis of a *molten binary salt*, *e.g.* **MX**, where **M** is a metallic element and **X** is a non-metallic element:

→ Ions of metal **M** are *reduced* at the *cathode* to produce the metallic element.

$$M^{n+}(l) + ne^- \rightarrow M(l)$$

→ Ions of non-metal **X** are *oxidised* at the *anode* to produce the non-metallic element.

$$2X^{n-}(l) \rightarrow X_2(l) + 2ne^-$$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- Electrolysis of an *aqueous salt*:

→ If the metal is *above hydrogen* in the electrochemical series, then *hydrogen ions* are preferentially reduced at the cathode to produce hydrogen gas:

$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$

→ If the metal is *below hydrogen* in the electrochemical series, then *metal ions* are preferentially reduced at the cathode to produce the metallic element:

$$M^{n+}(aq) + ne^- \rightarrow M(s)$$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- Electrolysis of an *aqueous salt*.

→ If the aqueous solution is *dilute*, or it contains the *salt of a nitrate or sulfate*, then *hydroxide ions* are preferentially oxidised at the anode to produce oxygen gas and water:

$$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$$

→ If the aqueous solution is a *concentrated* solution of either a *chloride*, *bromide* or *iodide*, then the chloride, bromide or iodide ions are preferentially oxidised at the anode to produce the Group 17 element:

$$2X^-(aq) \rightarrow X_2(aq) + 2e^-$$

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Electrochemistry

Electrolysis of Aqueous Electrolytes

- Aqueous electrolytes are aqueous solutions of ionic compounds or acids (*i.e.* solutions that contain mobile cations, anions and water molecules).

- Because aqueous electrolytes contain cations, anions and water molecules, rules need to be established to determine what will be *selectively discharged* at the electrodes.

→ What will be selectively *oxidised* at the *anode*, *anions* or *water molecules*?

→ What will be selectively *reduced* at the *cathode*, *cations* or *water molecules*?

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Electrochemistry

Electrolysis of Aqueous Electrolytes

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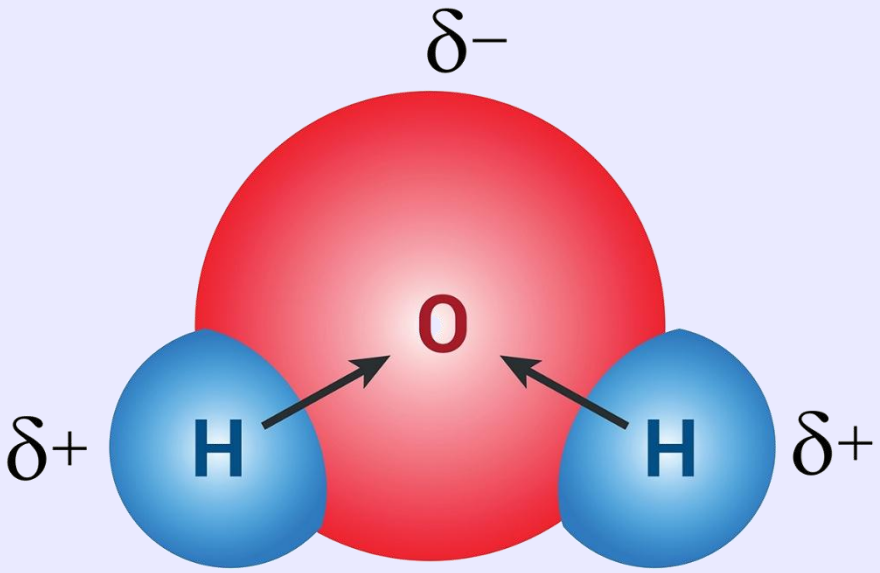

- A polar water molecule.

- Due to an uneven distribution of electrons within a molecule of water, the oxygen atom carries a *slight negative charge* (δ–) while the two hydrogen atoms each carry a *slight positive charge* (δ+).

- Consequently, water molecules are attracted towards the anode and the cathode during the electrolysis of aqueous electrolytes.

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Electrochemistry

Electrolysis of Aqueous Electrolytes

- During the electrolysis of aqueous electrolytes, only *one* species can be oxidised at the anode, and only *one* species can be reduced at the cathode.

- When there is more than one species competing to be discharged at the same electrode, the one that requires the *least energy* to be discharged will be *selectively discharged*.

- The order in which chemical species are selectively discharged is determined by their *standard electrode potentials* (symbol $E^{\ominus}$). Based upon their standard electrode potentials, chemical species are arranged in an *electrochemical series*.

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Electrochemistry

Electrolysis of Aqueous Electrolytes

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✶ Factors Affecting Selective Discharge:

(a) Position in the electrochemical series.

- An *electrochemical series* is a series in which species are arranged in an increasing or decreasing order of their standard electrode potential, $E^{\ominus}$ values.

- The electrode (reduction) potential (E) is a value which shows how easily a species is reduced. By convention, the half-reactions are written as *reductions* (*i.e.* the electrons are written on the left-hand-side). This means that in these reversible half-equations, the *forward reactions* ($\rightarrow$) demonstrate *reduction* while the *backward reactions* ($\leftarrow$) demonstrate *oxidation*.

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Electrochemistry

Electrolysis of Aqueous Electrolytes

The more positive (or less negative) an electrode potential, the more likely it is for that species to undergo reduction.

The more positive (or less negative) an electrode potential, the more likely it is for that species to be selectively reduced at the cathode.

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Electrochemistry

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At the Cathode	Half-equations	$E^{\ominus}$ / V	Ease of Discharge
K^+	$K^+ + e^- \rightleftharpoons K$	−2.92	• Increasing ease with which the cations are reduced.
Na^+	$Na^+ + e^- \rightleftharpoons Na$	−2.71	
Mg^{2+}	$Mg^{2+} + 2e^- \rightleftharpoons Mg$	−2.36	
Al^{3+}	$Al^{3+} + 3e^- \rightleftharpoons Al$	−1.68	
H_2O	$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	−0.83	
Zn^{2+}	$Zn^{2+} + 2e^- \rightleftharpoons Zn$	−0.76	
Fe^{2+}	$Fe^{2+} + 2e^- \rightleftharpoons Fe$	−0.44	
Pb^{2+}	$Pb^{2+} + 2e^- \rightleftharpoons Pb$	−0.13	
H^+	**$2H^+ + 2e^- \rightleftharpoons H_2$**	**0.00**	
Cu^{2+}	$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34	
Ag^+	$Ag^+ + e^- \rightleftharpoons Ag$	+0.80	

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Electrochemistry

Electrolysis of Aqueous Electrolytes

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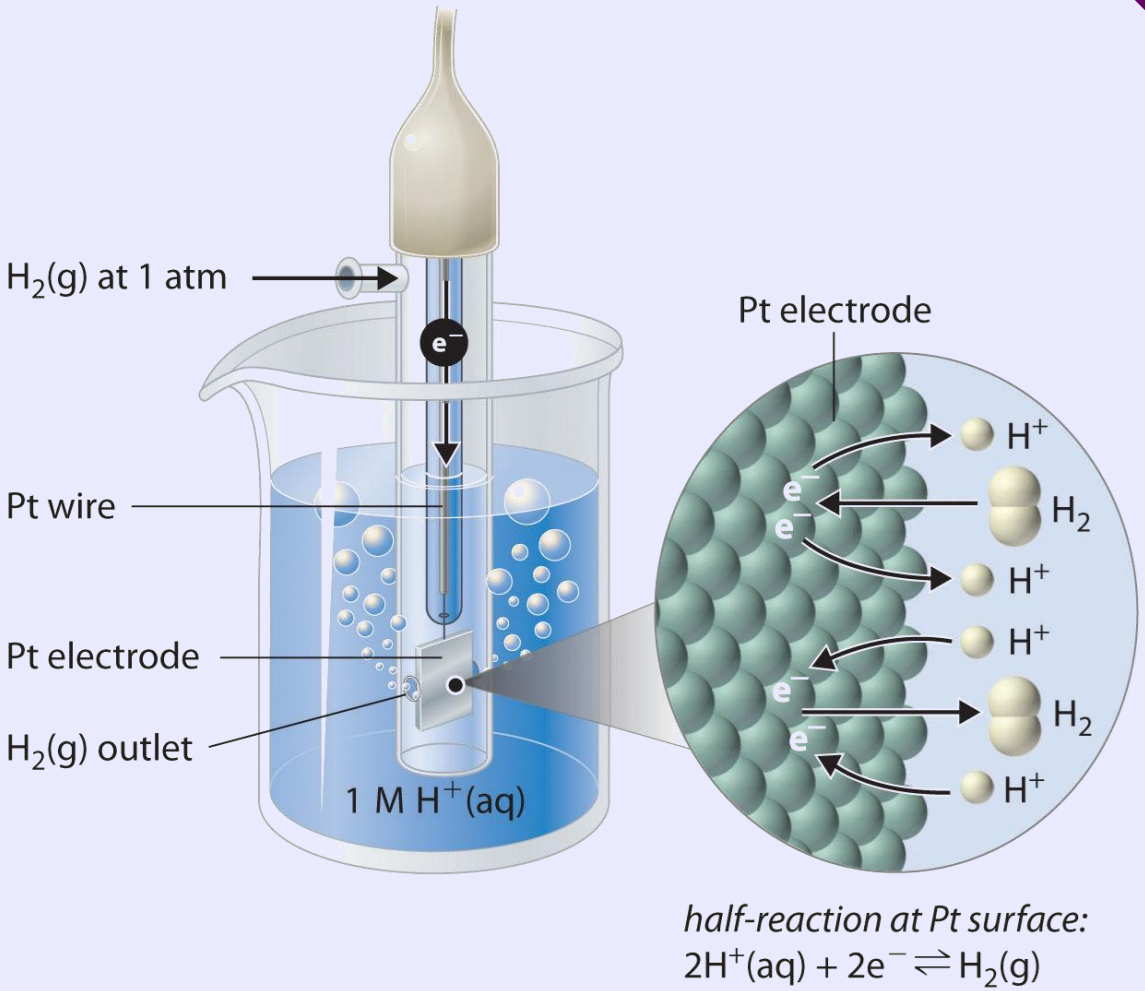
- Standard electrode potentials are measured relative to the Standard Hydrogen Electrode (SHE).



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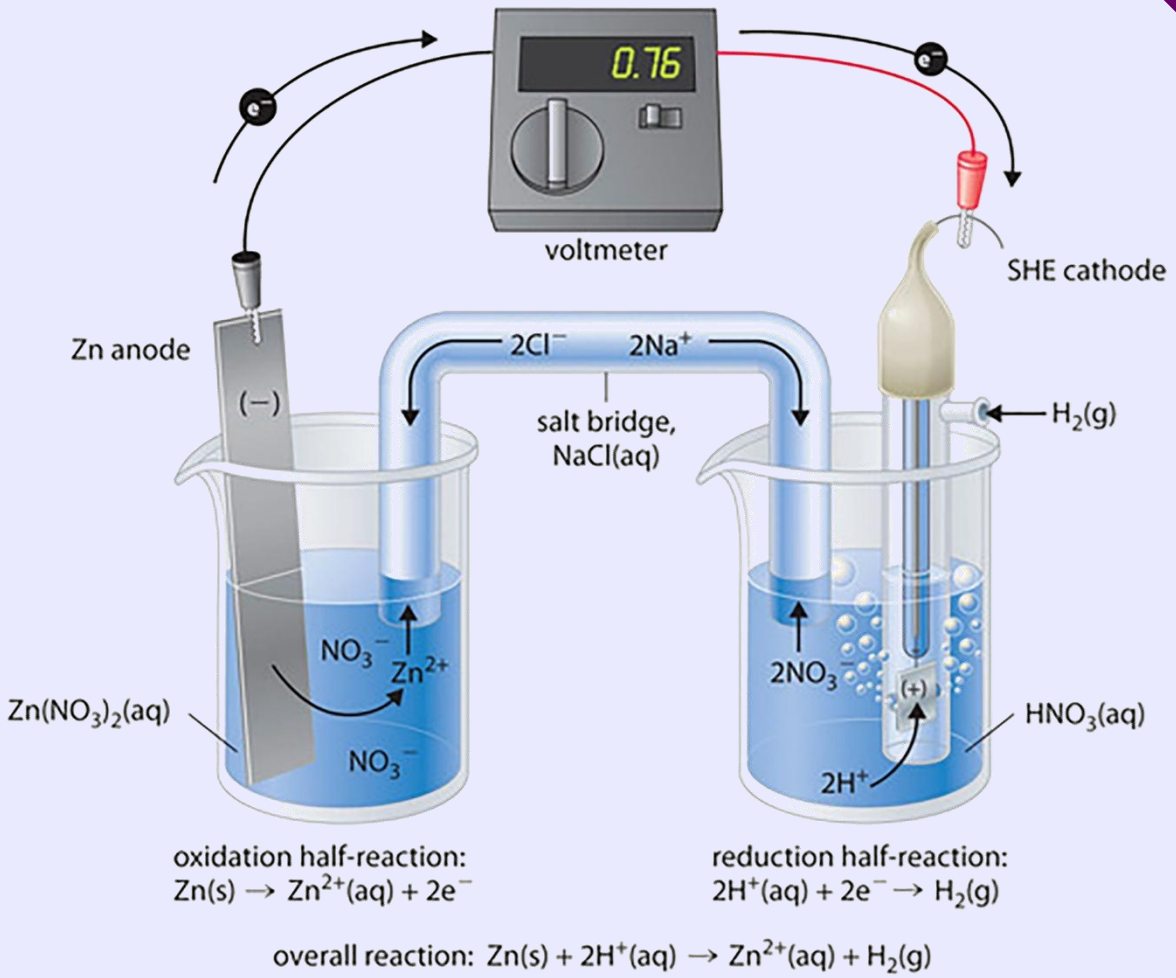
Electrochemistry

Electrolysis of Aqueous Electrolytes

- Measuring the standard electrode potential of the zinc half-cell relative to the Standard Hydrogen Electrode.



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Electrochemistry

Electrolysis of Aqueous Electrolytes

At the cathode, reduction of the cations with the more positive (or less negative) $E^{\ominus}$ will take place.

- **Example 1:** the *positive* standard electrode potential of silver ($E^{\ominus}$ = +0.80 V) suggests that *it is likely* that the silver ions (Ag^+) will be *reduced* to form silver atoms (Ag) at the cathode.

$$Ag^+ + e^- \rightleftharpoons Ag \qquad E^{\ominus} = +0.80\ V$$

$$Ag^+ + e^- \rightarrow Ag$$

likely to happen

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the cathode, reduction of the cations with the more positive (or less negative) $E^{\ominus}$ will take place.

• **Example 2:** The *negative* standard electrode potential of sodium ($E^{\ominus}$ = –2.71 V) suggests that *it is unlikely* that the sodium ions (Na^+) will be *reduced* to form sodium atoms (Na) at the cathode.

$$Na^+ + e^- \rightleftharpoons Na \qquad E^{\ominus} = -2.71\ V$$

$$Na^+ + e^- \rightarrow Na$$

unlikely to happen

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Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the cathode, reduction of the cations with the more positive (or less negative) $E^{\ominus}$ will take place.

- **Example 3:** The chemical species present in the electrolyte are Na^+ and H_2O.

$$Na^+ + e^- \rightleftharpoons Na \qquad E^{\ominus} = -2.71\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \qquad E^{\ominus} = -0.83\ V$$

Since H_2O is lower in the electrochemical series than Na^+ (*i.e.* $E^{\ominus}(H_2O \mid H_2)$ is more positive or less negative than $E^{\ominus}(Na^+ \mid Na)$), H_2O has a higher tendency to be reduced than Na^+, so *H_2O is preferentially reduced* at the cathode, resulting in effervescence of hydrogen gas.

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

Electrochemistry

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- Selective discharge of anions can be deduced from the following section of the electrochemical series.
- At the *anode*, *oxidation* of the *anions* with the *less positive (or more negative)* $E^{\ominus}$ takes place.

At the Anode	Half-equations	$E^{\ominus}$ / V	Ease of Discharge
F^-	$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87	• Increasing ease with which the anions are oxidised.
SO_4^{2-}	$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01	
Cl^-	$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36	
H_2O	$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23	
Br^-	$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07	
I^-	$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54	
OH^-	$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40	

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Electrochemistry

Electrolysis of Aqueous Electrolytes

At the anode, oxidation of the anions with the less positive (or more negative) $E^{\ominus}$ will take place.

- **Example 4:** The *very small positive* standard electrode potential of OH^- suggests that *it is likely* that the hydroxide ions (OH^-) will be *oxidised* to form H_2O and O_2 at the anode.

- The half-equation for $E^{\ominus}$ is always written as *reduction*:

$$O_2 + H_2O + 4e^- \rightleftharpoons 4OH^- \qquad E^{\ominus} = +0.40\ V$$

The *reverse reaction* must be written to show *oxidation*:

$$4OH^- \rightarrow O_2 + H_2O + 4e^-$$

likely to happen

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the anode, oxidation of the anions with the less positive (or more negative) $E^{\ominus}$ will take place.

- **Example 5:** The *very large positive* standard electrode potential of F^- suggests that *it is unlikely* that the fluoride ions (F^-) will be *oxidised* to form F_2 at the anode.

- The half-equation for $E^{\ominus}$ is always written as *reduction*:

$$F_2 + 2e^- \rightleftharpoons 2F^- \qquad E^{\ominus} = +2.87\ V$$

The *reverse reaction* must be written to show *oxidation*:

$$2F^- \rightarrow F_2 + 2e^-$$

unlikely to happen

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Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the anode, oxidation of the anions with the less positive (or more negative) $E^{\ominus}$ will take place.

- **Example 6:** The chemical species present in the electrolyte are Cl^- and H_2O.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

Since H_2O is lower in the electrochemical series than Cl^- (*i.e.* $E^{\ominus}(O_2|H_2O)$ is less positive or more negative than $E^{\ominus}(Cl_2|Cl^-)$), H_2O has a higher tendency to be oxidised than Cl^- so *H_2O is preferentially oxidised* at the anode, resulting in the effervescence of oxygen gas.

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

✶ Factors Affecting Selective Discharge:

(b) Concentration of the ion present in the electrolyte (because the concentration of the electrolyte affects standard electrode potentials).

- *Higher concentration* of an ion makes it *easier* / *more likely to be selectively discharged*.

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

- **Example 7:** Consider the electrolysis of *concentrated* NaC*l*(aq) (brine) using inert electrodes. Both Cl^- and H_2O present in the brine are attracted towards the anode.

- H_2O should be preferentially oxidised, but because there is a high concentration of Cl^- in the brine, Cl^- is preferentially oxidised at the anode. The difference between the $E^\ominus$ values of Cl^- and H_2O is small, and *the effect of the high concentration of Cl^- is sufficient for Cl^- to be preferentially oxidised*.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^\ominus = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^\ominus = +1.23\ V$$

- At the anode, Cl^- is oxidised to Cl_2:

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

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O' Level

Electrochemistry

Electrolysis of Aqueous Salts

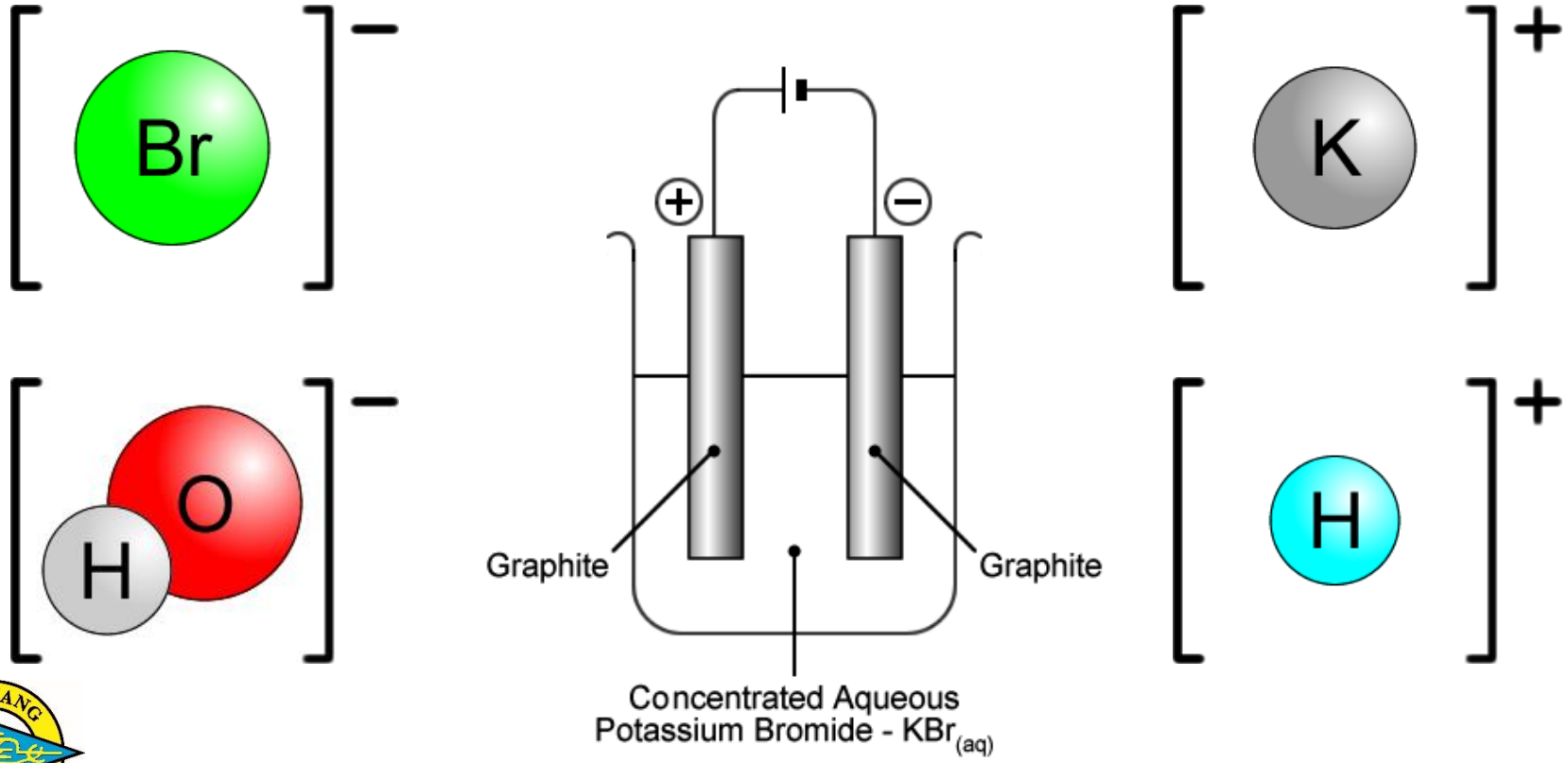
Could I please see some examples?

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous potassium bromide* is electrolysed using inert electrodes?

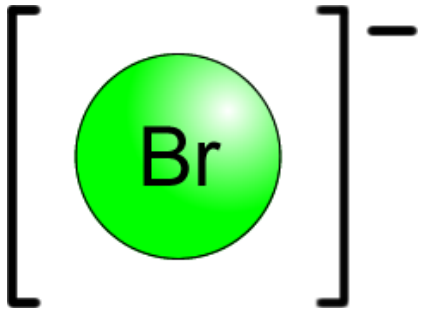


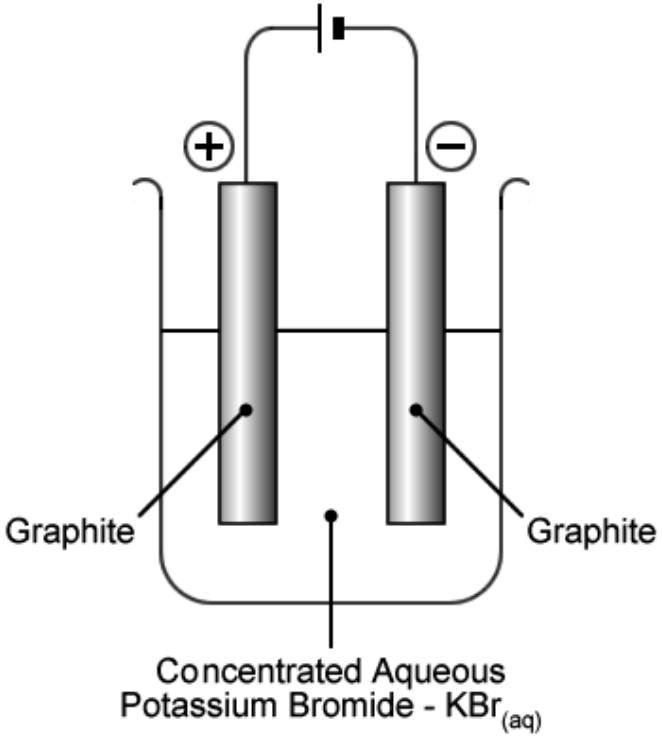
O' Level

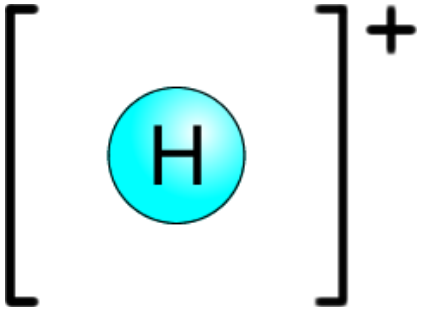
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous potassium bromide* is electrolysed using inert electrodes?







Electrochemistry
Electrolysis of Aqueous Salts

O' Level

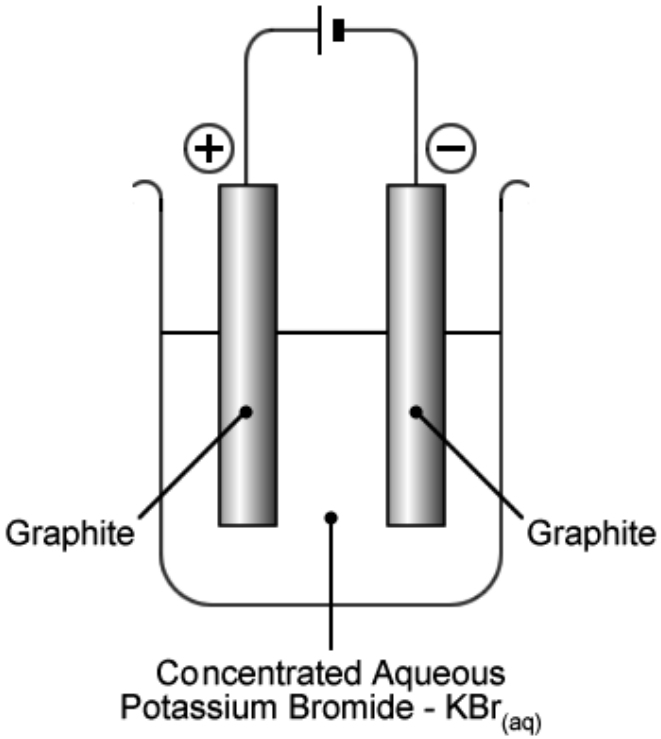
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous potassium bromide* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged bromide ions and hydroxide ions (anions) are both attracted to the positive anode.

At high concentration, bromide ions are preferentially oxidised to molecular bromine at the anode:

$2Br^-(aq) \rightarrow Br_2(aq) + 2e^-$



b) At the *cathode (–ve)*:

Positively charged potassium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Potassium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

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O' Level

Electrochemistry

Electrolysis of Aqueous Salts

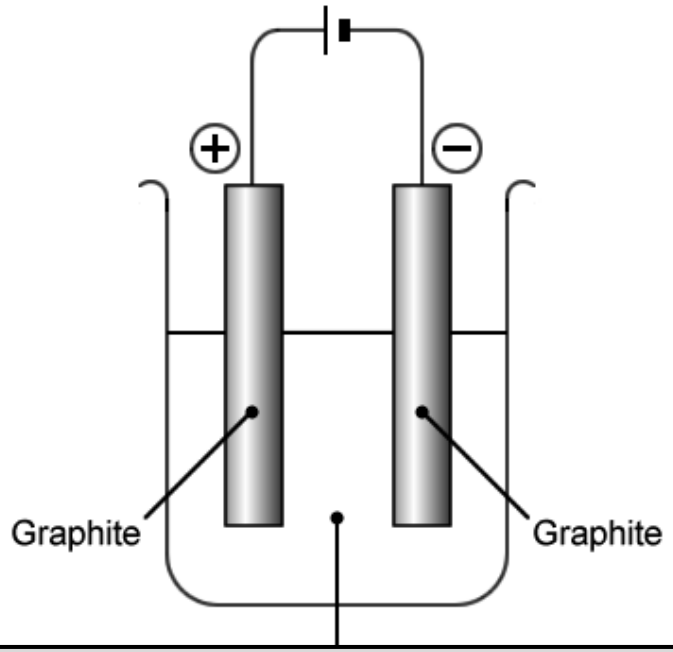
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous potassium bromide* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged bromide ions and hydroxide ions (anions) are both attracted to the positive anode.

At high concentration, bromide ions are preferentially oxidised to molecular bromine at the anode:

$2Br^-(aq) \rightarrow Br_2(aq) + 2e^-$



Becomes dilute aqueous KBr(aq) / KOH(aq)

b) At the *cathode (–ve)*:

Positively charged potassium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Potassium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$K^+ + e^- \rightleftharpoons K \quad E^{\ominus} = -2.92\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$Br_2 + 2e^- \rightleftharpoons 2Br^- \quad E^{\ominus} = +1.07\ V$$

$$2Br^- \rightarrow Br_2 + 2e^-$$

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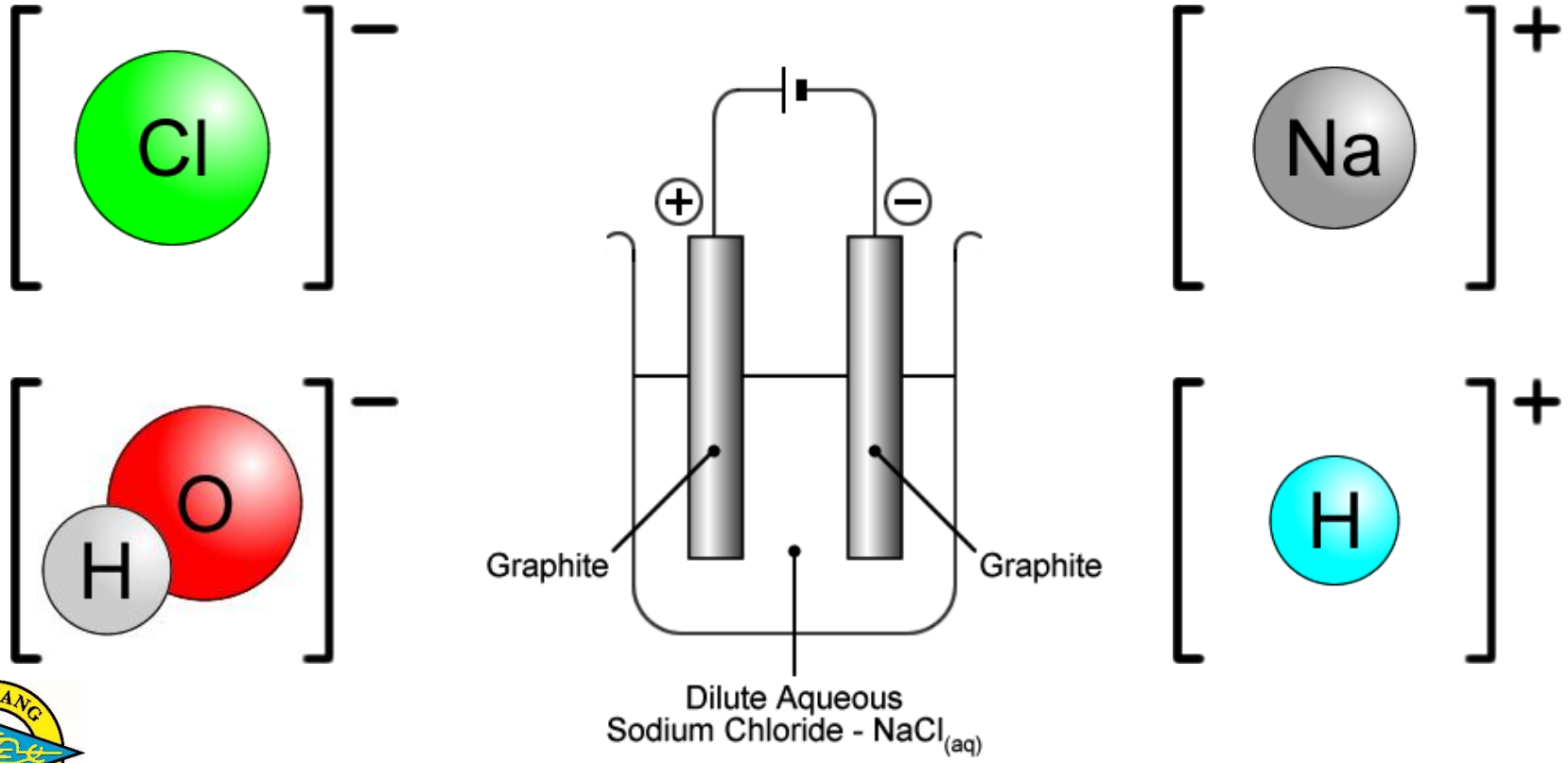
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous sodium chloride* is electrolysed using inert electrodes?

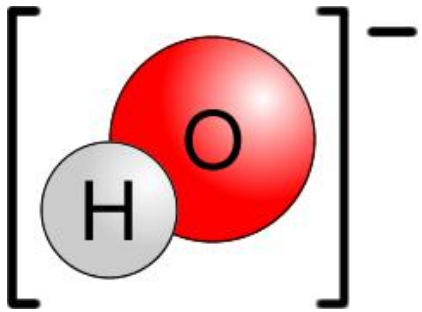


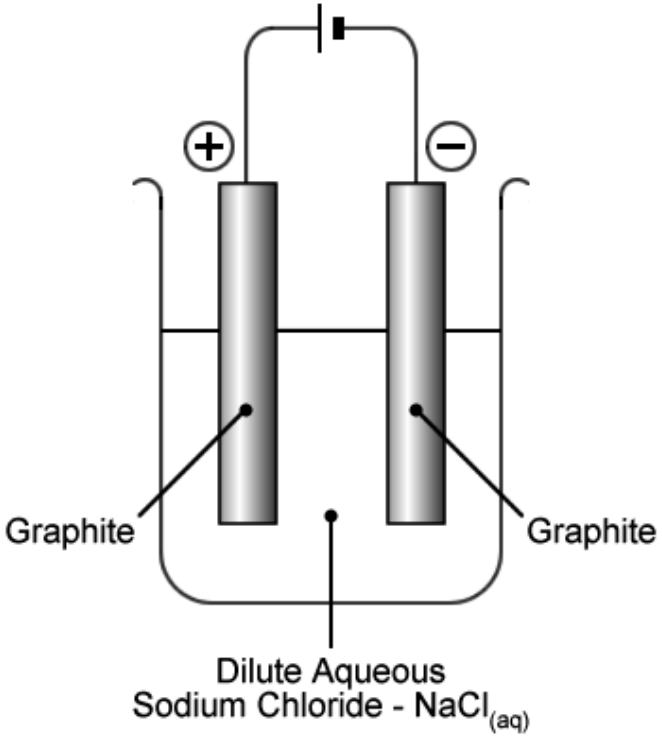
O' Level

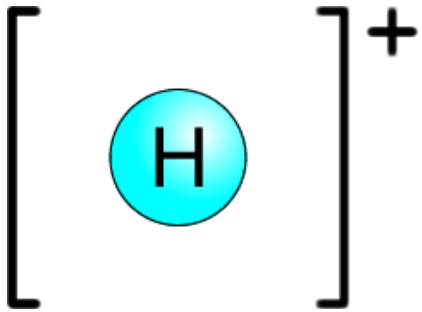
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous sodium chloride* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Aqueous Salts

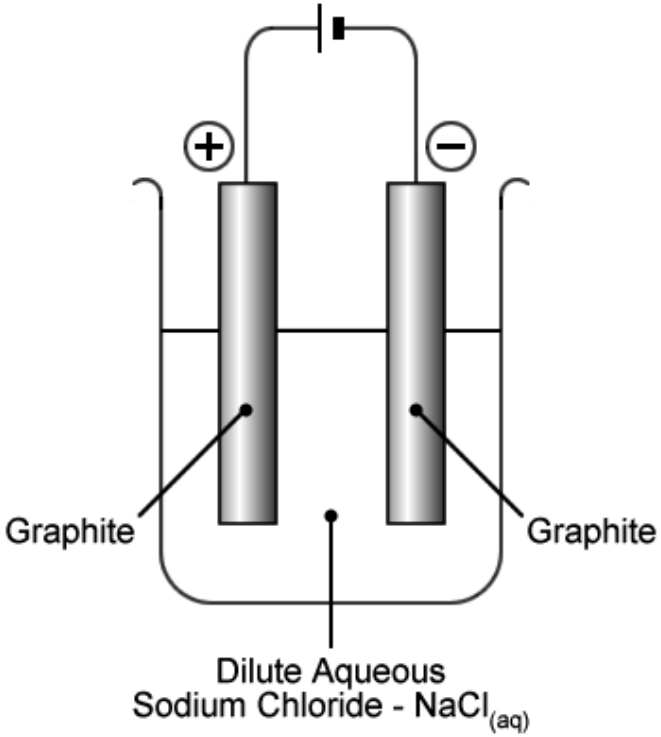
- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous sodium chloride* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

Because the solution is dilute, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Positively charged sodium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Sodium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous sodium chloride* is electrolysed using inert electrodes?

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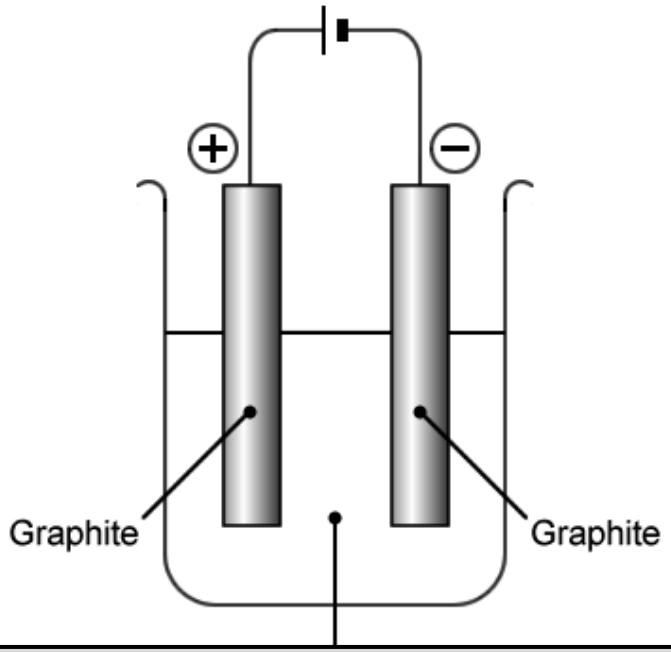


b) At the *cathode (–ve)*:

Positively charged sodium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Sodium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Becomes concentrated NaC*l*(aq) / NaOH(aq)

Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$Na^+ + e^- \rightleftharpoons Na \quad E^{\ominus} = -2.71\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

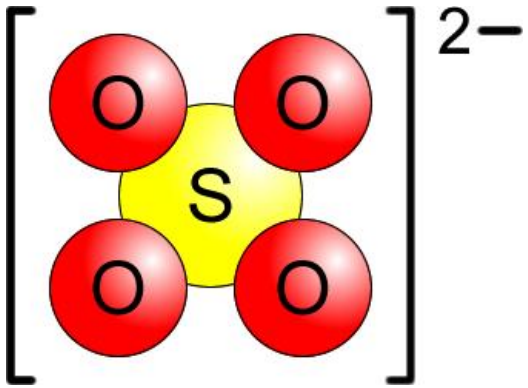
- New Integrated Programme 2025 – to align with A' Level Chemistry.

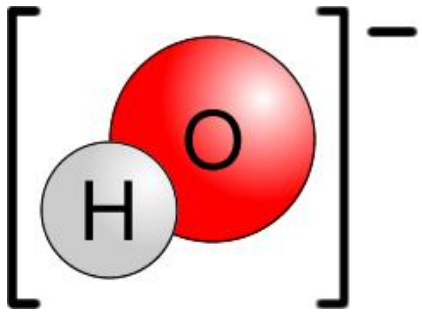
O' Level

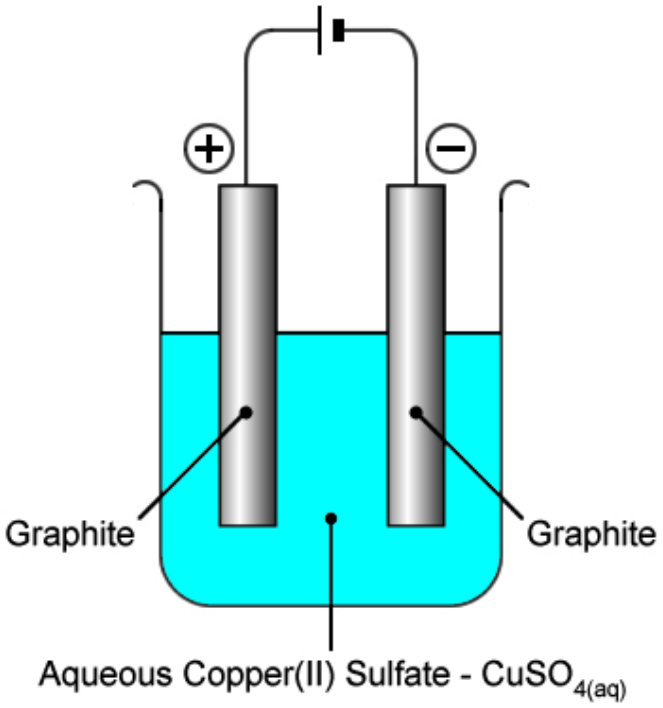
Electrochemistry

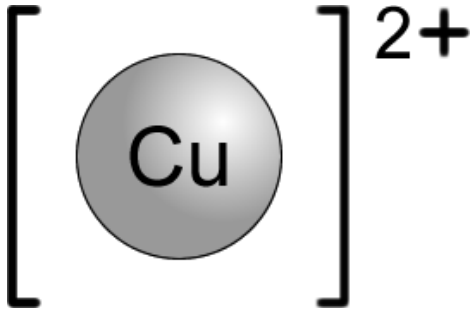
Electrolysis of Aqueous Salts

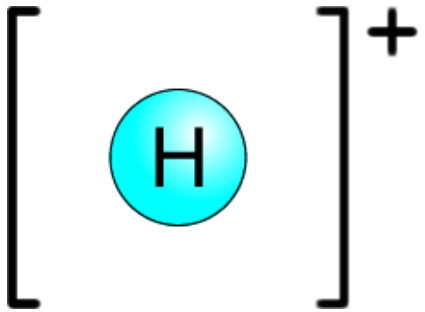
- What products are formed at **a)** the anode and **b)** the cathode when *aqueous copper(II) sulfate* is electrolysed using inert electrodes?









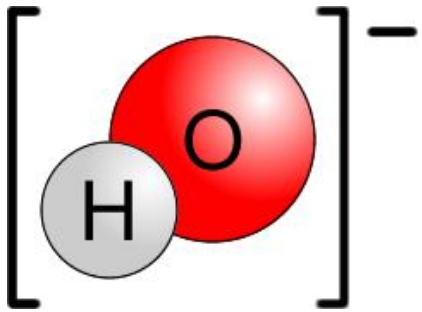


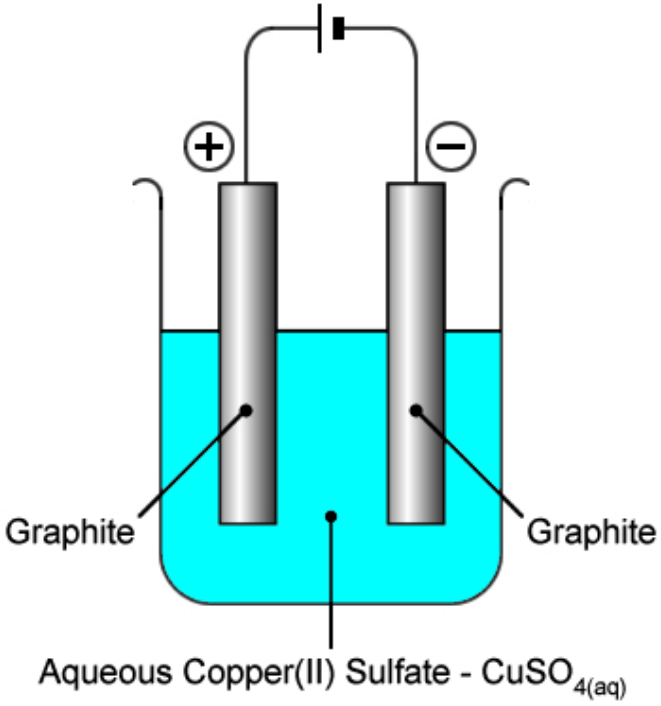
O' Level

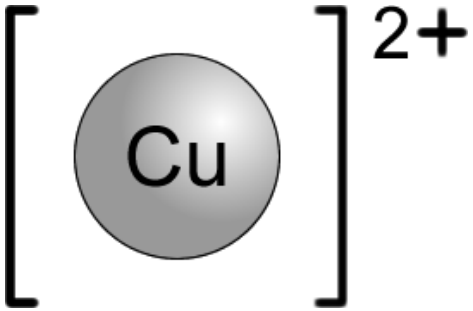
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous copper(II) sulfate* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous copper(II) sulfate* is electrolysed using inert electrodes?

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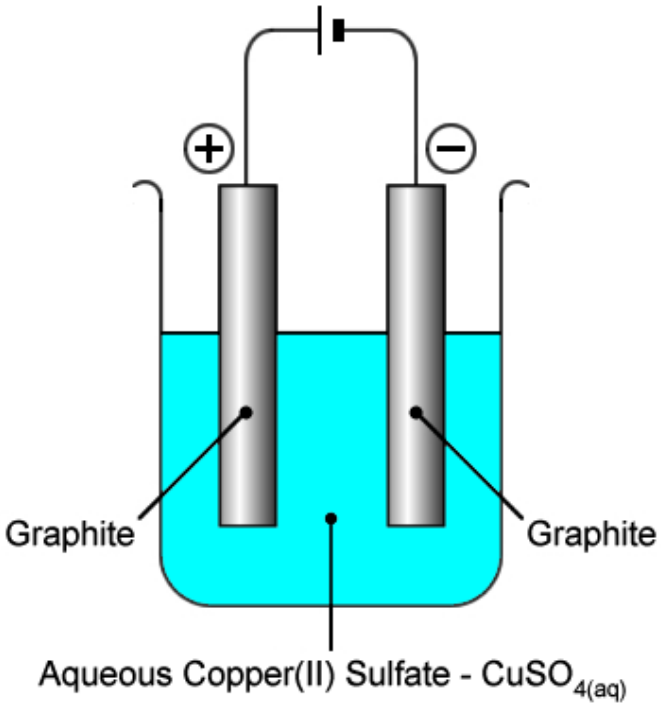
Negatively charged sulfate ions and hydroxide ions (anions) are both attracted to the positive anode.

Regardless of concentration, sulfate ions are not oxidised during electrolysis.

Consequently, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Positively charged copper(II) ions and hydrogen ions (cations) are both attracted to the negative cathode.

Copper is below hydrogen in the electrochemical series, therefore copper(II) ions are preferentially reduced to copper atoms at the cathode:

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous copper(II) sulfate* is electrolysed using inert electrodes?

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Negatively charged sulfate ions and hydroxide ions (anions) are both attracted to the positive anode.

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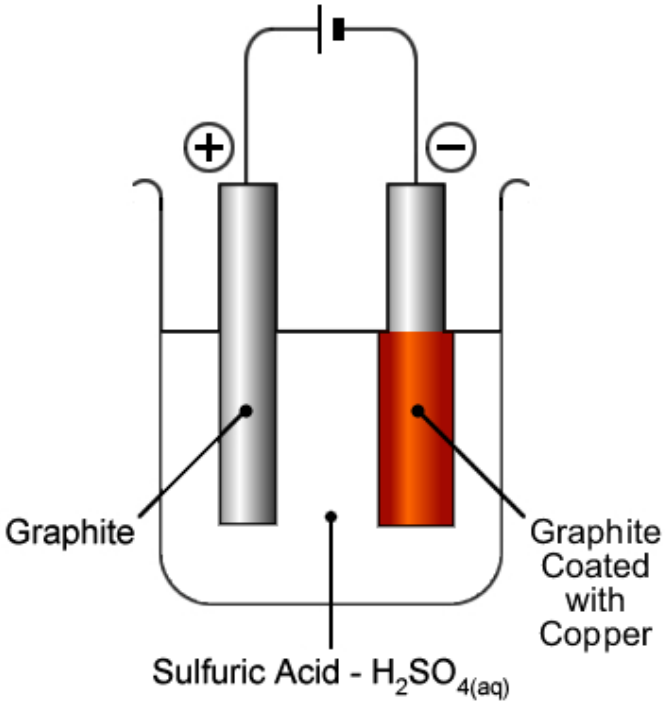

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Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \quad E^{\ominus} = +0.34\ V$$

$$Cu^{2+} + 2e^- \rightarrow Cu$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-} \quad E^{\ominus} = +2.01\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

NANYANG GIRLS' HIGH

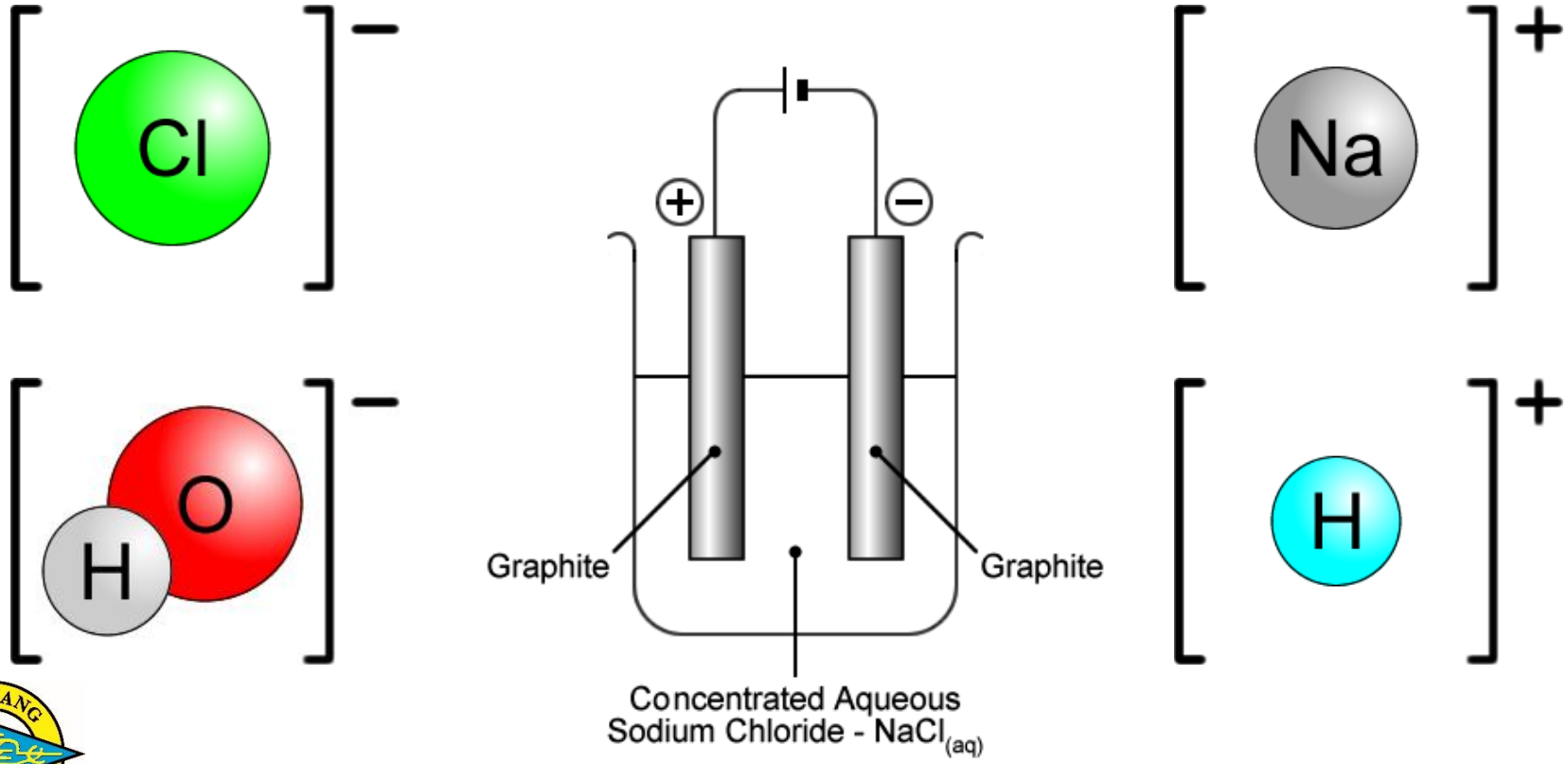
- New Integrated Programme 2025 – to align with A' Level Chemistry.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous sodium chloride* is electrolysed using inert electrodes?



O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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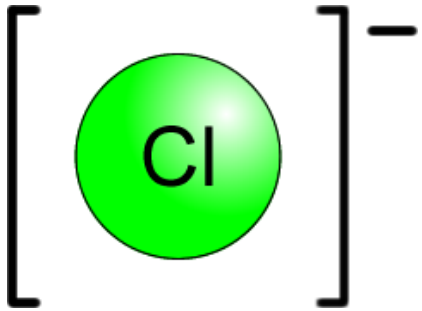
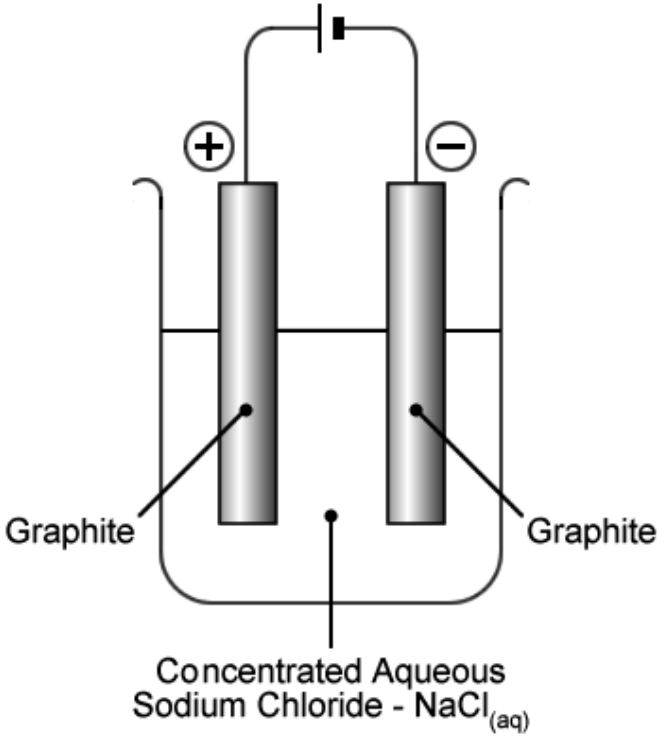
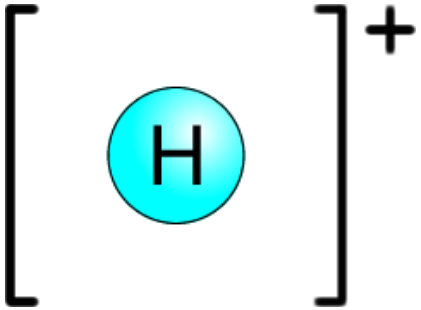






O' Level

Electrochemistry

Electrolysis of Aqueous Salts

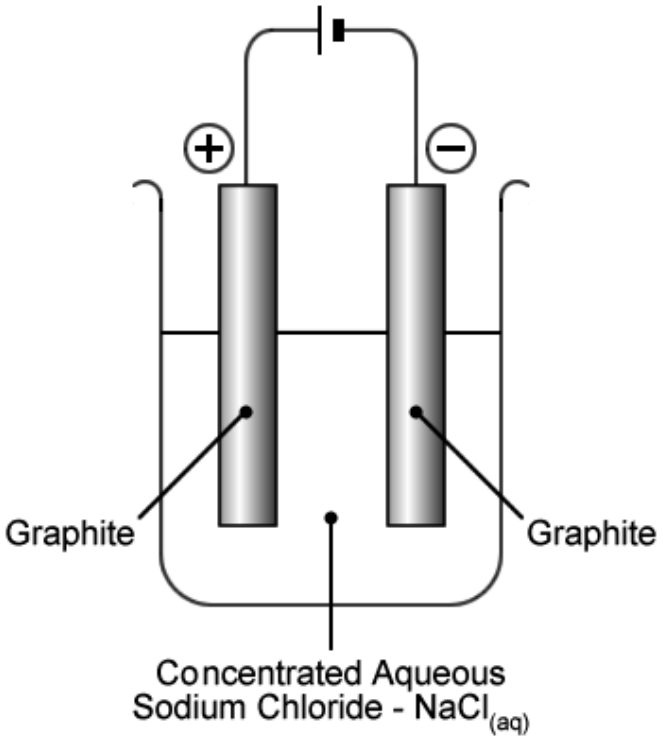
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous sodium chloride* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

At high concentration, chloride ions are preferentially oxidised to molecular chlorine at the anode:

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$



b) At the *cathode (–ve)*:

Positively charged sodium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Sodium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

NANYANG GIRLS' HIGH

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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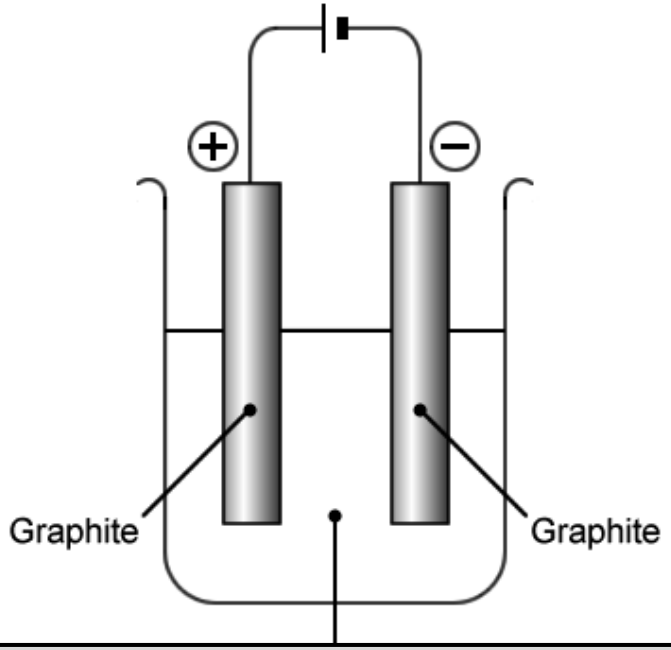


b) At the *cathode (–ve)*:

Positively charged sodium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Sodium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Becomes dilute aqueous NaCl(aq) / NaOH(aq)

Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$Na^+ + e^- \rightleftharpoons Na \quad E^{\ominus} = -2.71\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

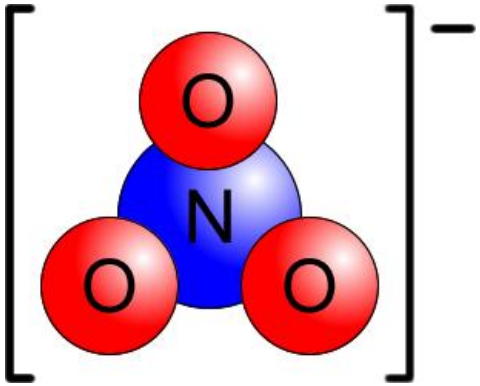
- New Integrated Programme 2025 – to align with A' Level Chemistry.

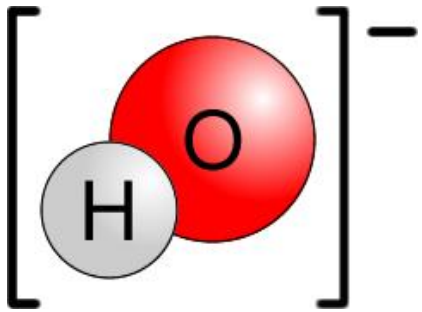
O' Level

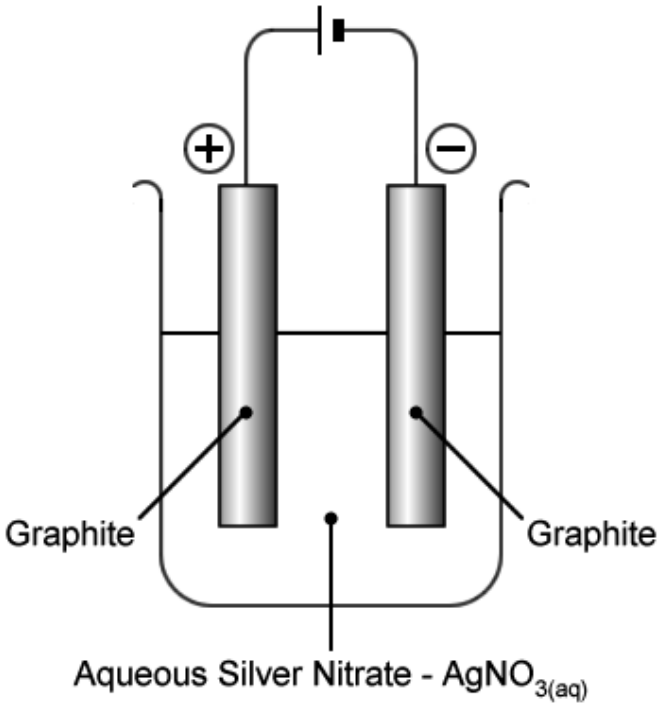
Electrochemistry

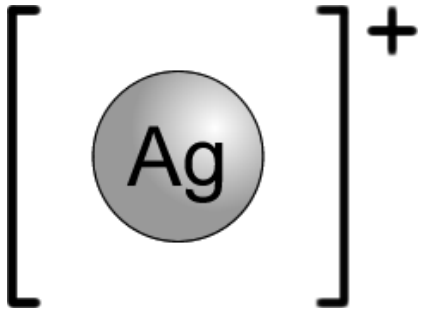
Electrolysis of Aqueous Salts

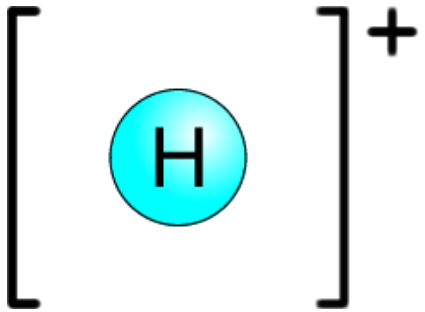
- What products are formed at **a)** the anode and **b)** the cathode when *aqueous silver nitrate* is electrolysed using inert electrodes?









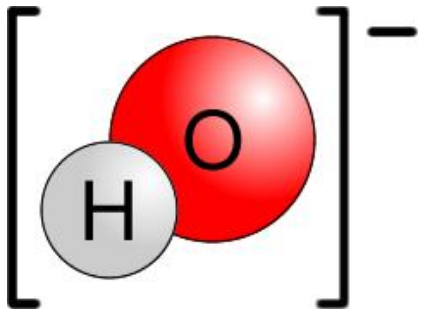


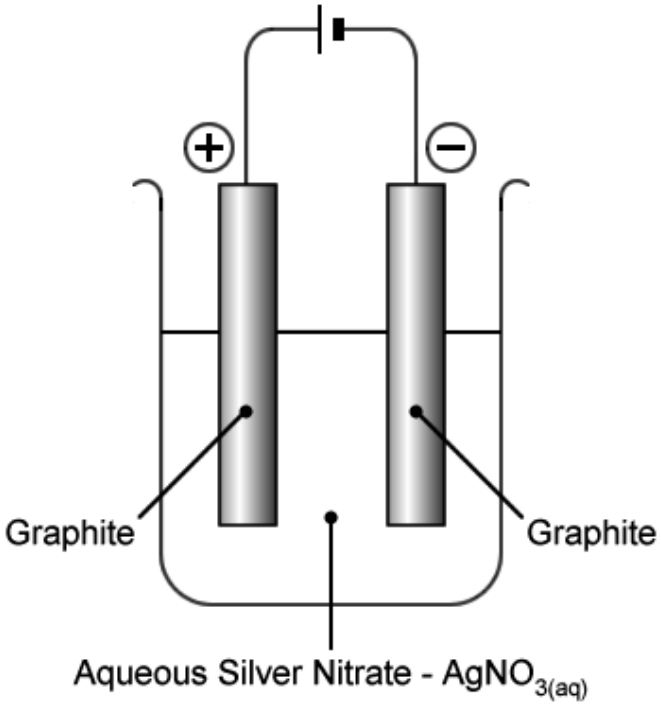
O' Level

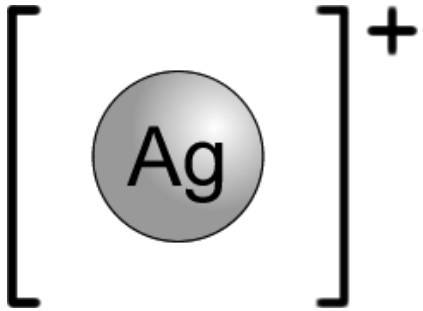
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous silver nitrate* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous silver nitrate* is electrolysed using inert electrodes?

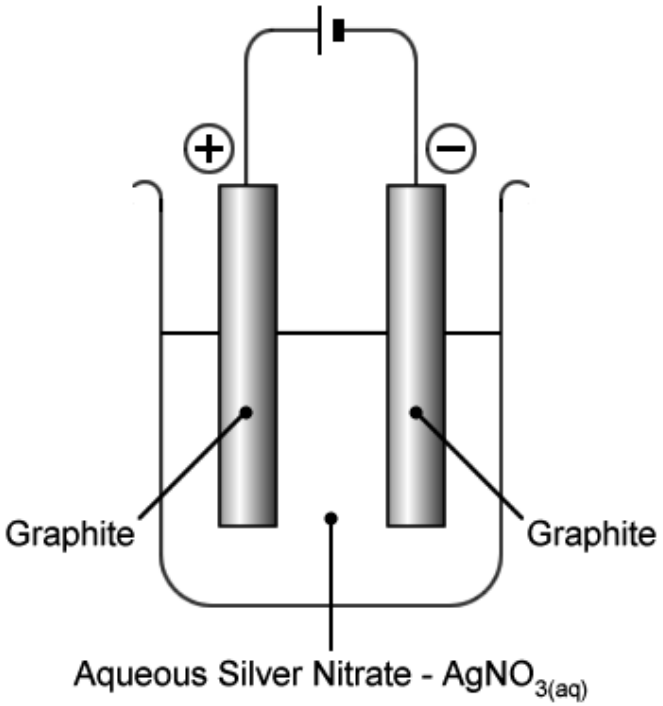
a) At the *anode (+ve)*:

Negatively charged nitrate ions and hydroxide ions (anions) are both attracted to the positive anode.

Regardless of concentration, nitrate ions are not oxidised during electrolysis.

Consequently, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Positively charged silver ions and hydrogen ions (cations) are both attracted to the negative cathode.

Silver is below hydrogen in the electrochemical series, therefore silver ions are preferentially reduced to silver atoms at the cathode:

$Ag^+(aq) + e^- \rightarrow Ag(s)$

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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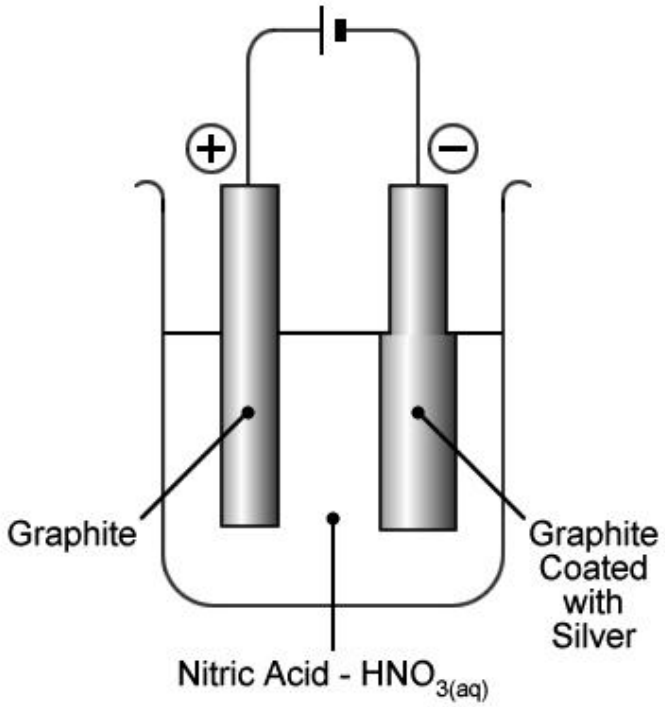

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Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$Ag^+ + e^- \rightleftharpoons Ag \quad E^{\ominus} = +0.80\ V$$

$$Ag^+ + e^- \rightarrow Ag$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

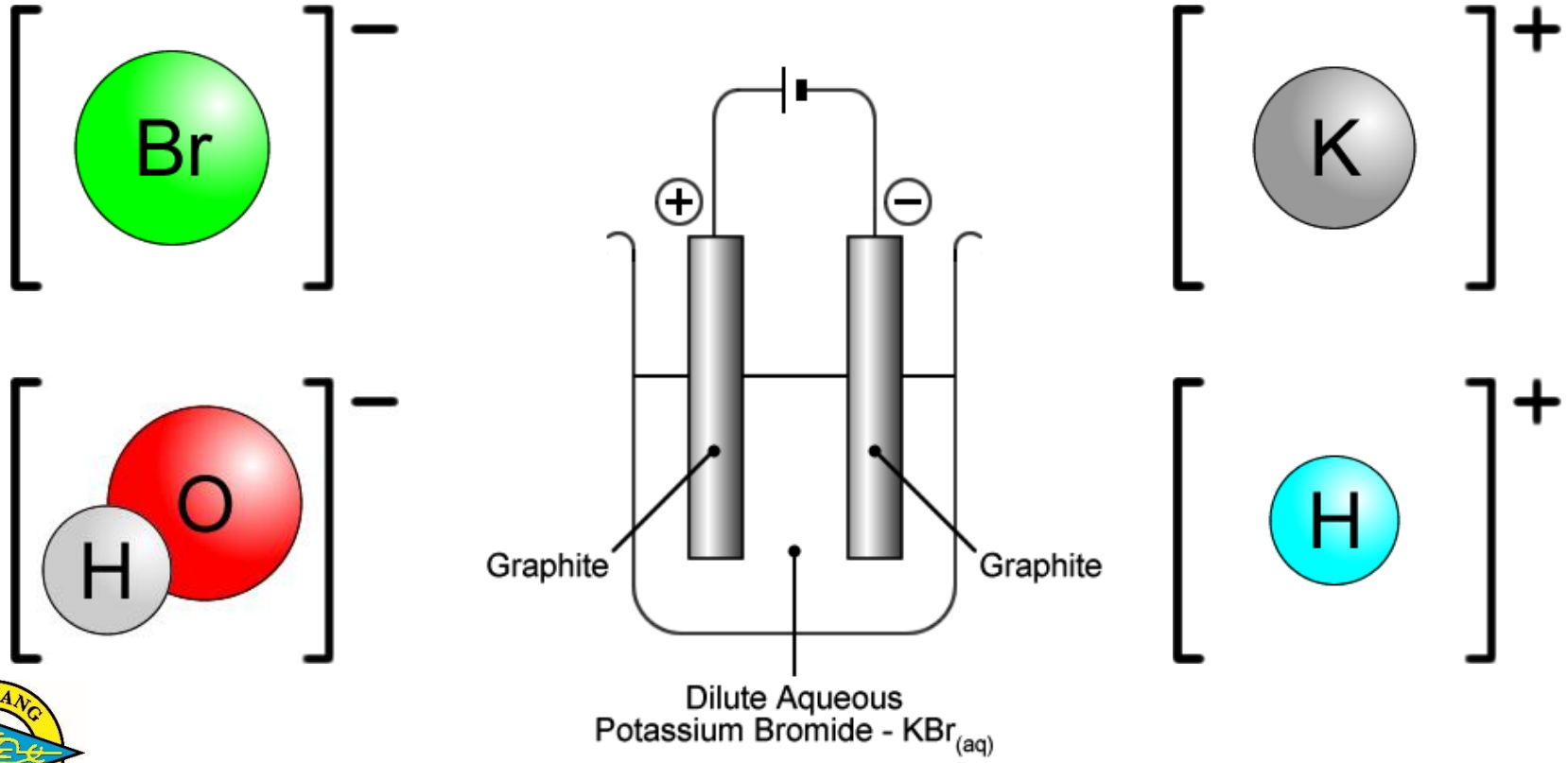
- New Integrated Programme 2025 – to align with A' Level Chemistry.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous potassium bromide* is electrolysed using inert electrodes?



O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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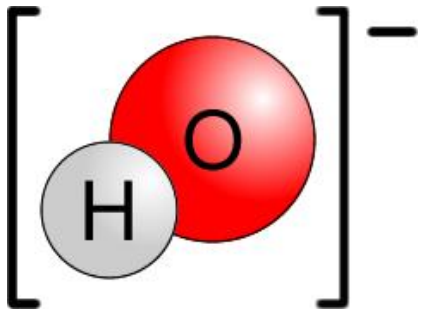
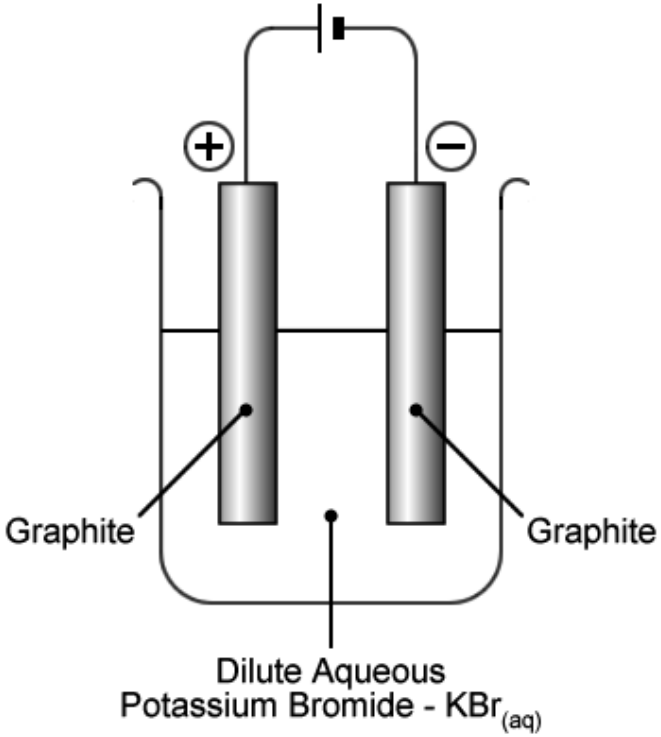
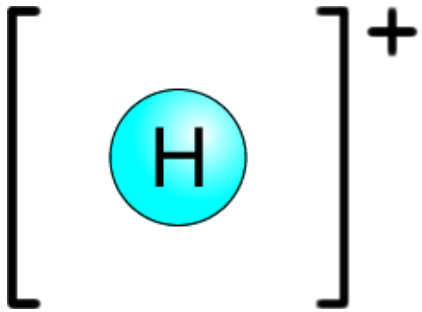






O' Level

Electrochemistry

Electrolysis of Aqueous Salts

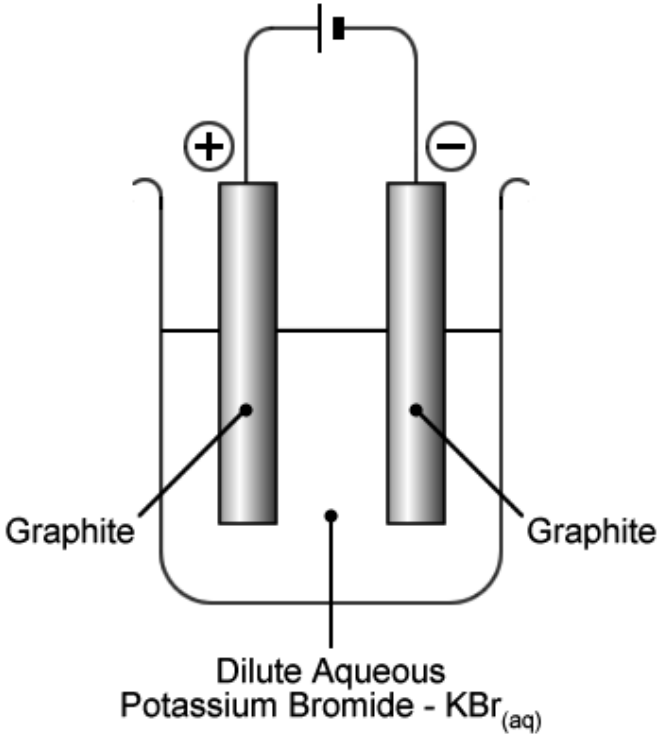
- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous potassium bromide* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged bromide ions and hydroxide ions (anions) are both attracted to the positive anode.

Because the solution is dilute, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Positively charged potassium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Potassium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

NANYANG GIRLS' HIGH

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

• What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous potassium bromide* is electrolysed using inert electrodes?

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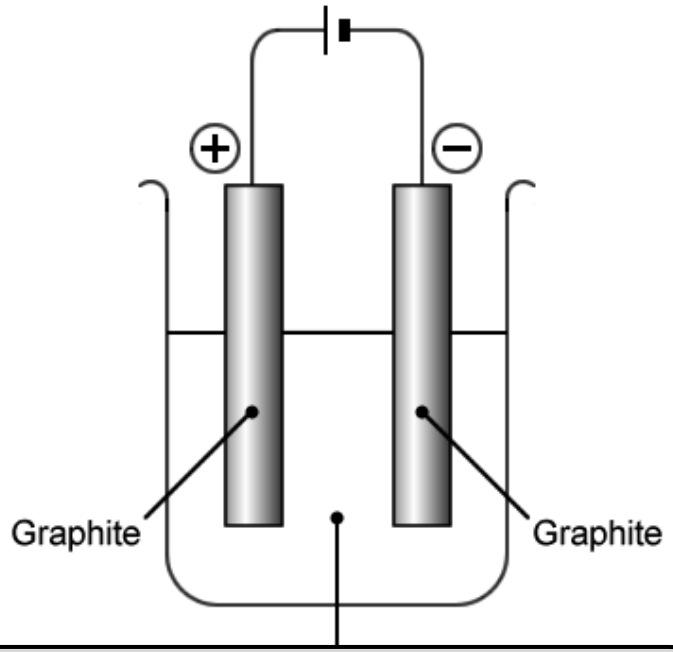


Becomes concentrated KBr(aq) / KOH(aq)

b) At the *cathode (–ve)*:

Positively charged potassium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Potassium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$K^+ + e^- \rightleftharpoons K \quad E^{\ominus} = -2.92\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$Br_2 + 2e^- \rightleftharpoons 2Br^- \quad E^{\ominus} = +1.07\ V$$

$$2Br^- \rightarrow Br_2 + 2e^-$$

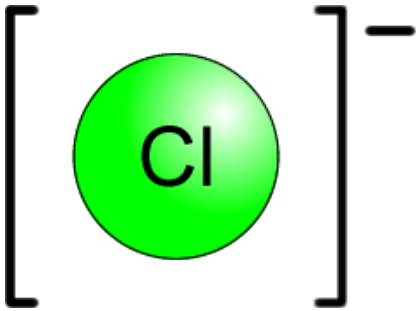
- New Integrated Programme 2025 – to align with A' Level Chemistry.

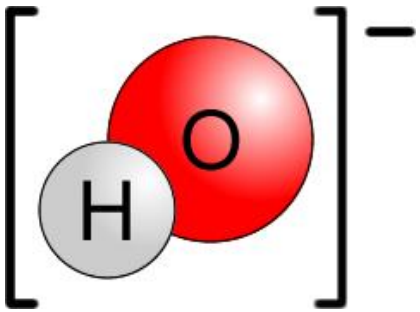
O' Level

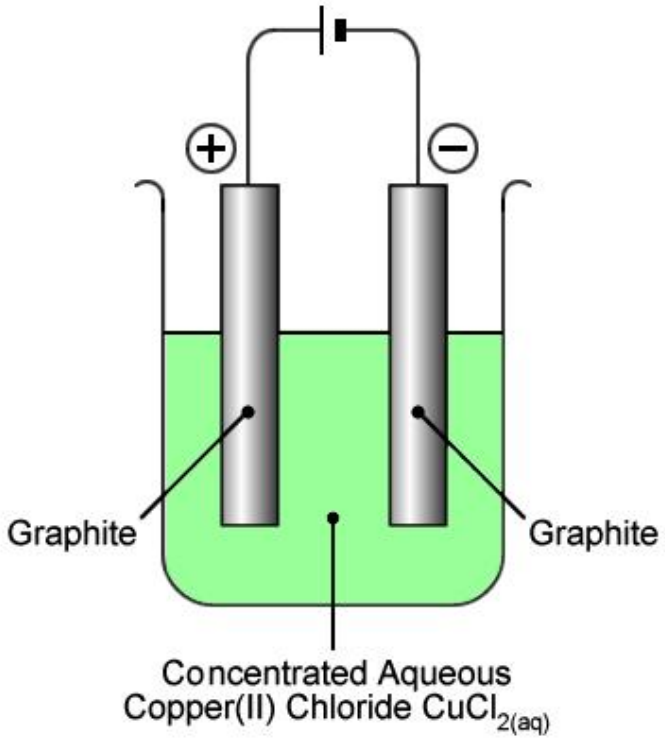
Electrochemistry

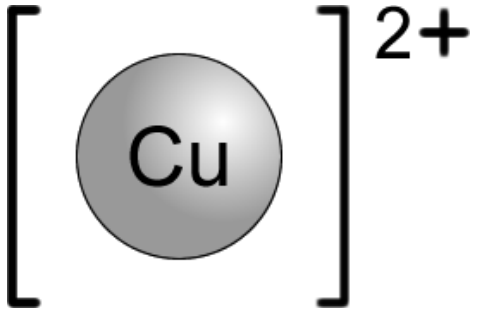
Electrolysis of Aqueous Salts

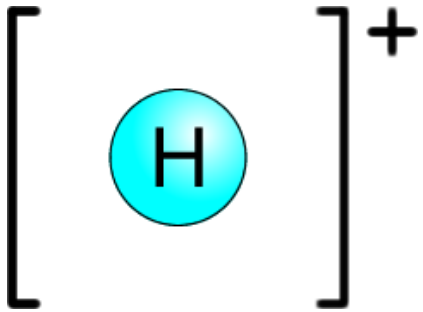
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous copper(II) chloride* is electrolysed using inert electrodes?









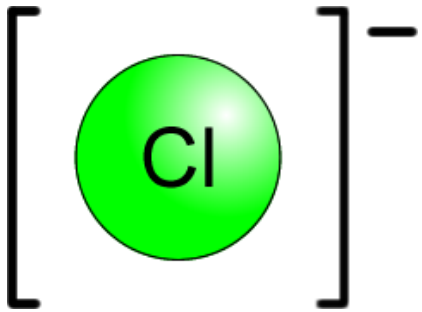


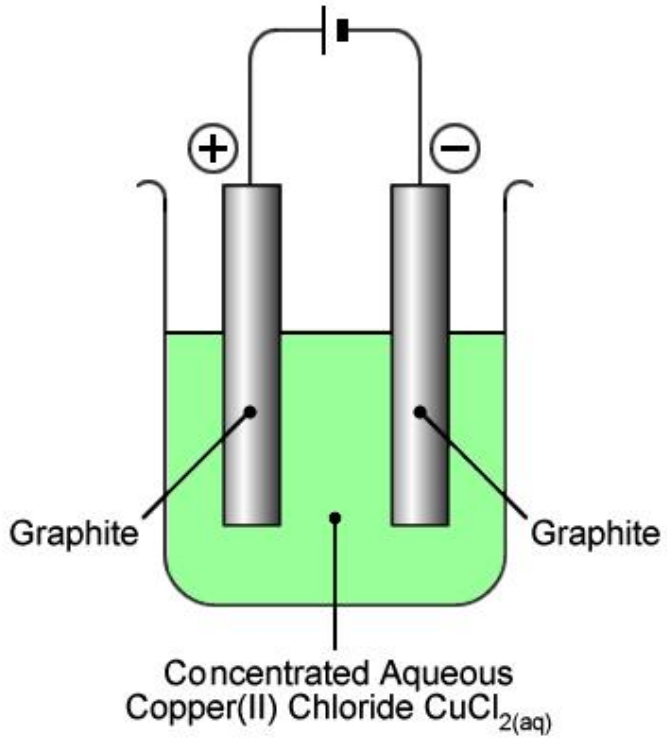
O' Level

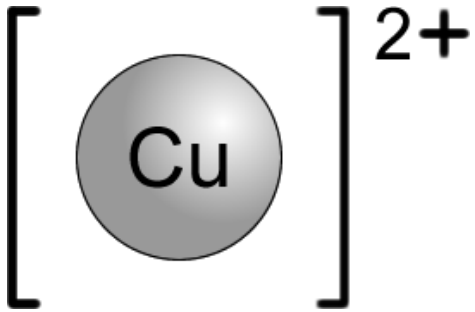
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous copper(II) chloride* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Aqueous Salts

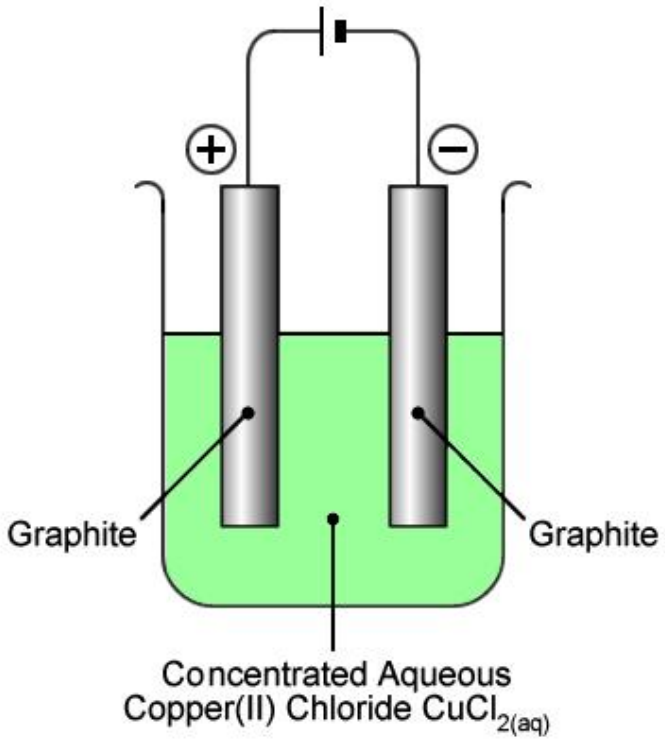
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated aqueous copper(II) chloride* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

At high concentration, chloride ions are preferentially oxidised to molecular chlorine at the anode:

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$



b) At the *cathode (–ve)*:

Positively charged copper(II) ions and hydrogen ions (cations) are both attracted to the negative cathode.

Copper is below hydrogen in the electrochemical series, therefore copper(II) ions are preferentially reduced to copper atoms at the cathode:

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

NANYANG GIRLS' HIGH

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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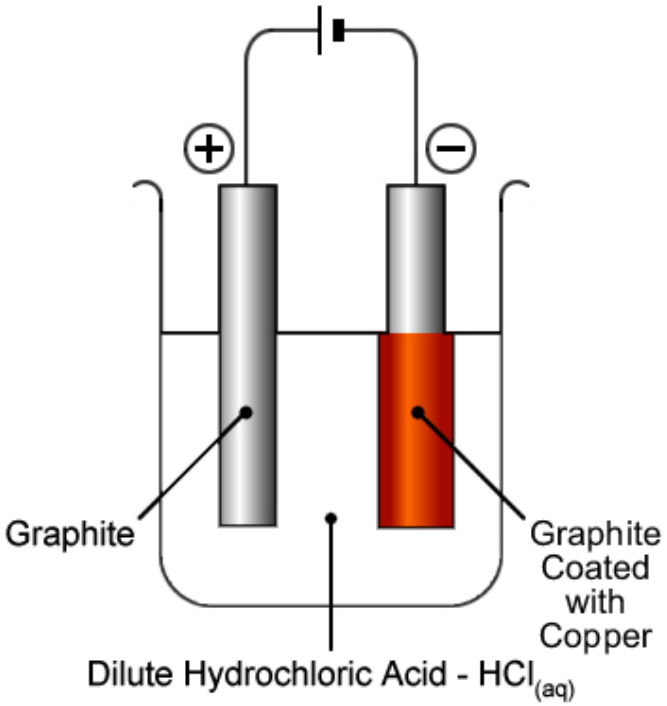

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NANYANG GIRLS' HIGH

Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \quad E^{\ominus} = +0.34\ V$$

$$Cu^{2+} + 2e^- \rightarrow Cu$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

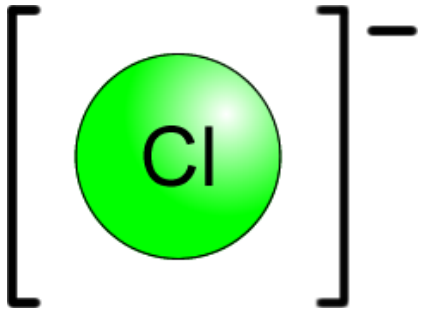
- New Integrated Programme 2025 – to align with A' Level Chemistry.

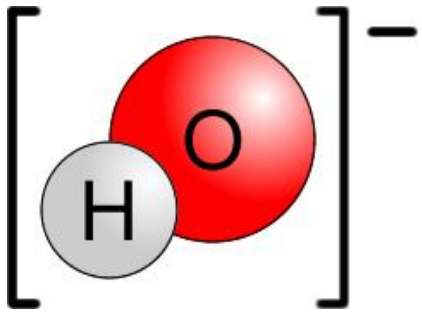
O' Level

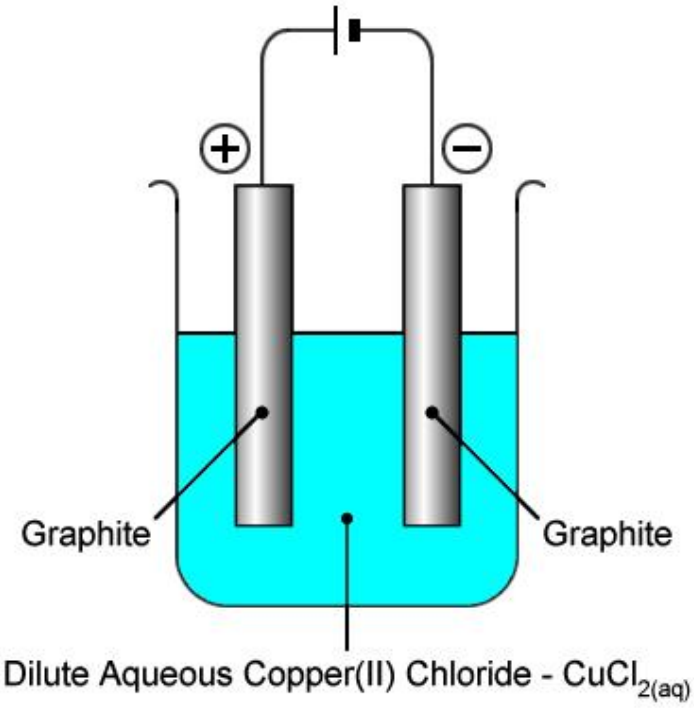
Electrochemistry

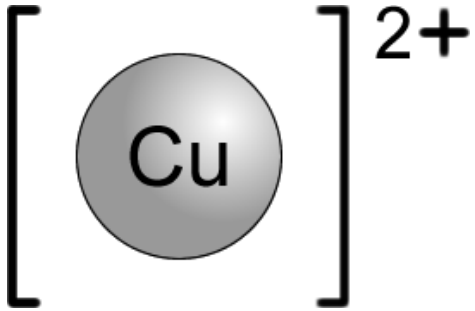
Electrolysis of Aqueous Salts

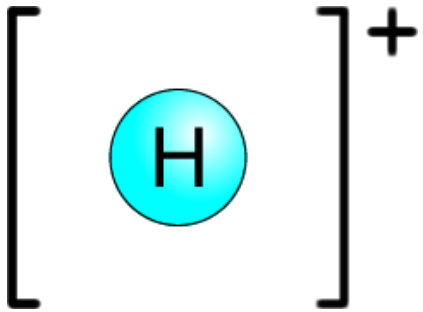
- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous copper(II) chloride* is electrolysed using inert electrodes?









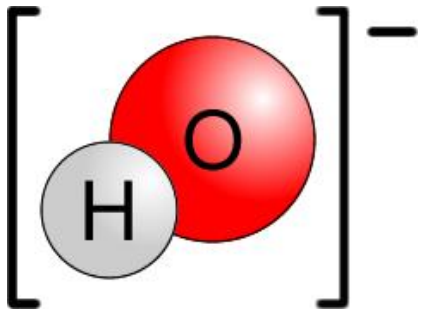


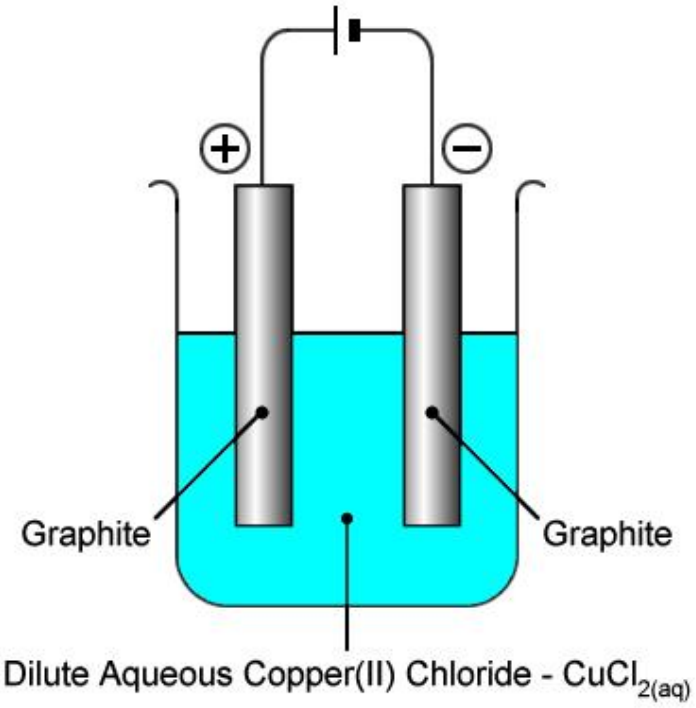
O' Level

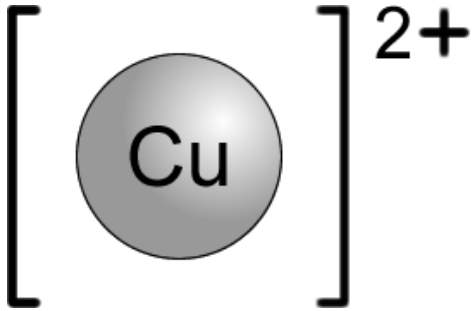
Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous copper(II) chloride* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at **a)** the anode and **b)** the cathode when *dilute aqueous copper(II) chloride* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

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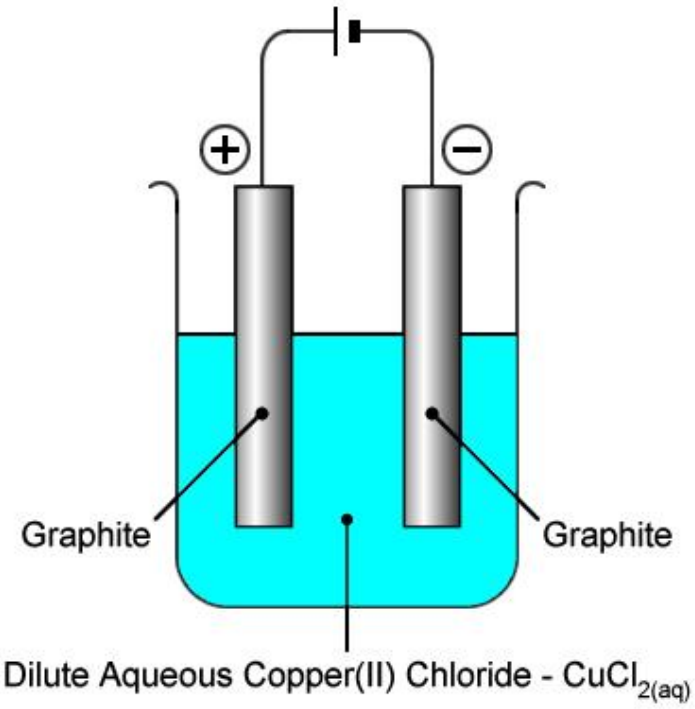

b) At the *cathode (–ve)*:

Positively charged copper(II) ions and hydrogen ions (cations) are both attracted to the negative cathode.

Copper is below hydrogen in the electrochemical series, therefore copper(II) ions are preferentially reduced to copper atoms at the cathode:

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O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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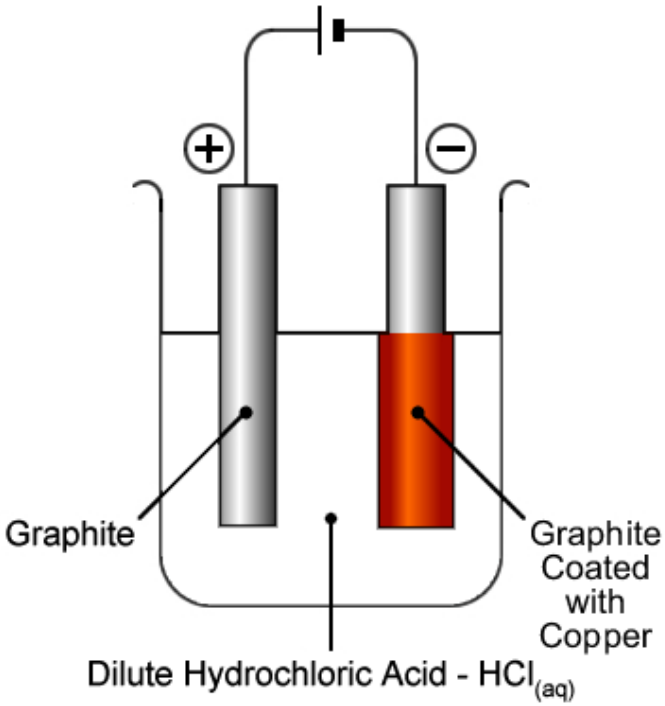

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Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

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$$Cu^{2+} + 2e^- \rightarrow Cu$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

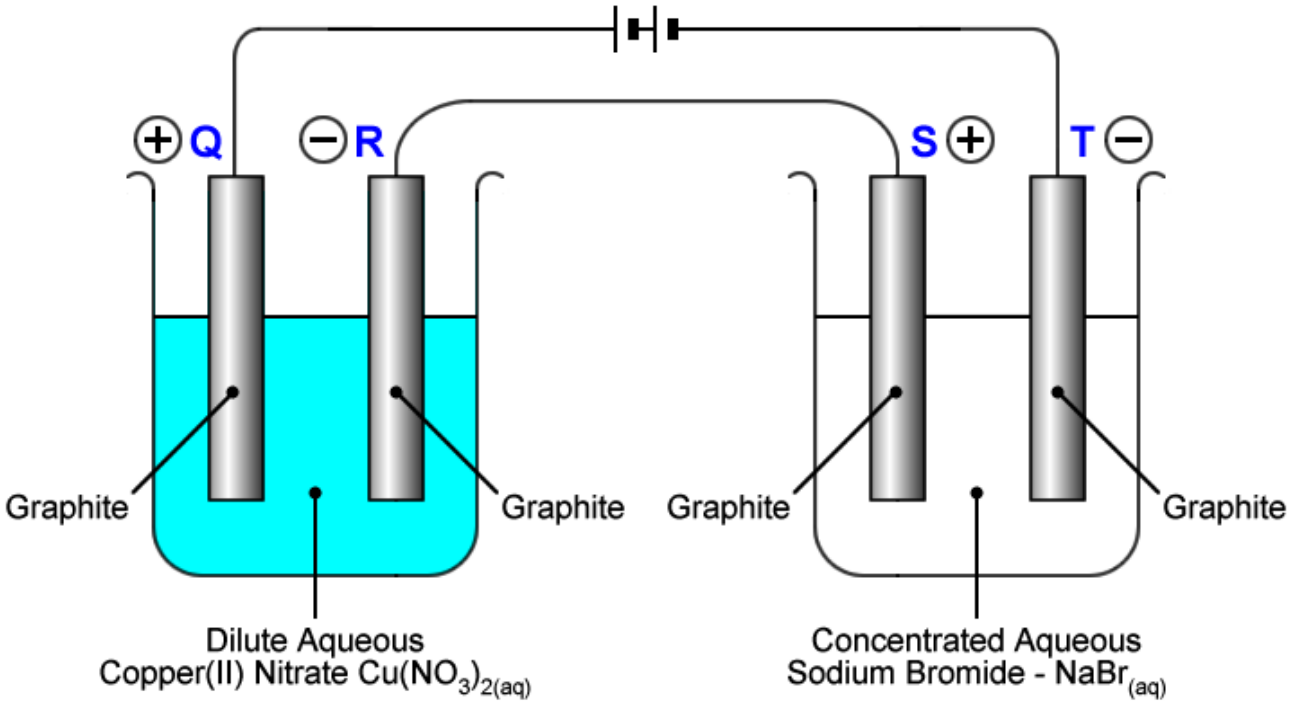
- New Integrated Programme 2025 – to align with A' Level Chemistry.

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

- What products are formed at the electrodes **Q**, **R**, **S**, and **T** when the following system is electrolysed using inert electrodes?



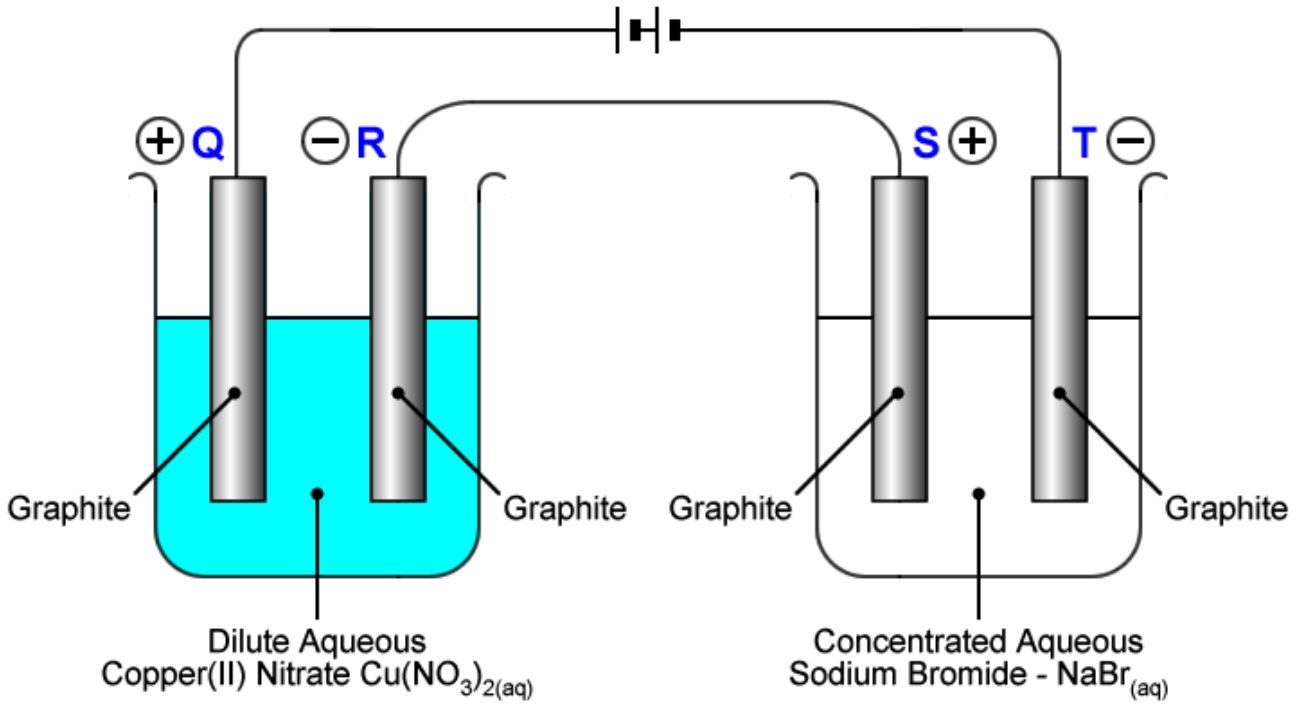
O' Level

Electrochemistry

Electrolysis of Aqueous Salts

Q: $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$ **R:** $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

S: $2Br^-(aq) \rightarrow Br_2(aq) + 2e^-$ **T:** $2H^+(aq) + 2e^- \rightarrow H_2(g)$



O' Level

Electrochemistry

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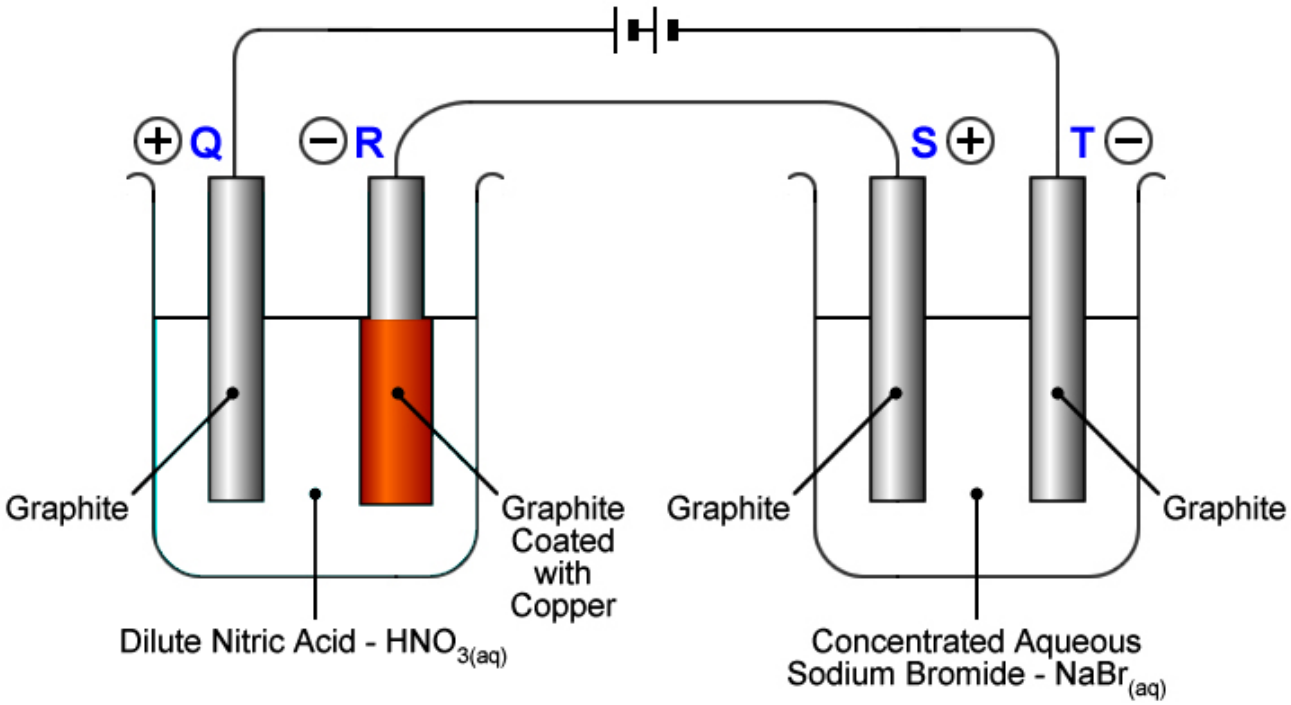

O' Level

Electrochemistry

Electrolysis of Aqueous Salts

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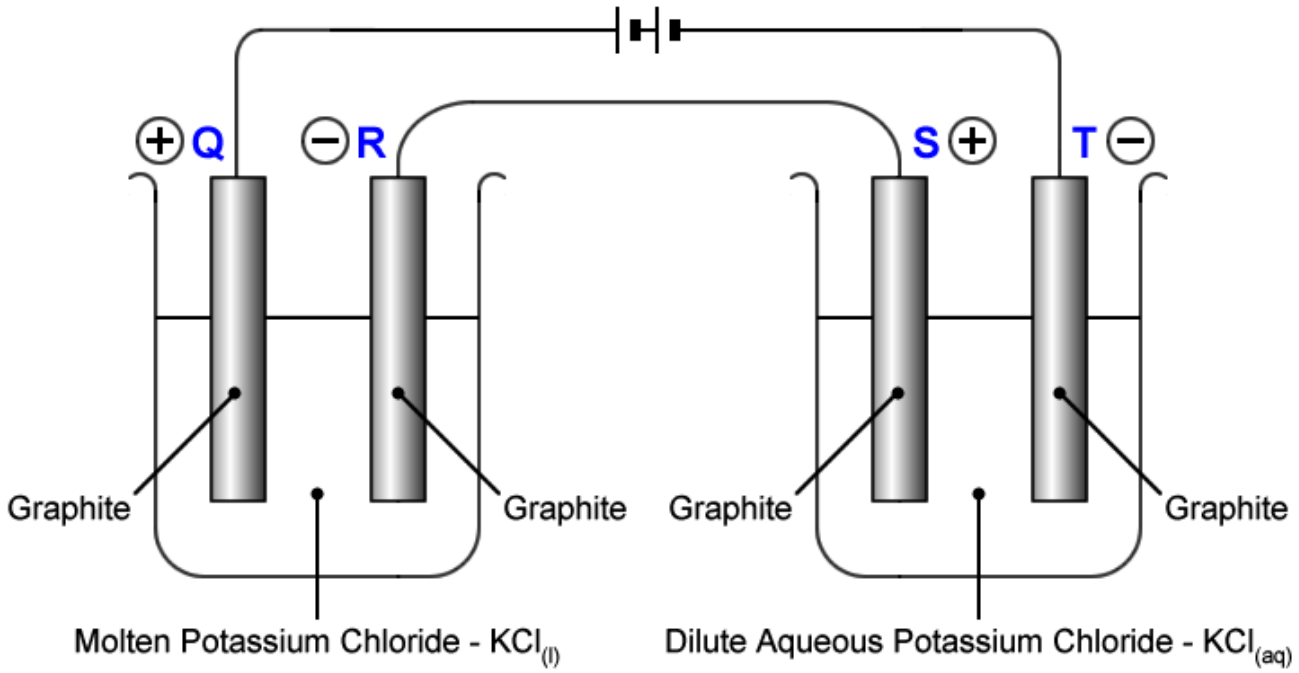


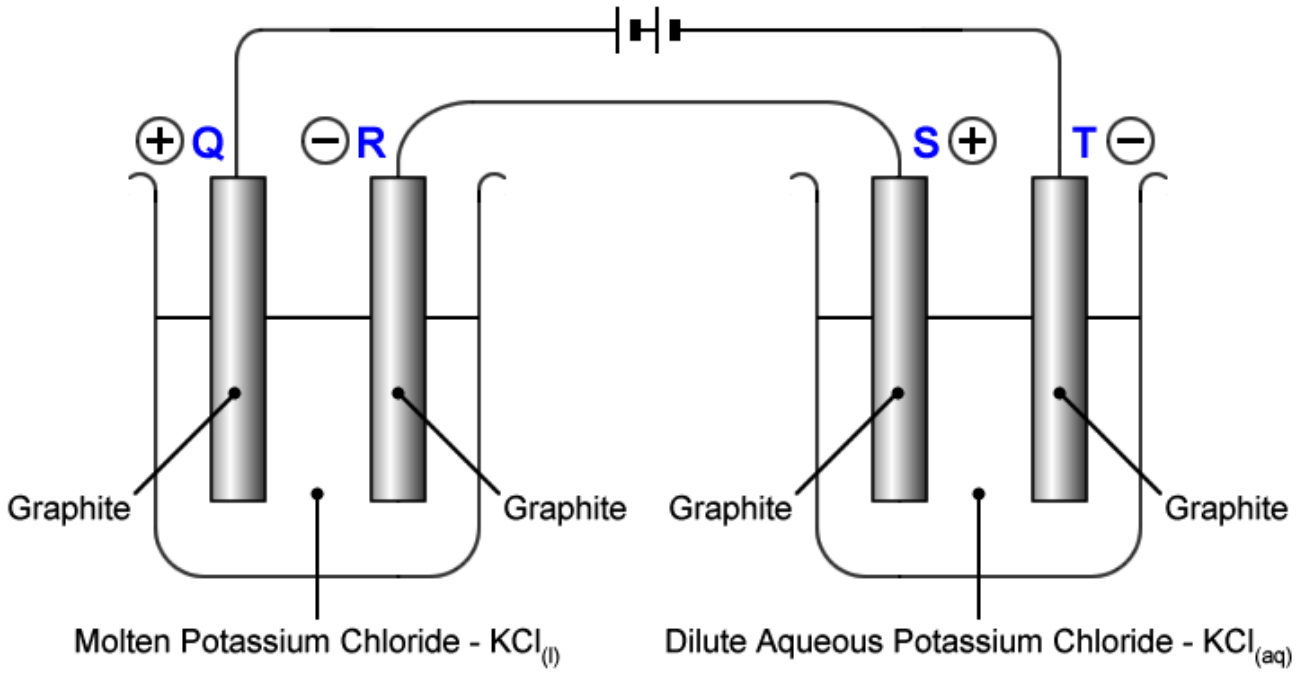
O' Level

Electrochemistry

Electrolysis of Aqueous Salts

Q: $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$ **R:** $K^+(l) + e^- \rightarrow K(l)$

S: $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$ **T:** $2H^+(aq) + 2e^- \rightarrow H_2(g)$



O' Level

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

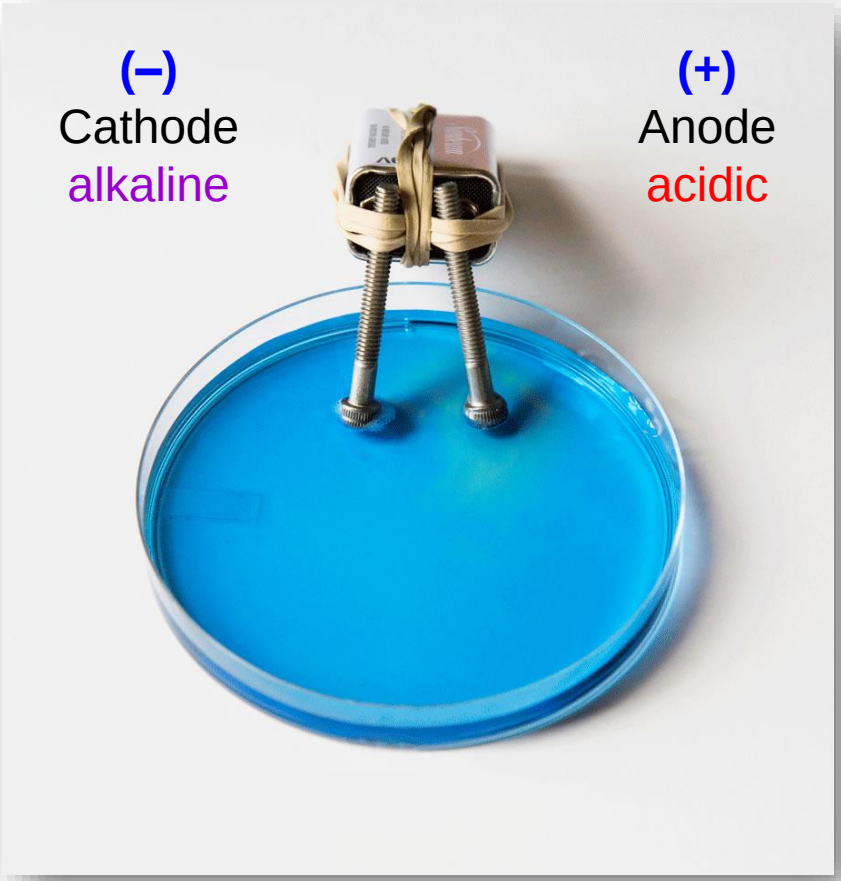
How does the pH of an electrolyte change during electrolysis?

NANYANG GIRLS' HIGH

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

O' Level



• The indicator bromothymol blue is yellow below pH 6.

Anode (+)

Water Dissociates

$4H_2O(l) \rightarrow 4H^+(aq) + 4OH^-(aq)$

Hydroxide Ions are Oxidised

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

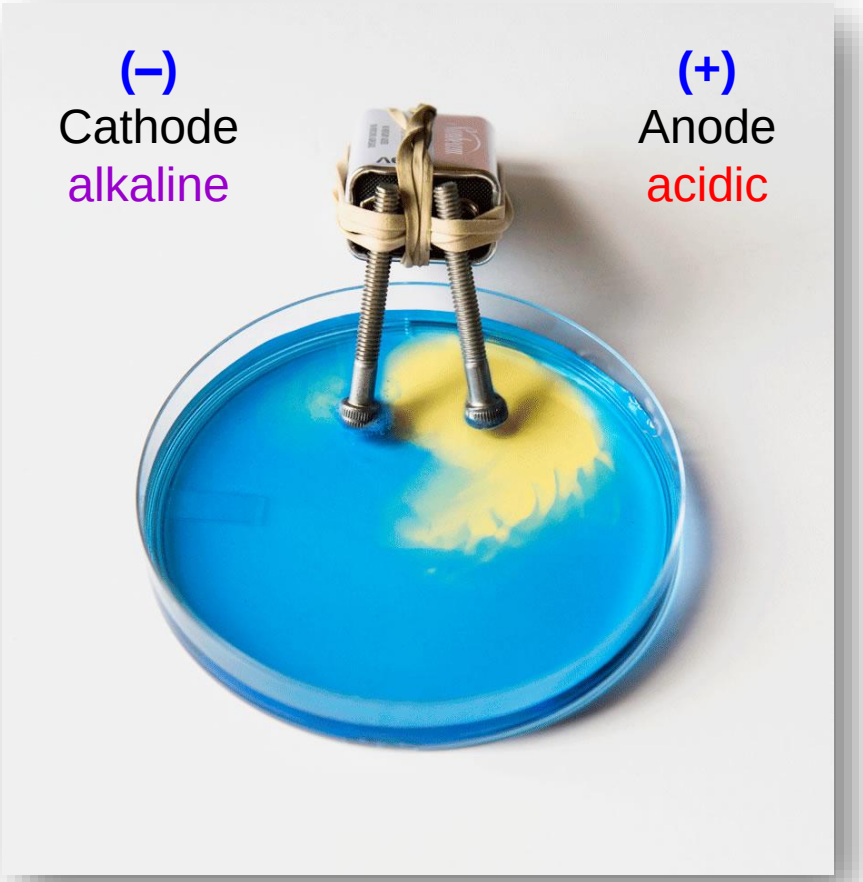
• As $OH^-(aq)$ are oxidised, the concentration of the $OH^-(aq)$ at the anode decreases.

• The $4H^+(aq)$ that are not reduced will make the solution at the anode *acidic* (pH < 7).

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

O' Level



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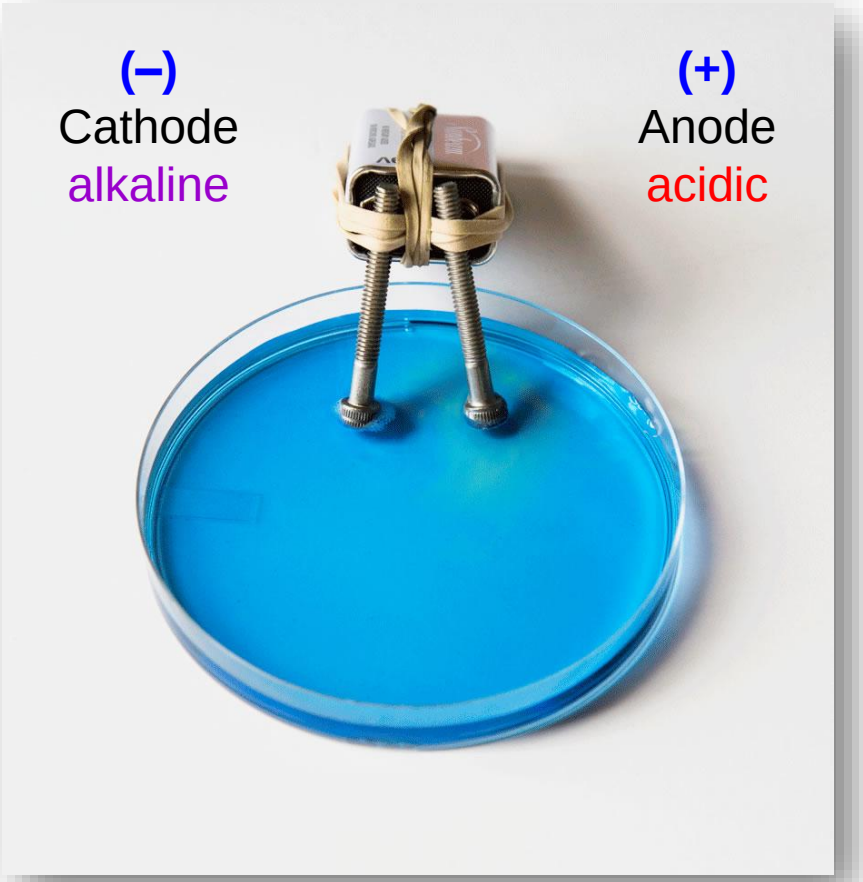
Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

O' Level



• The indicator bromothymol blue is yellow below pH 6.

Cathode (–)

Water Dissociates

$2H_2O(l) \rightarrow 2H^+(aq) + 2OH^-(aq)$

Hydrogen Ions are Reduced

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

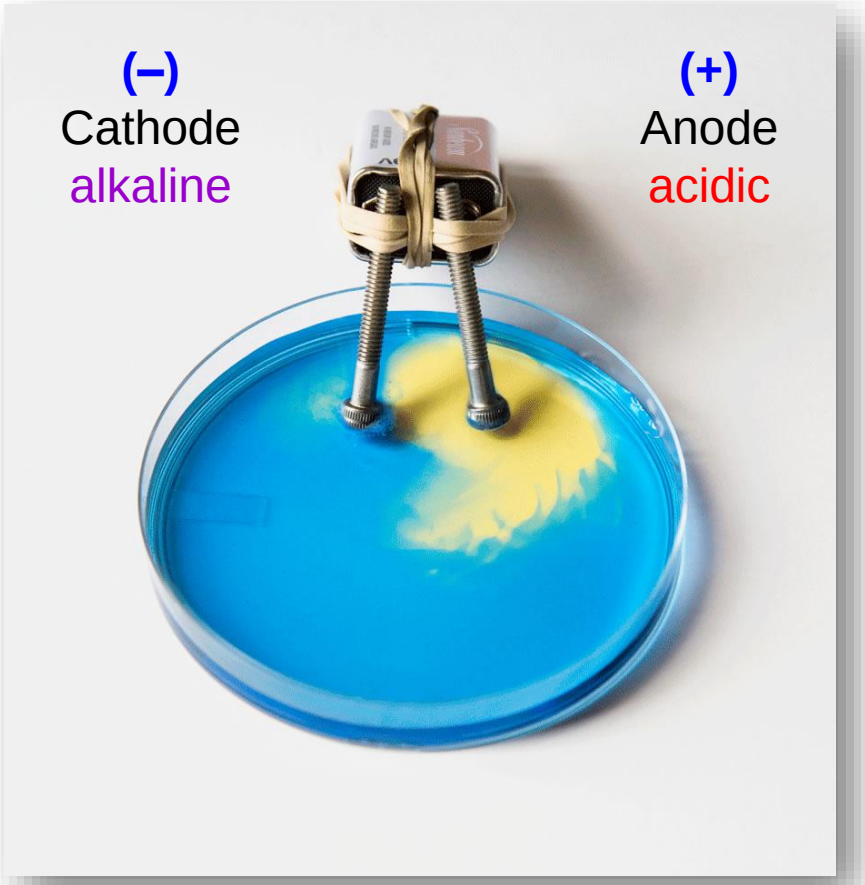
• As $H^+(aq)$ are reduced, the concentration of $H^+(aq)$ at the cathode decreases.

• The $2OH^-(aq)$ that are not oxidised will make the solution at the cathode *alkaline* (pH > 7).

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

O' Level



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Cathode (–)

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Hydrogen Ions are Reduced

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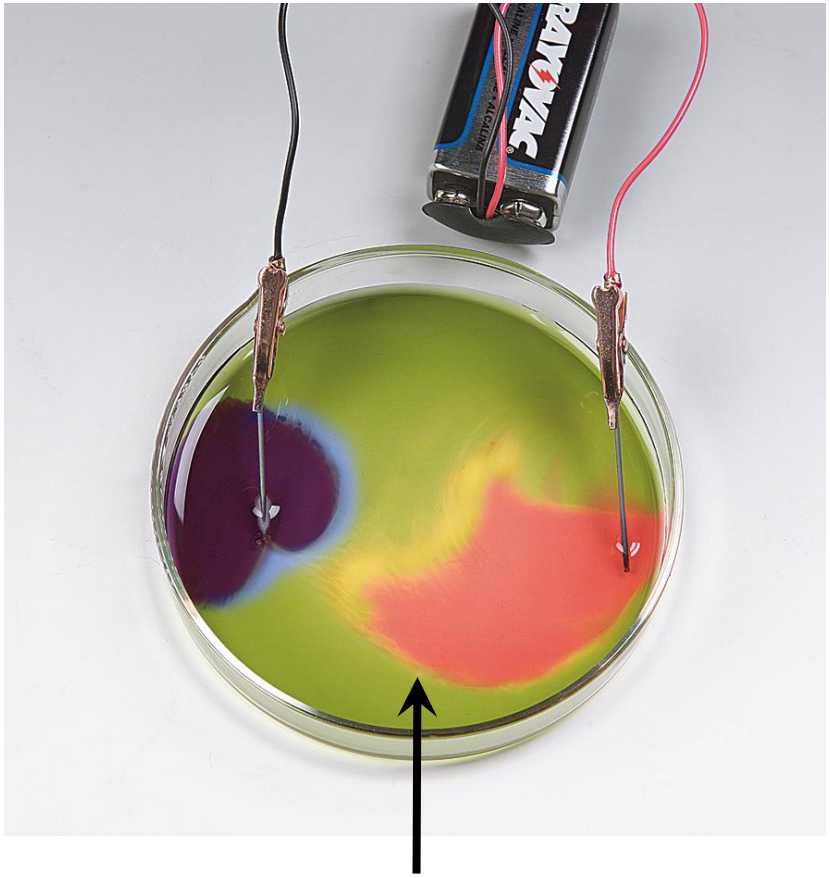
O' Level

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH



- Electrolyte with Universal Indicator added.

GREEN = *neutral* (pH = 7)

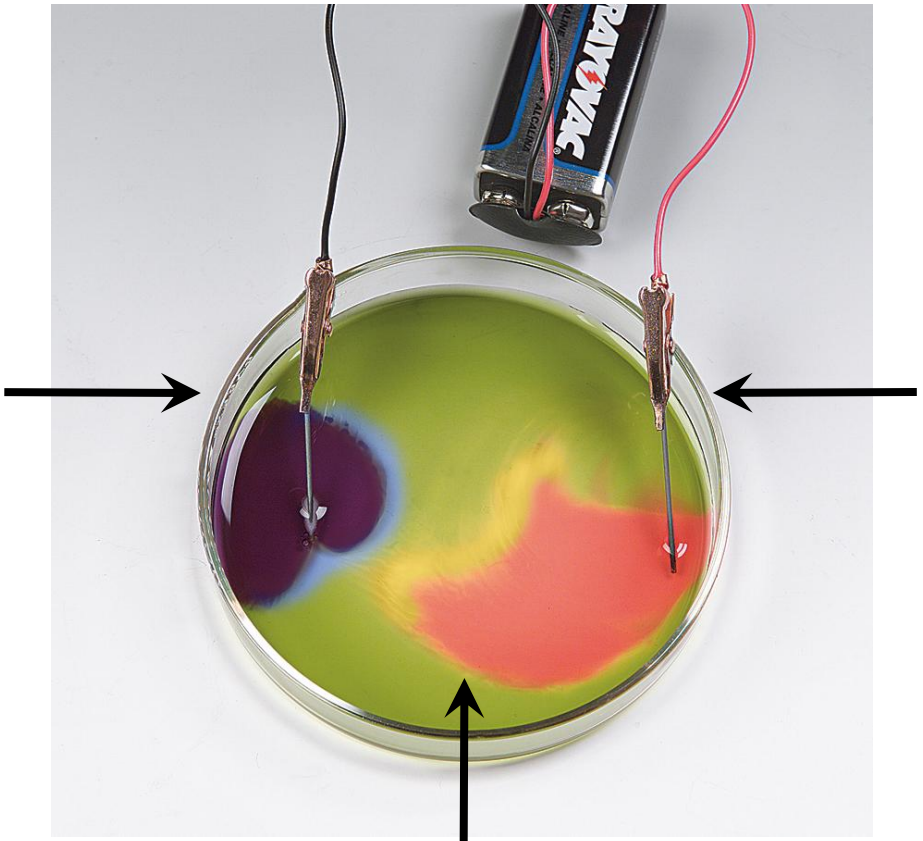
O' Level

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

- Cathode (–)

$H^+(aq)$ are reduced.
The remaining $OH^-(aq)$ ions cause the solution to become *alkaline* (pH > 7) causing the Universal Indicator to turn **BLUE**.



- Anode (+)

$OH^-(aq)$ are oxidised.
The remaining $H^+(aq)$ ions cause the solution to become *acidic* (pH < 7) causing the Universal Indicator to turn **RED**.

- Electrolyte with Universal Indicator added.

GREEN = *neutral* (pH = 7)

Electrochemistry

Electrolysis of Aqueous Salts – Changes in pH

Updated for A' Level

At the Cathode:

$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$ $\quad E^\ominus = -0.83$ V

Water is reduced, forming hydroxide ions which make the solution alkaline and turns the universal indicator **blue** / **purple**.

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

At the Anode

$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$ $\quad E^\ominus = +1.23$ V

Water is oxidised, forming hydrogen ions which make the solution acidic and turns the universal indicator **red**.

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

- New Integrated Programme 2025 – to align with A' Level Chemistry.

O' Level

Electrochemistry

Electrolysis of Acids and Alkalis

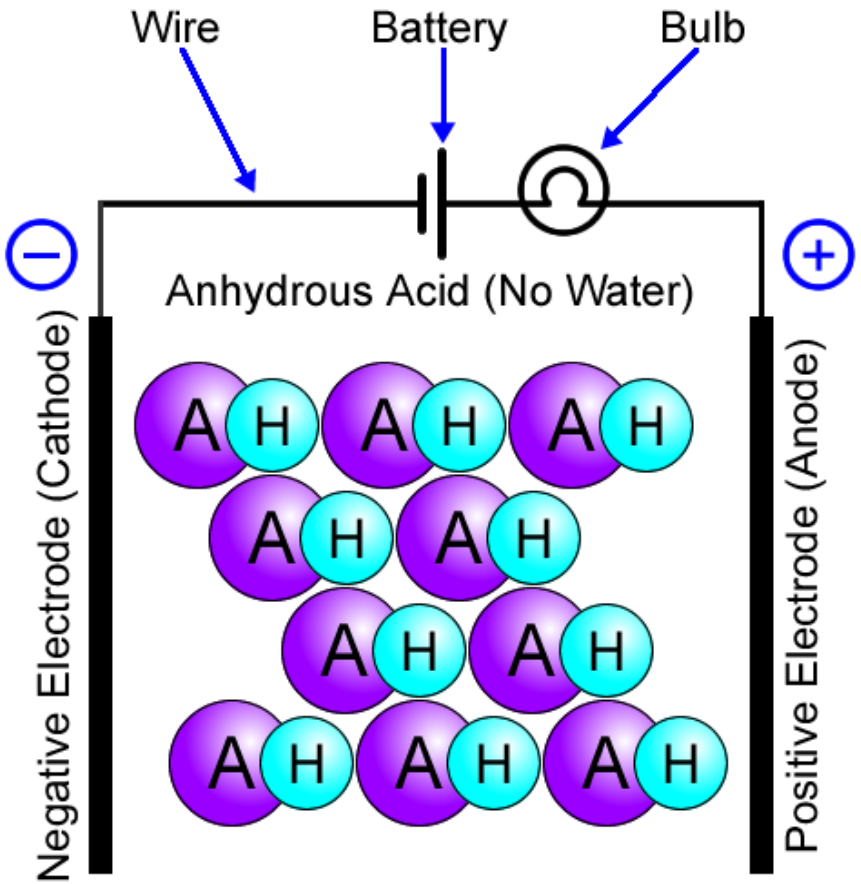
What happens during the electrolysis of acids and alkalis?

NANYANG GIRLS' HIGH

Electrochemistry

Electrolysis of Acids and Alkalis

O' Level

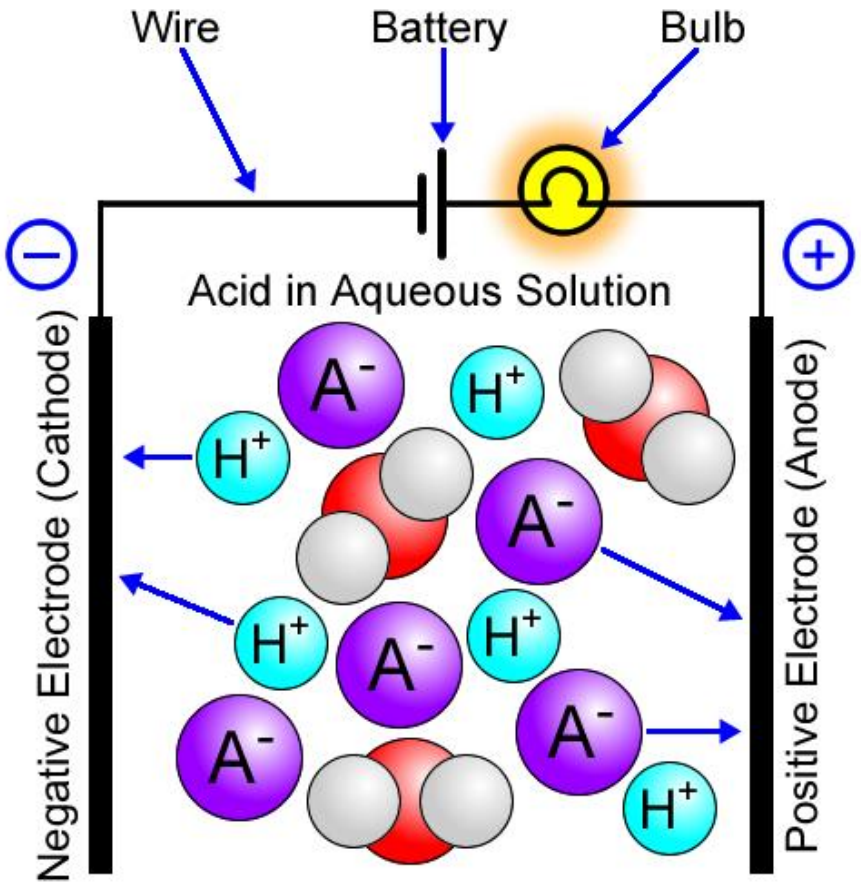


- A pure acid, one that has not dissolved in water, will be composed only of simple covalent molecules. There are *no mobile ions* to serve as charge carrying particles. The *pure acid is an electrical insulator*.

O' Level

Electrochemistry

Electrolysis of Acids and Alkalis

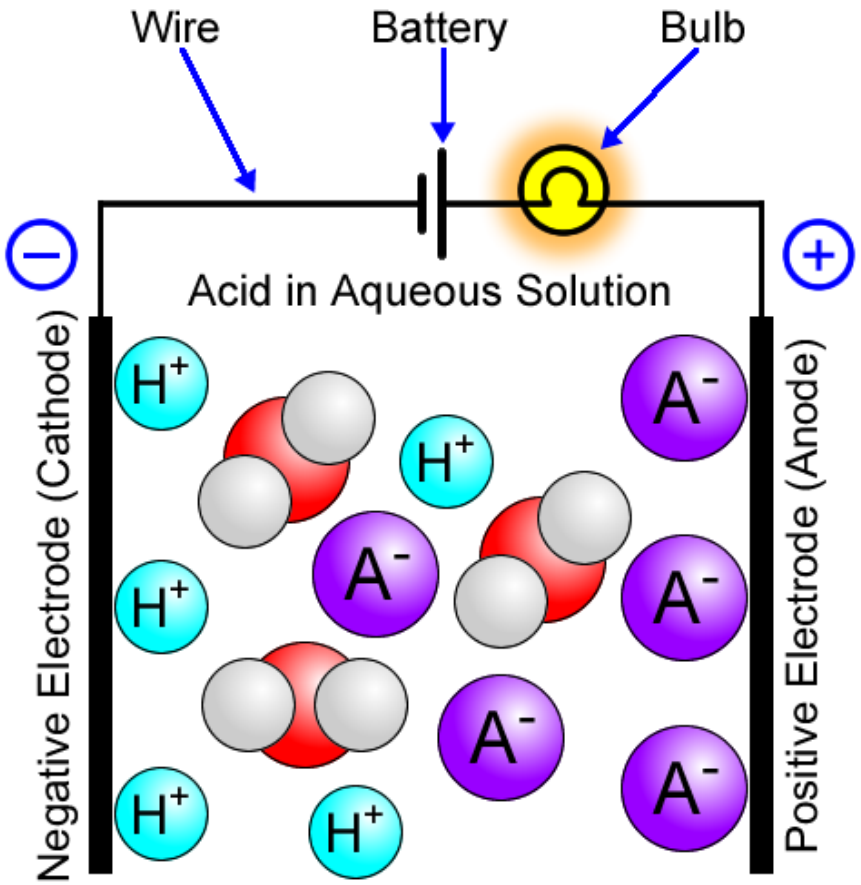


- Once dissolved in water, the acid will *ionize* to form positively charged hydrogen ions and anions. *The ions are free to move throughout the solution* and therefore serve as mobile charge carrying particles.

Electrochemistry

Electrolysis of Acids and Alkalis

O' Level



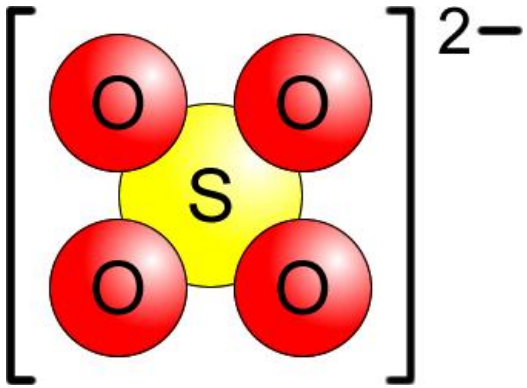
- When electrodes are inserted into the acidic solution, the *positively charged hydrogen ions are attracted towards the cathode*, while the *anions are attracted towards the anode*. The movement of ions towards the electrode of opposite charge constitutes the flow of electricity.

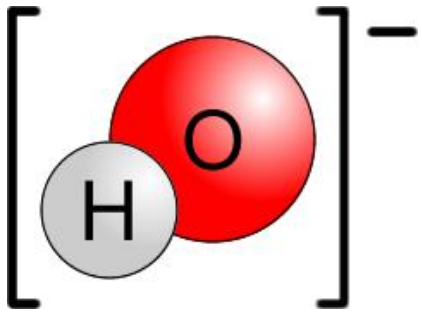
O' Level

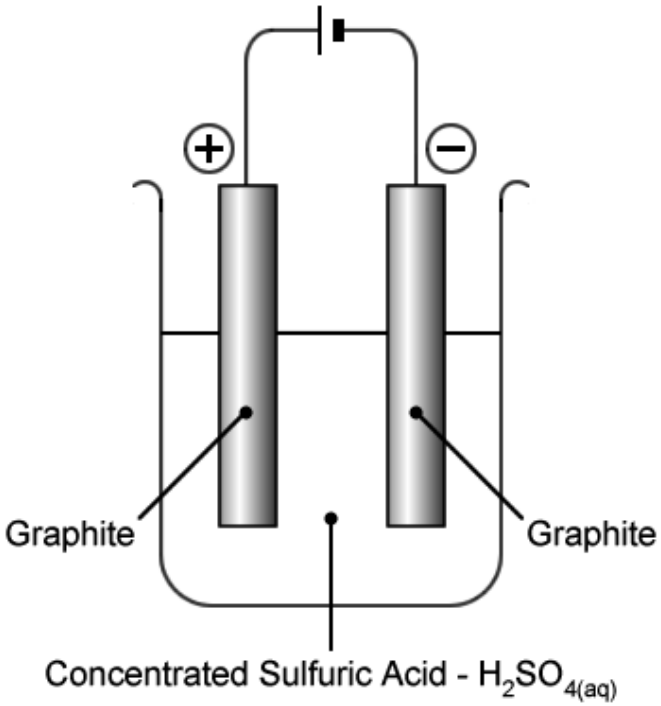
Electrochemistry

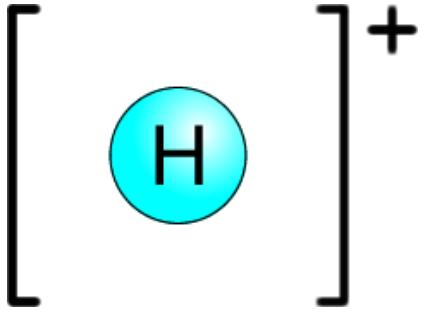
Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated sulfuric acid* is electrolysed using inert electrodes?







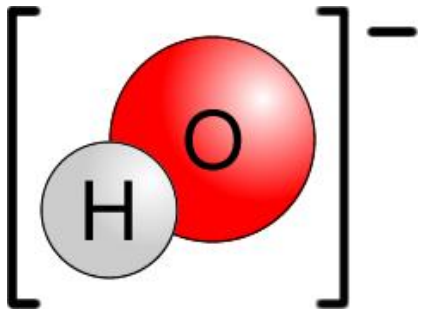


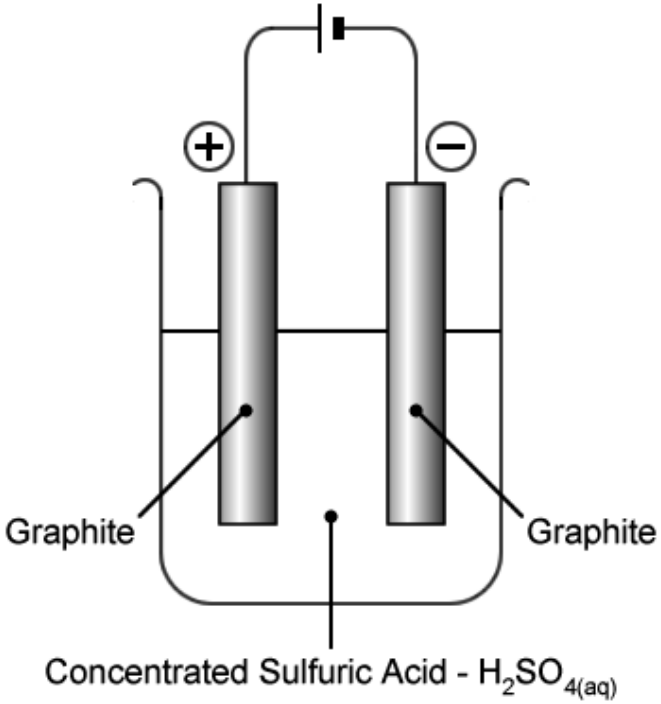
O' Level

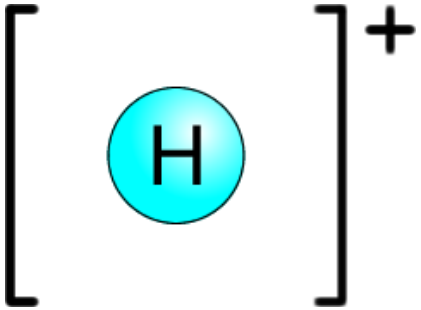
Electrochemistry

Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated sulfuric acid* is electrolysed using inert electrodes?







O' Level

Electrochemistry

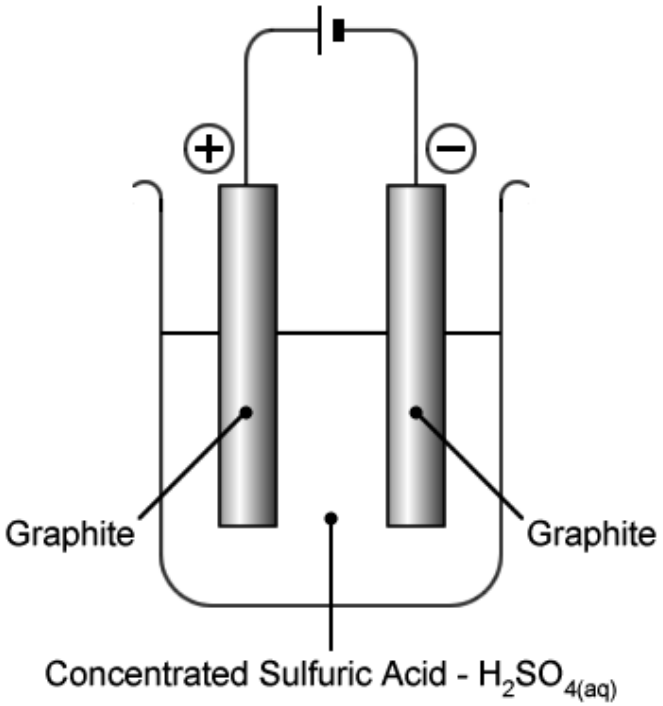
Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated sulfuric acid* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged sulfate ions and hydroxide ions (anions) are both attracted to the positive anode. Regardless of concentration, sulfate ions are not oxidised during electrolysis. Consequently, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Hydrogen ions are the only cations present in the solution.

Positively charged hydrogen ions are attracted towards the negatively charged cathode where they are reduced to molecular hydrogen:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H^+ + 2e^- \rightleftharpoons H_2 \quad E^{\ominus} = +0.00\ V$$

$$2H^+ + 2e^- \rightarrow H_2$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-} \quad E^{\ominus} = +2.01\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

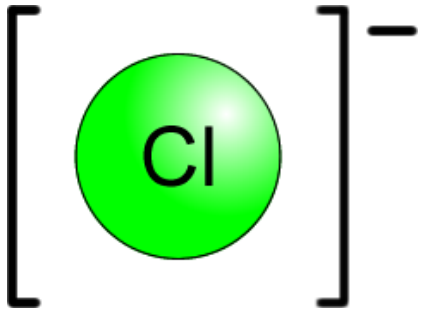
- New Integrated Programme 2025 – to align with A' Level Chemistry.

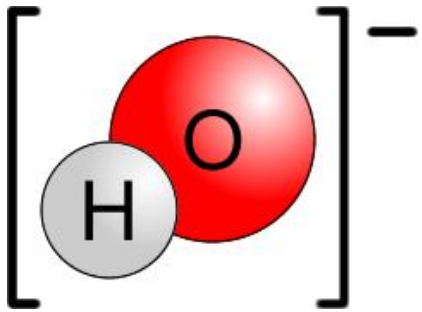
O' Level

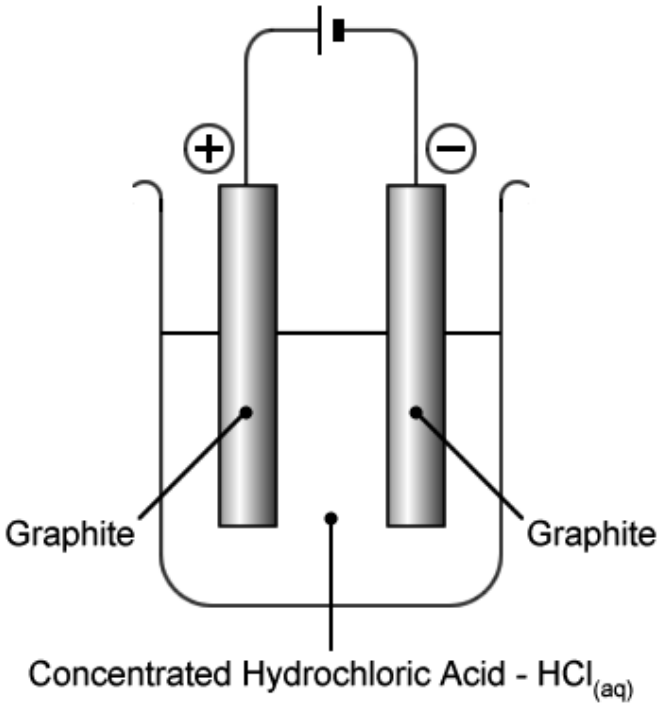
Electrochemistry

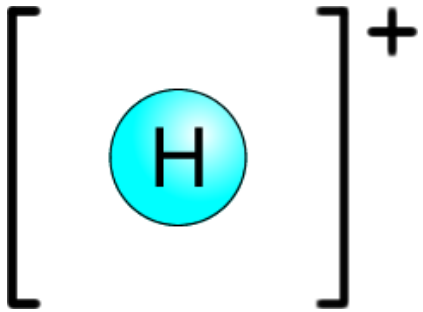
Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated hydrochloric acid* is electrolysed using inert electrodes?







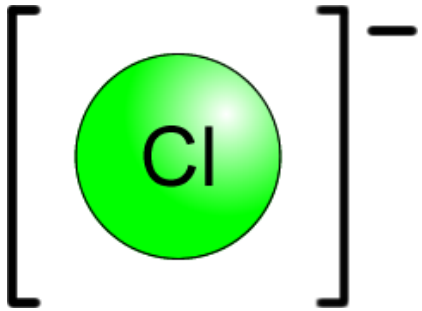


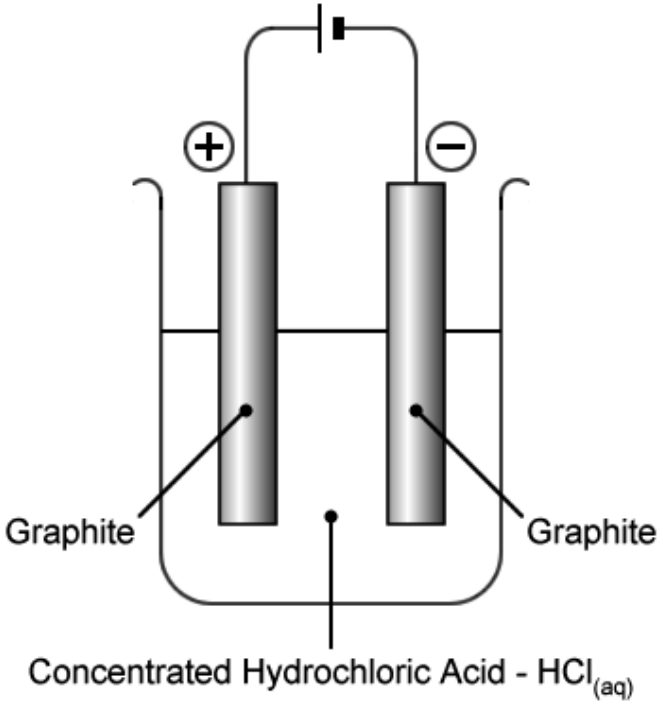
O' Level

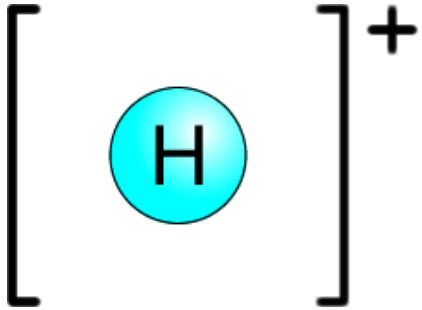
Electrochemistry

Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *concentrated hydrochloric acid* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Acids and Alkalis

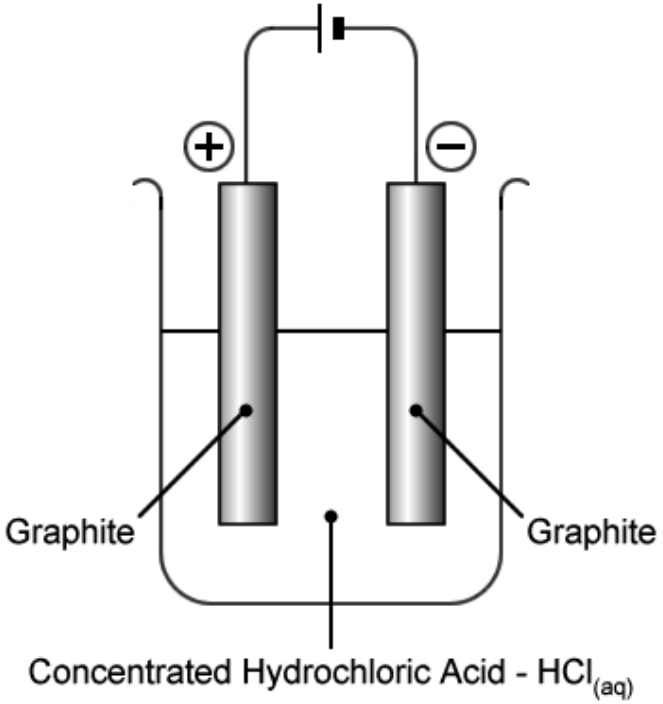
- What products are formed at **a)** the anode and **b)** the cathode when *concentrated hydrochloric acid* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

At high concentration, chloride ions are preferentially oxidised to molecular chlorine at the anode:

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$



b) At the *cathode (–ve)*:

Hydrogen ions are the only cations present in the solution.

Positively charged hydrogen ions are attracted towards the negatively charged cathode where they are reduced to molecular hydrogen:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Updated for A' Level

Electrochemistry

Electrolysis of Aqueous Electrolytes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H^+ + 2e^- \rightleftharpoons H_2 \quad E^{\ominus} = +0.00\ V$$

$$2H^+ + 2e^- \rightarrow H_2$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

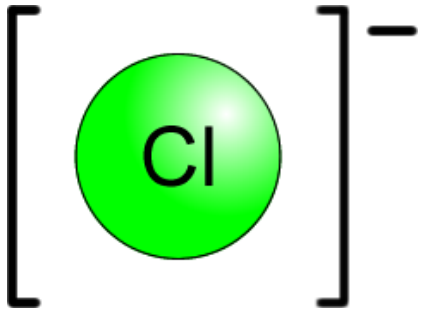
- New Integrated Programme 2025 – to align with A' Level Chemistry.

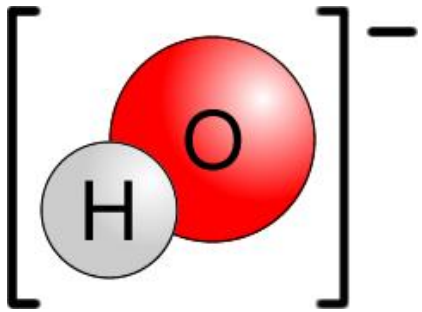
O' Level

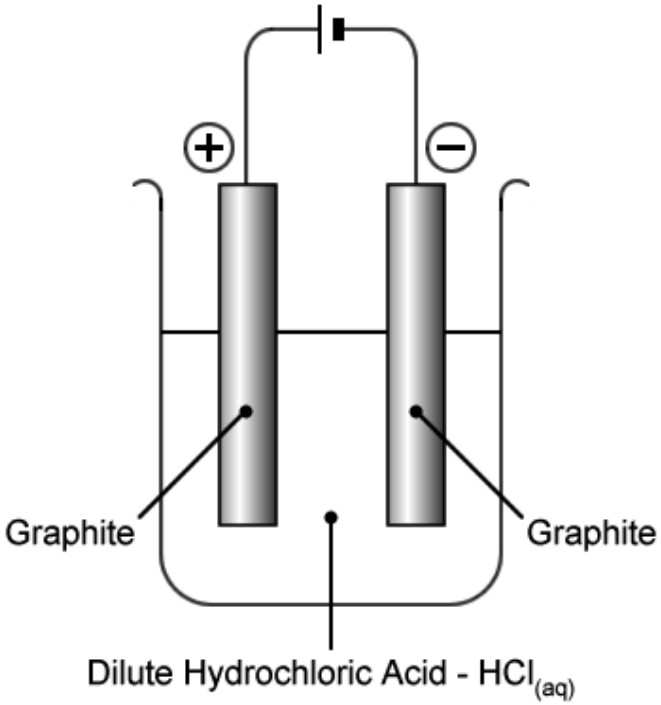
Electrochemistry

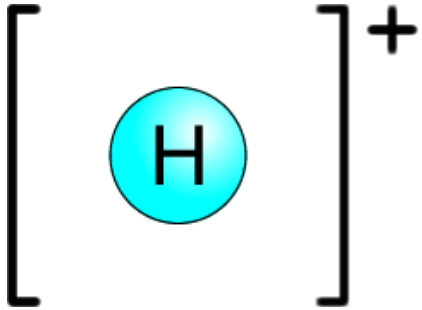
Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *dilute hydrochloric acid* is electrolysed using inert electrodes?







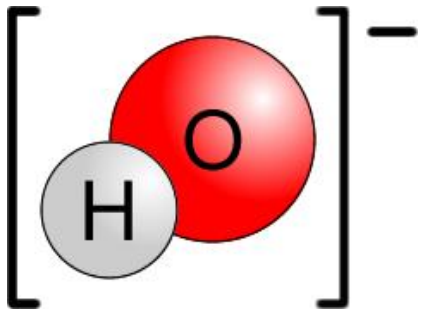


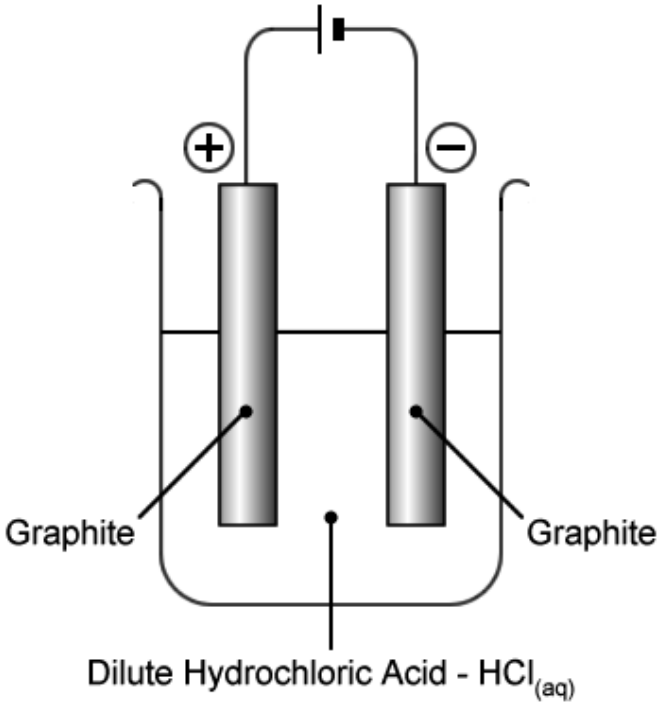
O' Level

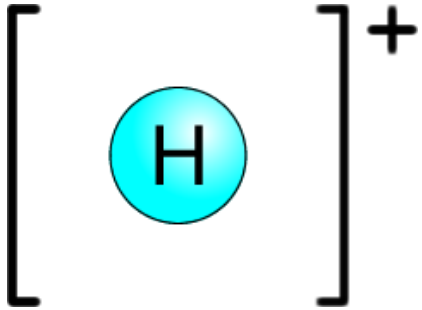
Electrochemistry

Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *dilute hydrochloric acid* is electrolysed using inert electrodes?







O' Level

Electrochemistry

Electrolysis of Acids and Alkalis

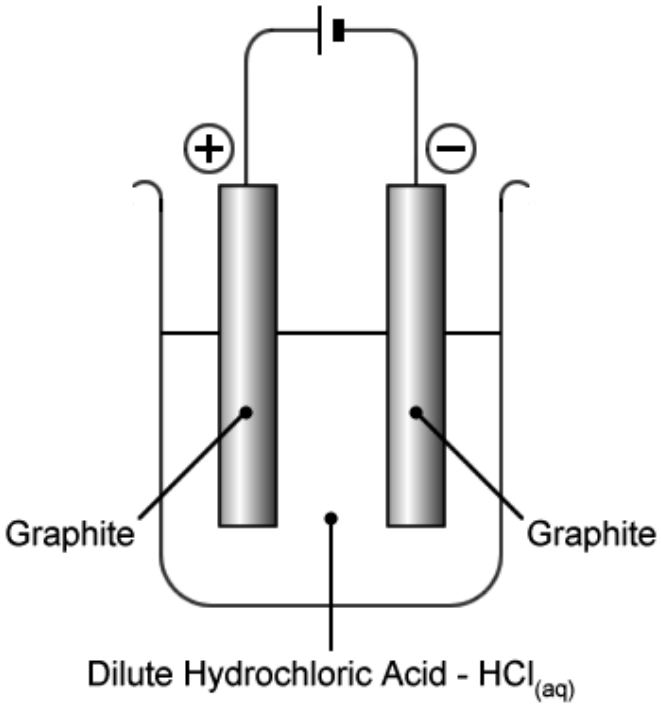
- What products are formed at **a)** the anode and **b)** the cathode when *dilute hydrochloric acid* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Negatively charged chloride ions and hydroxide ions (anions) are both attracted to the positive anode.

Because the solution is dilute, hydroxide ions are preferentially oxidised to molecular oxygen and water at the anode:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Hydrogen ions are the only cations present in the solution.

Positively charged hydrogen ions are attracted towards the negatively charged cathode where they are reduced to molecular hydrogen:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H^+ + 2e^- \rightleftharpoons H_2 \quad E^{\ominus} = +0.00\ V$$

$$2H^+ + 2e^- \rightarrow H_2$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$Cl_2 + 2e^- \rightleftharpoons 2Cl^- \quad E^{\ominus} = +1.36\ V$$

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

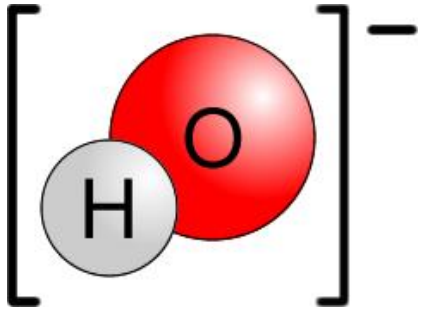
- New Integrated Programme 2025 – to align with A' Level Chemistry.

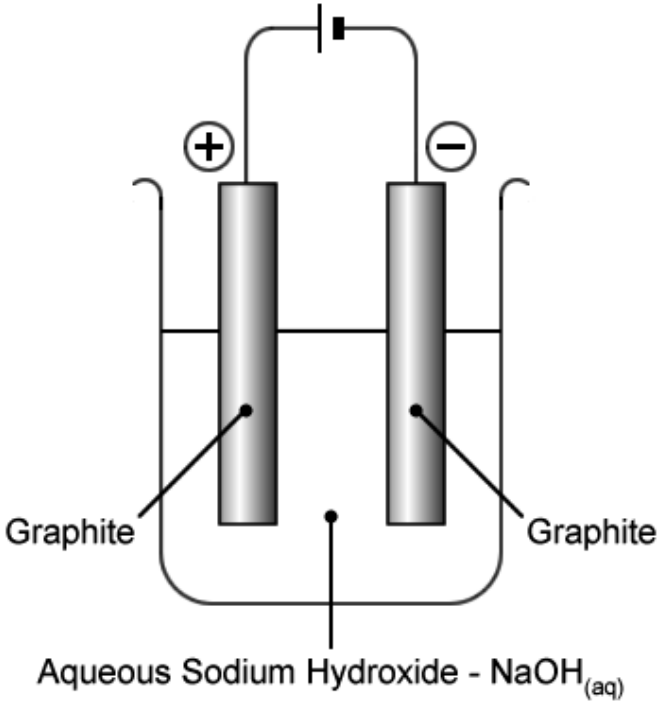
O' Level

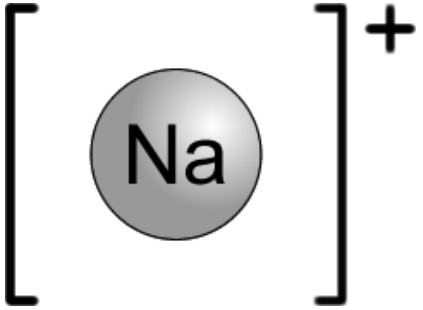
Electrochemistry

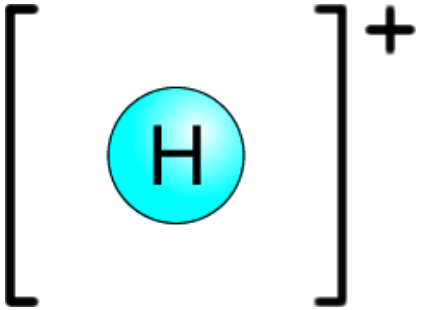
Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous sodium hydroxide* is electrolysed using inert electrodes?







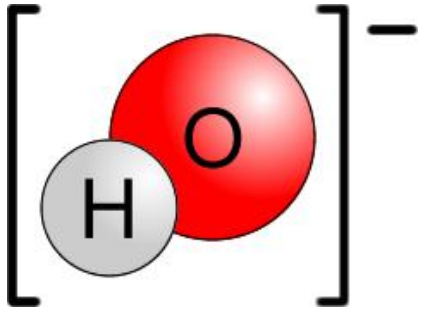


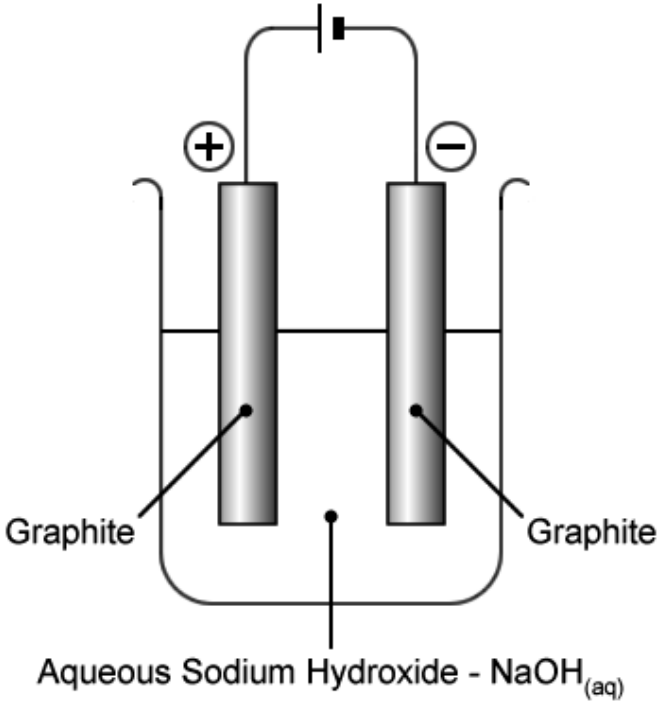
O' Level

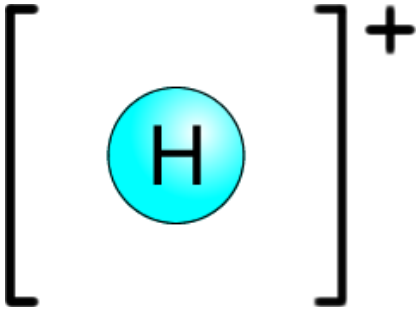
Electrochemistry

Electrolysis of Acids and Alkalis

- What products are formed at **a)** the anode and **b)** the cathode when *aqueous sodium hydroxide* is electrolysed using inert electrodes?







NANYANG GIRLS' HIGH

O' Level

Electrochemistry

Electrolysis of Acids and Alkalis

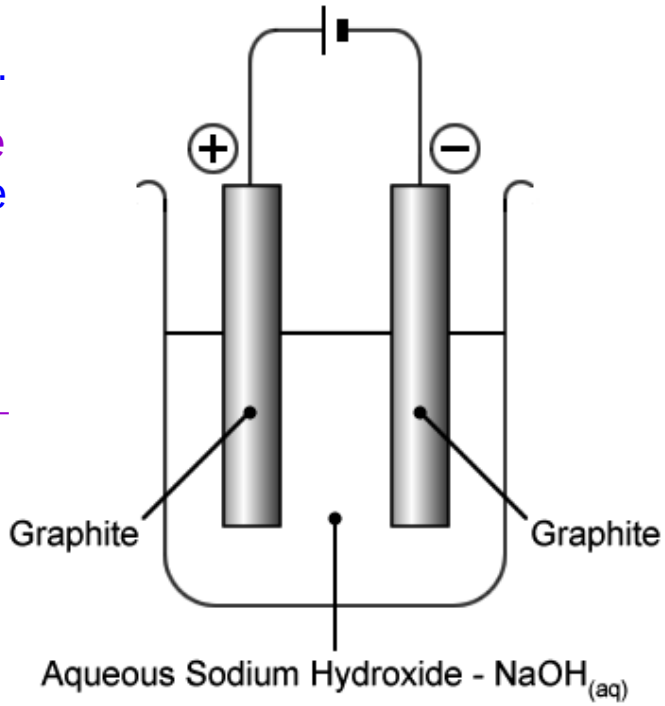
- What products are formed at **a)** the anode and **b)** the cathode when *aqueous sodium hydroxide* is electrolysed using inert electrodes?

a) At the *anode (+ve)*:

Hydroxide ions are the only anions present in the solution.

Negatively charged hydroxide ions are attracted towards the positively charged anode where they are oxidised to molecular oxygen and water:

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$



b) At the *cathode (–ve)*:

Positively charged sodium ions and hydrogen ions (cations) are both attracted to the negative cathode.

Sodium is above hydrogen in the electrochemical series, therefore hydrogen ions are preferentially reduced to molecular hydrogen at the cathode:

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Electrochemistry

Electrolysis of Aqueous Electrolytes

Updated for A' Level

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$$Na^+ + e^- \rightleftharpoons Na \quad E^{\ominus} = -2.71\ V$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad E^{\ominus} = -0.83\ V$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$$

$$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^- \quad E^{\ominus} = +0.40\ V$$

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$$

- New Integrated Programme 2025 – to align with A' Level Chemistry.

Electrochemistry

Electrolysis using Active Electrodes

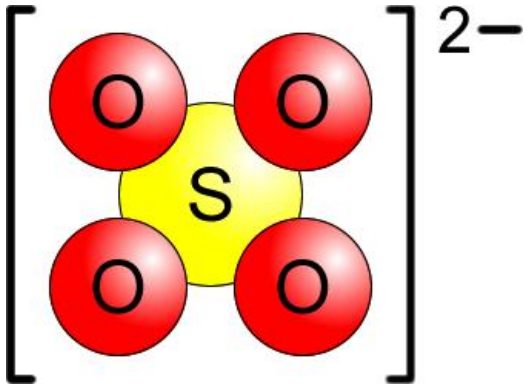
What happens during the electrolysis of aqueous copper(II) sulfate using copper electrodes?

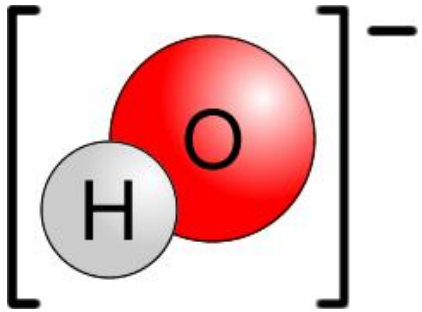
- *Anodes* made of *metal* may be *oxidised* during electrolysis.

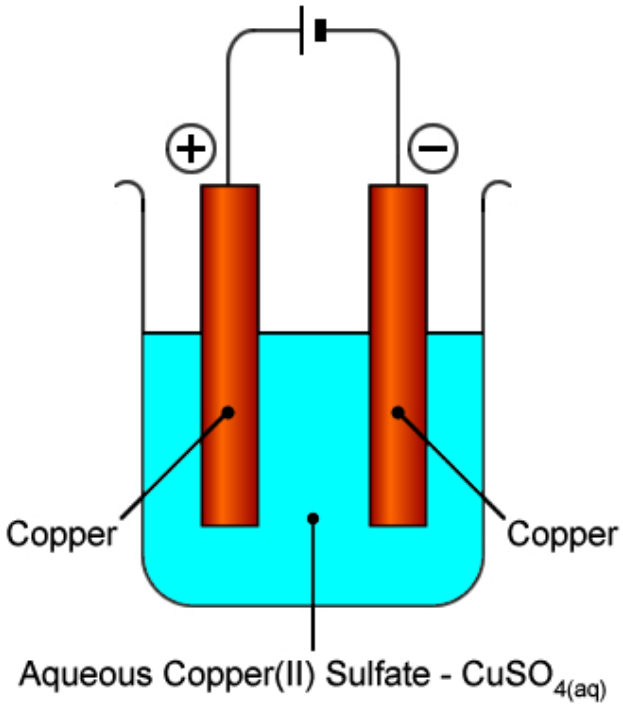
Electrochemistry

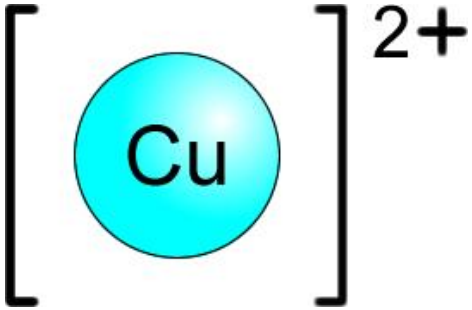
Electrolysis using Active Electrodes

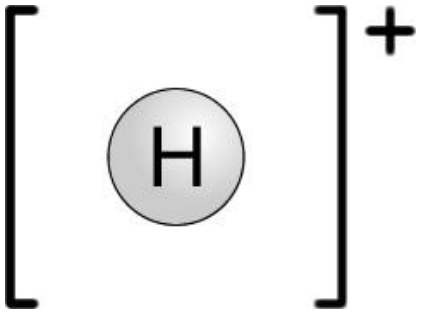
- What products are formed at **a)** the anode and **b)** the cathode when *aqueous copper(II) sulfate* is electrolysed using *copper* electrodes?











Electrochemistry

Electrolysis using Active Electrodes

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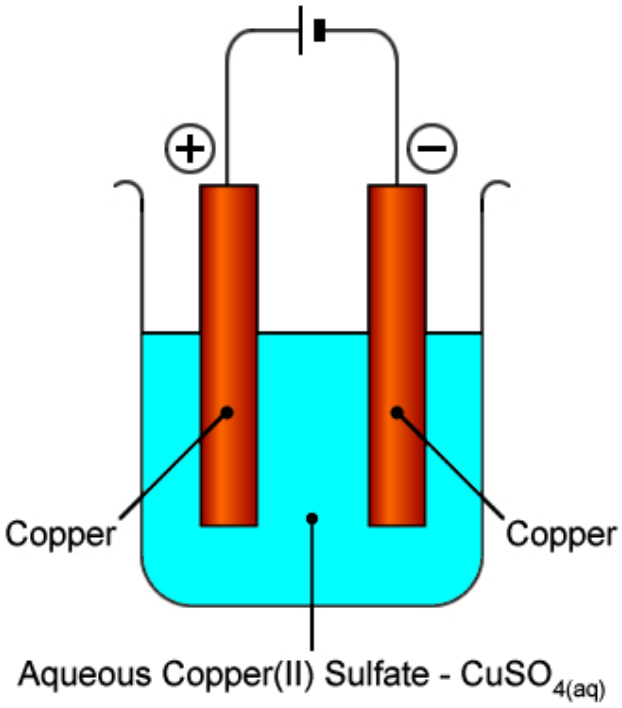
a) At the *anode (+ve)*:

If the anode is made of a metal whose cations also exist in the electrolyte, then the anode is described as being active, *i.e.* it will participate in the electrolysis and undergo oxidation.
In this example, the copper atoms of the anode will be oxidised to form copper(II) ions:

$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$



b) At the *cathode (–ve)*:

Positively charged copper(II) ions and hydrogen ions (cations) are both attracted to the negative cathode.

Copper is below hydrogen in the electrochemical series, therefore copper(II) ions are preferentially reduced to copper atoms at the cathode:

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

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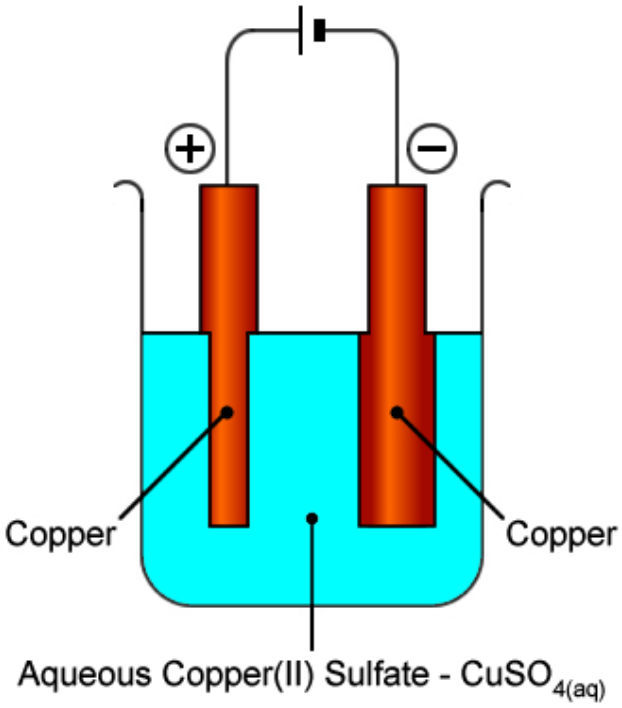

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Updated for A' Level

Electrochemistry

Electrolysis using Active Electrodes

At the Cathode:

More positive / less negative $E^{\ominus}$ is preferentially reduced.

$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$ $\quad E^{\ominus} = -0.83$ V

$Cu^{2+} + 2e^- \rightleftharpoons Cu$ $\quad E^{\ominus} = +0.34$ V

$Cu^{2+} + 2e^- \rightarrow Cu$

At the Anode

More negative / less positive $E^{\ominus}$ is preferentially oxidised.

More concentrated is preferentially oxidised.

$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$ $\quad E^{\ominus} = +2.01$ V

$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$ $\quad E^{\ominus} = +1.23$ V

$Cu^{2+} + 2e^- \rightleftharpoons Cu$ $\quad E^{\ominus} = +0.34$ V

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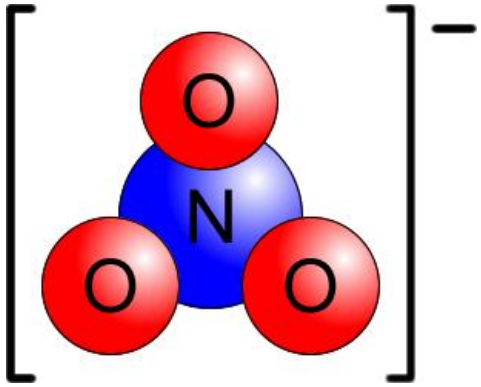
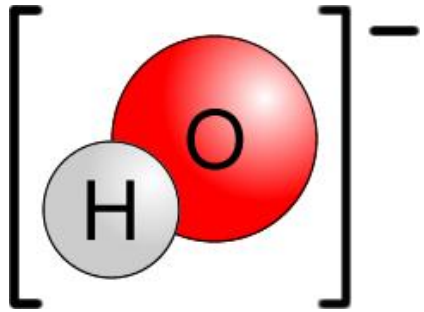
- New Integrated Programme 2025 – to align with A' Level Chemistry.

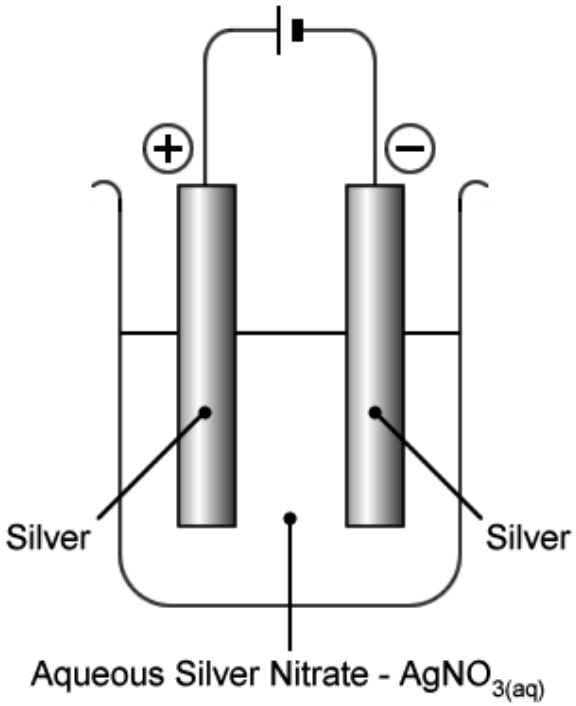
Electrochemistry

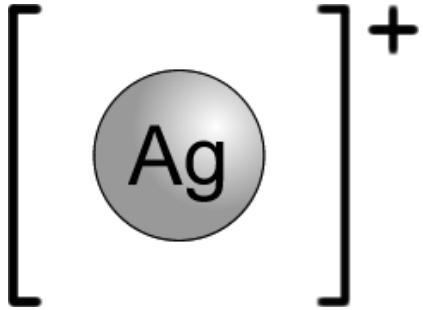
Electrolysis using Active Electrodes

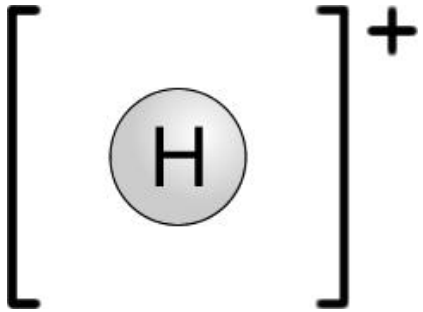
- What products are formed at **a)** the anode and **b)** the cathode when *aqueous silver nitrate* is electrolysed using *silver* electrodes?











Electrochemistry

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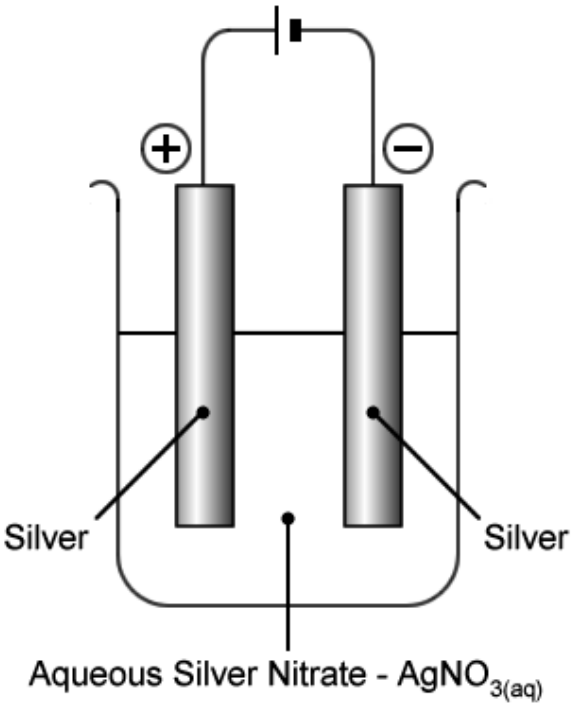

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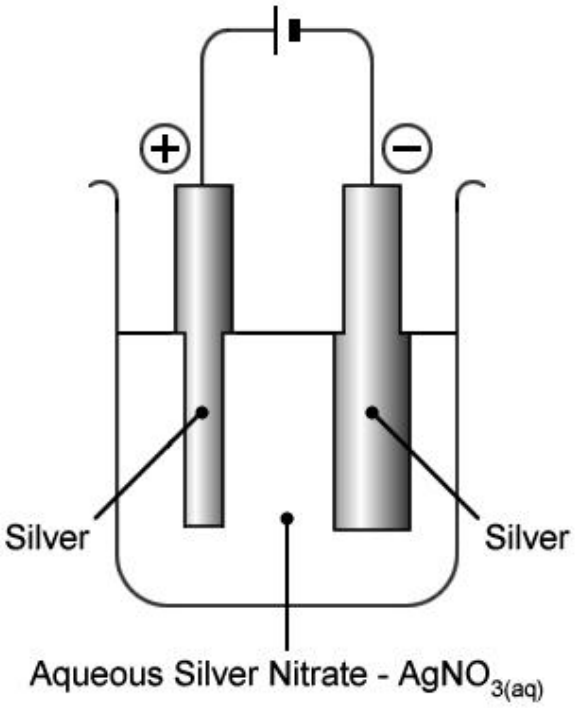

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Electrochemistry

Mole Calculations in Electrochemistry

Are there any mole calculations that I can do for electrochemistry?

Electrochemistry

Mole Calculations in Electrochemistry

- The number of moles of electrons that flow through a circuit is given by Faraday's equation of electrolysis:

$$\text{moles of electrons} = \frac{\text{current (A)} \times \text{time (s)}}{96\,500}$$

Where…

current = the electrical current that flows through the circuit measured in amperes (amps, A).

time = the time that the electrical current flows for measured in seconds (s).

96 500 = Faraday's Constant measured in coulombs per mole (C mol^{-1}).

Electrochemistry

Mole Calculations in Electrochemistry

- Calculate the mass of pure copper deposited at the cathode during the electrolysis of aqueous coper(II) sulfate if a current of 3.00 A flows for 482.5 minutes.

Electrochemistry

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a) Convert time into seconds:

482.5 minutes = 482.5 $\times$ 60 = 28950 s

Electrochemistry

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a) Convert time into seconds:

482.5 minutes = 482.5 × 60 = 28950 s

b) Calculate moles of electrons that flowed through the circuit in this time:

moles of electrons = (3.00 × 28950) ÷ 96 500 = 0.900 mol

Electrochemistry

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Electrochemistry

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- Calculate the mass of pure copper deposited at the cathode during the electrolysis of aqueous coper(II) sulfate if a current of 3.00 A flows for 482.5 minutes.

c) Calculate moles of pure copper deposited:

Electrochemistry

Mole Calculations in Electrochemistry

- Calculate the mass of pure copper deposited at the cathode during the electrolysis of aqueous coper(II) sulfate if a current of 3.00 A flows for 482.5 minutes.

c) Calculate moles of pure copper deposited:

from the ionic half-equation for reduction of Cu^{2+} at the cathode,

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

2 mol of electrons deposit 1 mol of Cu(s)

$\therefore$ 0.900 mol of electrons deposit $^1/_2 \times 0.900 =$ 0.450 mol of Cu(s)

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d) Calculate mass of pure copper deposited:

mass in grams = mol $\times$ A_r = $0.450 \times 63.5 =$ 28.575 g

= 28.6 g to 3 s.f.

Electrochemistry

Mole Calculations in Electrochemistry

- The electrolysis of molten sodium chloride produces sodium and chlorine. Calculate the time in seconds taken for a current of 50.0 A to produce 120 dm^3 of chlorine gas.

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b) Calculate moles of electrons produced when this many moles of chlorine gas are produced:

from the ionic half-equation for oxidation of Cl^- at the anode,

$$2Cl(l) \rightarrow Cl_2(g) + 2e^-$$

$\therefore$ the production of 1 mol of $Cl(g)$ produces 2 mol of electrons

$\therefore$ the production of 5.00 mol of $Cl_2(g)$ produces 2×5.00 = 10.0 mol of electrons

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moles of electrons = (current in A $\times$ time in s) $\div$ 96 500

…to make *time* the subject of the equation.

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time in s = (10.0 × 96 500) ÷ 50.0 = 19 300 s

Electrochemistry

Presentation on

The Electrolysis of Aqueous Salts, Acids and Alkalis

by Dr. Chris Slatter

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Nanyang Girls' High School

2 Linden Drive

Singapore

288683

8th February 2016

Updated 19th March 2025