

4.1 Reactivity of metals

Name: _____ Class: _____ Date: _____

Total: 29 marks

KEY WORDS reactivity series • displacement • reduction

Objective

Order metals by reactivity, predict displacement, choose extraction methods and (HT) use electron-transfer redox. Original questions for spec statements 4.4.1.1–4.4.1.4.

1 Key knowledge and worked examples

Reactivity series: K, Na, Li, Ca, Mg, (C), Zn, Fe, (H), Cu. Carbon and hydrogen are non-metal reference points; the comparison here is at room temperature. Reactivity = **tendency to form positive ions**.

- water: K/Na/Li/Ca react; Mg very slow; Zn, Fe, Cu none;
- dilute acid: Mg, Zn, Fe $\rightarrow$ salt + H₂; Cu none;
- **displacement:** a more reactive metal displaces a less reactive one – $\text{Zn} + \text{CuSO}_4 \rightarrow \text{ZnSO}_4 + \text{Cu}$.

Extraction: gold occurs native; metals **below carbon** $\rightarrow$ **carbon reduction** (Zn, Fe, Cu oxides + C); metals **above carbon** (Al, Mg) $\rightarrow$ **electrolysis**. **Reduction = loss of oxygen; oxidation = gain of oxygen**.

(HT): **OIL RIG** – oxidation is loss (of electrons), reduction is gain. Ionic equation: $\text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu}$ (zinc oxidised, copper reduced).

more reactive ↑	potassium	cold water: hydroxide + hydrogen
	sodium	cold water: hydroxide + hydrogen
	lithium	cold water: hydroxide + hydrogen
	calcium	cold water: hydroxide + hydrogen
	magnesium	cold water: extremely slow
	CARBON	reference for oxide reduction
	zinc	dilute HCl / H ₂ SO ₄ : salt + hydrogen
	iron	dilute HCl / H ₂ SO ₄ : salt + hydrogen
	HYDROGEN	reference for acid / cathode products
	copper	no reaction with cold water or dilute HCl

Carbon and hydrogen are non-metals. Compare metals under matching conditions.

Worked example (3 marks, HT). Zinc is added to copper(II) sulfate solution. Write the ionic equation and identify what is oxidised.

$\text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu}$; zinc loses two electrons – oxidised; copper ions gain them – reduced.

2 Practice

2.1 Place in reactivity order: calcium, copper, magnesium, sodium. [1]

2.2 Which of Mg, Zn, Fe and Cu does not react with dilute hydrochloric acid? [1]

2.3 Why is aluminium extracted by electrolysis rather than carbon reduction? [1]

2.4 At room temperature, describe the water reactions of K, Na, Li and Ca, including the types of products. Contrast Mg with Zn, Fe and Cu in cold water. Give two conditions to keep the same when comparing suitable samples. [6]

3 Exam-style questions

3.1 Iron displaces copper from copper sulfate solution but cannot displace magnesium from magnesium sulfate. Deduce the reactivity order of the three metals and explain in terms of ions. [4]

3.2 Explain, in terms of oxygen, which reactant is reduced and which is oxidised in: $2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2$. [3]

3.3 (*HT*) For $\text{Mg} + \text{Fe}^{2+} \rightarrow \text{Mg}^{2+} + \text{Fe}$, write the two half-equations and state which species is reduced. [4]

3.4 Clean, equally sized samples of metals X, Y and Z are placed separately in solutions of their salts. X displaces Y; Z displaces X. Order the three metals and explain the evidence. X also displaces copper but does not displace magnesium. What can you conclude about X? [5]

3.5 A metal M is found above carbon in the reactivity series. Its oxide cannot be reduced by heating with carbon. Another metal N is below carbon. A proposed process uses carbon to remove oxygen from N's oxide, but produces carbon dioxide. Explain the chemical choice for each metal and evaluate one environmental disadvantage of the proposed process. Do not describe a named industrial furnace. [4]

Solutions

2.1 Sodium > calcium > magnesium > copper.

2.2 Copper.

2.3 Aluminium is more reactive than carbon, so carbon cannot reduce its oxide.

2.4 K, Na, Li and Ca react with cold water to form the metal hydroxide and hydrogen. Magnesium reacts extremely slowly; Zn, Fe and Cu show no observable cold-water reaction under the stated comparison. Control any two appropriate conditions: water temperature/volume, exposed metal surface or sample condition, and observation time. Highly reactive metals use an approved teacher demonstration rather than an independent student acid comparison.

3.1 Iron > copper, because iron displaces copper – iron atoms form ions more readily; magnesium > iron, because iron cannot displace magnesium; order: $\text{Mg} > \text{Fe} > \text{Cu}$; reactivity is the tendency to lose electrons and form positive ions.

3.2 Iron oxide loses oxygen to become iron – iron is reduced; carbon gains oxygen to become carbon dioxide – carbon is oxidised; overall, carbon reduces iron oxide to iron.

3.3 $\text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-$; $\text{Fe}^{2+} + 2\text{e}^- \rightarrow \text{Fe}$; the iron(II) ion gains electrons, so Fe^{2+} is reduced; magnesium is oxidised.

3.4 $\text{X} > \text{Y}$; $\text{Z} > \text{X}$; hence $\text{Z} > \text{X} > \text{Y}$. Magnesium > X > copper; the successful displacement means X forms positive ions more readily than copper, but less readily than magnesium. These results do not give X's exact identity.

3.5 Carbon cannot reduce M's oxide because M is more reactive than carbon; use another method such as electrolysis of a suitable molten compound. Carbon can remove oxygen from the oxide of the less reactive N. Producing carbon dioxide contributes to greenhouse-gas emissions; evaluate the supplied process, rather than claiming extraction has no environmental cost.