Developing Metals (DM)

Revision guide

Clarity, confidence, and top grades.

What this storyline covers

- Redox and half-equations
- Manganate(VII) titrations
- Electrochemical cells
- Standard electrode potentials
- Transition metals and the d-block
- Complexes, ligands and colour
- Reactions of iron and copper ions
- Catalysis and colorimetry

Required practicals in this storyline: manganate(VII) titrations, electrochemical cells (**PAG8**) and colorimetry (**PAG9**), plus test-tube reactions of transition-metal ions.



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i How to use this guide

Developing Metals brings together two big A2 themes: **redox and electrochemistry** (cells, electrode potentials, feasibility) and the **chemistry of the transition metals** (complexes, colour, catalysis). The redox work builds on Elements from the Sea, and the electron-configuration ideas on Elements of Life. There is a lot of precise colour chemistry to learn here, so use the tables and test yourself on them.

How it is assessed

OCR B is context-led, so DM content can appear in **any** of the three written papers, in any context:

- **Paper 1** — Fundamentals of chemistry (110 marks)
- **Paper 2** — Scientific literacy, including the pre-release Advance Notice article (100 marks)
- **Paper 3** — Practical skills in chemistry (60 marks)

How to revise it

- Learn the **definitions in the teal boxes** word-for-word — they are marks you can guarantee.
- Work every **worked example** yourself before reading the solution.
- Memorise the **colour changes** and complex formulae exactly — they are common, easy marks.
- Use the **spec checklist** on the last page to confirm you can do every point.

1 Redox and half-equations

Spec reference: DM(c). Builds on ES(f).

Recap — redox

Oxidation is loss of electrons (oxidation state rises); **reduction** is gain of electrons (oxidation state falls). An **oxidising agent** is itself reduced; a **reducing agent** is itself oxidised.

Balancing redox equations in acid DM(c)

- Balance the atoms being oxidised or reduced, then balance **O with H_2O**, **H with H^+**, and finally **charge with electrons**.
- Add the two half-equations together so that the electrons cancel.

Worked example — manganate(VII) and iron(II)

reduction: $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

oxidation: $Fe^{2+} \rightarrow Fe^{3+} + e^-$ (× 5 to cancel the electrons)

overall: $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

2 Manganate(VII) titrations

Spec reference: DM(a).

- **Manganate(VII)** (MnO_4^-, purple) is a strong oxidising agent used in redox titrations, carried out in **dilute sulfuric acid**.
- It is **self-indicating**: the end point is the **first permanent pale pink**, when a drop of excess manganate(VII) is no longer decolourised.

Worked example — finding $[Fe^{2+}]$

25.0 cm^3 of an iron(II) solution needed 24.0 cm^3 of 0.0200 mol dm^{-3} $KMnO_4$. The ratio is 1 MnO_4^- : 5 Fe^{2+}.

moles $MnO_4^- = 0.0200 \times 24.0/1000 = 4.80 \times 10^{-4}$ mol

moles $Fe^{2+} = 5 \times 4.80 \times 10^{-4} = 2.40 \times 10^{-3}$ mol

$[Fe^{2+}] = 2.40 \times 10^{-3} \div (25.0/1000) = 0.0960$ mol dm^{-3}

3 Electrochemical cells

Spec references: DM(d), DM(e). Practical: PAG8.

- A cell joins two **half-cells** by an external **wire** (electrons flow) and a **salt bridge** (ions flow to complete the circuit and balance charge).
- **Metal ion / metal half-cell:** a metal dipping into a solution of its ions, e.g. Cu in Cu^{2+}(aq).
- **Ion / ion half-cell:** two oxidation states of the same element in solution, e.g. Fe^{2+}/Fe^{3+}, with an inert **platinum** electrode (acidified if needed).

How the cell works (DM(e))

- **Oxidation** happens at the **more negative** electrode, releasing electrons that flow out through the wire.
- **Reduction** happens at the **more positive** electrode, which gains those electrons.
- Electrons flow through the **external wire** from negative to positive; ions flow through the **salt bridge**.

4 Standard electrode potentials

Spec reference: DM(f).

Key definition

The **standard electrode potential ($E^{\ominus}$)** of a half-cell is its potential measured relative to the **standard hydrogen electrode** under standard conditions (298 K, 100 kPa, all solutions 1.00 mol dm^{-3}). The hydrogen electrode is defined as **0.00 V**: $2H^+ + 2e^- \rightleftharpoons H_2$.

Calculating $E^{\ominus}_{cell}$ DM(f)

Worked example — a zinc–copper cell

$E^{\ominus}(Cu^{2+}/Cu) = +0.34$ V and $E^{\ominus}(Zn^{2+}/Zn) = -0.76$ V.

$E^{\ominus}_{cell} = E^{\ominus}(positive) - E^{\ominus}(negative) = +0.34 - (-0.76) = +1.10$ V

Zinc (more negative) is oxidised; copper(II) is reduced.

Feasibility and rusting DM(f)

- A reaction is **feasible** when **$E^{\ominus}_{cell}$ is positive**. The species with the more positive $E^{\ominus}$ oxidises the one with the more negative $E^{\ominus}$.
- A feasible reaction may still **not occur** because the **rate is too slow** (high activation enthalpy), or because the conditions are **not standard**, changing the actual potentials.
- **Rusting** is electrochemical: iron is oxidised ($Fe \rightarrow Fe^{2+} + 2e^-$) and oxygen reduced ($O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$); it needs **water and oxygen**. Prevent it with a **barrier** (paint, oil) or **sacrificial protection** (a more reactive metal such as zinc, as in galvanising, corrodes instead).

5 Transition metals and the d-block

Spec references: DM(g), DM(h). Builds on EL(f).

Key definition

A **transition metal** is a d-block element that forms one or more **stable ions with an incompletely filled d-subshell**. (Scandium and zinc are d-block but not transition metals, as Sc^{3+} has an empty d-subshell and Zn^{2+} a full one.)

Electron configurations DM(h)

- Fill **4s before 3d**, but note the stable-arrangement exceptions **Cr ($[Ar]3d^5 4s^1$)** and **Cu ($[Ar]3d^{10}4s^1$)**.
- When forming ions, **remove the 4s electrons first**: Fe $[Ar]3d^6 4s^2 \rightarrow Fe^{2+}$ $[Ar]3d^6 \rightarrow Fe^{3+}$ $[Ar]3d^5$; Cu $[Ar]3d^{10}4s^1 \rightarrow Cu^{2+}$ $[Ar]3d^9$.
- **Variable oxidation states** arise because the 3d and 4s energies are similar, so different numbers of electrons can be lost.

Metal	Common oxidation states	Colour in water
Iron	Fe^{2+}, Fe^{3+}	Fe^{2+} pale green; Fe^{3+} pale yellow / brown
Copper	Cu^+, Cu^{2+}	Cu^{2+} blue (Cu^+ usually colourless)

6 Complexes, ligands and shapes

Spec references: DM(b), DM(i), DM(j).

Key definitions

- A **ligand** is a species with a **lone pair** that forms a **coordinate (dative) bond** to a central metal ion (both electrons come from the ligand).
- A **complex** is a central metal ion surrounded by ligands. The **coordination number** is the number of dative bonds to the central ion.
- **Ligand substitution** is the replacement of one ligand by another.
- A **bidentate** ligand forms **two** dative bonds (e.g. ethanedioate, $C_2O_4^{2-}$); a **polydentate** ligand forms several.

Shapes DM(b)

- **Coordination number 6** → **octahedral** (90°), e.g. $[Fe(H_2O)_6]^{2+}$.
- **Coordination number 4** → **tetrahedral** (109.5°), e.g. $[CuCl_4]^{2-}$, or **square planar** (90°), as in cis-platin.

Ligand substitution DM(i), DM(j)

Complexes to know: $[Fe(H_2O)_6]^{2+}$, $[Fe(H_2O)_6]^{3+}$, $[Cu(H_2O)_6]^{2+}$, $[Cu(NH_3)_4]^{2+}$ and $[CuCl_4]^{2-}$. A substitution swaps the ligands, for example:

Worked example — copper and chloride

$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CuCl_4]^{2-} + 6H_2O$

The pale blue octahedral aqua complex becomes the yellow tetrahedral chloride complex.

7 Reactions and colours of iron and copper

Spec reference: DM(k).

Adding sodium hydroxide or ammonia precipitates the metal hydroxide. Learn these colours and ionic equations precisely.

Ion	With sodium hydroxide	With ammonia
Fe^{2+}(aq) pale green	green precipitate, $Fe(OH)_2$ $Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$	same green precipitate (no complex forms)
Fe^{3+}(aq) yellow / brown	orange-brown precipitate, $Fe(OH)_3$ $Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$	same orange-brown precipitate (no complex forms)
Cu^{2+}(aq) blue	blue precipitate, $Cu(OH)_2$ $Cu^{2+} + 2OH^- \rightarrow Cu(OH)_2$	blue precipitate, then dissolves in excess to a **deep blue** solution

8 Catalysis, colour and colorimetry

Spec references: DM(l), DM(m), DM(n). Practical: PAG9.

Catalysis DM(l)

- **Homogeneous catalysis:** the catalyst is in the same phase and works by changing **oxidation state** during the reaction, then returning to its original state.
- **Heterogeneous catalysis:** the reaction happens on the metal **surface**; transition metals use their **3d and 4s electrons** to form weak bonds to reactant molecules, holding them close so they react.

The origin of colour DM(m)

- In a complex, the ligands **split the d-orbitals** into two energy levels.
- An electron absorbs **visible light** to jump from the lower to the higher d-orbitals; the colour seen is the light that is **not absorbed**. (The detail of how the orbitals split is not required.)

Colorimetry DM(n)

- A **colorimeter** (or visible spectrophotometer) measures the **absorbance** of a coloured solution.
- Absorbance increases with concentration, so measuring known standards gives a **calibration graph** from which an unknown concentration can be read.

P Required practicals in this storyline

These PAG activities are most likely to be examined in Paper 3, but the techniques can appear in any paper.

Activity	What to be able to do
Manganate(VII) titration	titrate iron(II) against standardised $KMnO_4$ in dilute sulfuric acid; use the first permanent pink end point; calculate the concentration
Electrochemical cells (PAG8)	set up metal/metal-ion and ion/ion half-cells with a salt bridge; measure cell potentials and compare with predictions
Reactions of transition-metal ions	carry out test-tube reactions of iron and copper ions with sodium hydroxide and ammonia; record the colours and ligand substitutions
Colorimetry (PAG9)	use a colorimeter to find the concentration of a coloured solution from a calibration graph

Exam tip — electrode potentials

$E^{\ominus}_{cell}$ = $E^{\ominus}$(positive) − $E^{\ominus}$(negative), and a positive value means the reaction is **feasible**. But remember a feasible reaction can still be **too slow to happen**, and non-standard conditions shift the real potentials.

Spec coverage checklist — can you do every point?

Every assessable learning outcome for Developing Metals, with where it is covered in this guide. Tick each one once you can do it confidently.

DM(a)	Manganate(VII) and other titration calculations — §2
DM(b)	Coordination number, and the shapes of 4- and 6-coordinate complexes — §6
DM(c)	Balancing redox half-equations and full equations in acid — §1
DM(d)	Simple electrochemical cells (metal/metal-ion and ion/ion) — §3
DM(e)	The action of a cell: half-equations, electron flow and the salt bridge — §3
DM(f)	Standard electrode potentials; $E^{\ominus}_{cell}$, feasibility and rusting — §4
DM(g)	Transition metals as d-block ions with incomplete d-subshells; oxidation states and colours — §5
DM(h)	Electron configurations of d-block ions; variable oxidation states — §5
DM(i)	The terms ligand, complex and ligand substitution — §6
DM(j)	Dative bonding in complexes; bidentate and polydentate ligands; substitution equations — §6
DM(k)	Colour changes and ionic equations for Fe^{2+}, Fe^{3+} and Cu^{2+} with NaOH and ammonia — §7
DM(l)	Catalytic activity of transition metals (homogeneous and heterogeneous) — §8
DM(m)	The origin of colour in transition-metal complexes — §8
DM(n)	Measuring concentration with a colorimeter — §8