Colour by Design (CD)

Revision guide

Clarity, confidence, and top grades.

What this storyline covers

- The origins of colour and dye structure
- Benzene and the arenes
- Electrophilic substitution
- Diazonium compounds and azo dyes
- Carbonyl compounds and their reactions
- Fats and oils
- Organic synthesis and mechanisms
- Gas–liquid chromatography

Required practicals in this storyline: carbonyl tests and identifying functional groups (**PAG7**), reactions of aromatic compounds, and dye making and dyeing.



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i How to use this guide

Colour by Design is the final storyline and the most synoptic. It centres on **aromatic (benzene) chemistry** and the **chemistry of colour**, and it pulls together the organic reactions from across the whole course into **synthesis and mechanism** questions. Expect it to draw on What's in a Medicine?, Polymers and Life and The Ozone Story. The benzene nitration mechanism and the carbonyl tests are reliable sources of marks.

How it is assessed

OCR B is context-led, so CD 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.
- Practise the **nitration and cyanohydrin mechanisms** by hand, with curly arrows and partial charges.
- Learn the **carbonyl tests** and their observations exactly.
- Use the **spec checklist** on the last page to confirm you can do every point.

1 The origins of colour and dye molecules

Spec references: CD(a), CD(b), CD(m).

Key idea — why molecules are coloured

A coloured molecule absorbs **visible light**, promoting electrons between **electronic energy levels** in a delocalised system. The colour seen is the light that is **not absorbed**.

- The **chromophore** is the delocalised part of the molecule responsible for absorbing light, often a system of alternating, conjugated double bonds.
- The **greater the extent of delocalisation** in the chromophore, the **smaller the energy gap**, so the **longer the wavelength** absorbed. The same idea explains UV absorption.

The parts of a dye molecule CD(b)

- **Groups that modify the chromophore** — shift the colour.
- **Groups that affect solubility** — ionic groups such as $-SO_3^-$ or $-COOH$ make the dye water-soluble.
- **Groups that bond to fibres** — allow the dye to attach.

How dyes attach to fibres CD(a)

- By **intermolecular bonds** (instantaneous-dipole and hydrogen bonds), **ionic bonds** between charged groups, or **covalent bonds** (fibre-reactive dyes bond covalently to the fibre).

2 Benzene and the arenes

Spec references: CD(d), CD(e).

- **Arenes** are aromatic compounds containing a **benzene ring** (benzene is C_6H_6).
- One p-electron from each carbon is **delocalised** in a ring above and below the plane, giving an unusually **stable** π system.
- Because breaking this delocalisation costs energy, benzene undergoes **substitution** (keeping the ring), often slowly, **rather than addition**.

Two representations of benzene CD(e)



Kekulé delocalised

- The **Kekulé** structure shows alternating single and double bonds; the **delocalised** structure shows a circle for the ring of delocalised electrons.
- **Shape:** benzene is a **planar regular hexagon**, with all C–C bonds the **same length** and 120° bond angles.

Exam tip — evidence for delocalisation

The Kekulé structure (three C=C) predicts an enthalpy change of hydrogenation of about 3 × (−120) = −360 kJ mol^{-1}. The measured value for benzene is only about **−208 kJ mol^{-1}** — less exothermic, so benzene is **more stable** than the Kekulé model predicts. That extra stability is the evidence for delocalisation.

3 Electrophilic substitution of arenes

Spec reference: CD(g).

Benzene reacts with electrophiles by **substitution**, replacing a hydrogen on the ring.

Reaction	Reagents and conditions	Product
Halogenation	Cl_2 (or Br_2) with a halogen carrier ($AlCl_3$ or $FeCl_3$)	chlorobenzene (+ HCl)
Nitration	concentrated HNO_3, concentrated H_2SO_4 catalyst, about 50 °C	nitrobenzene (+ H_2O)
Sulfonation	concentrated (fuming) H_2SO_4	benzenesulfonic acid
Friedel–Crafts	RCl (alkylation) or RCOCl (acylation) with $AlCl_3$	alkyl- or acyl-benzene (+ HCl)

The nitration mechanism (CD(g))

- The electrophile is the **nitronium ion, NO_2^+**, made by: $HNO_3 + 2H_2SO_4 \rightarrow NO_2^+ + 2HSO_4^- + H_3O^+$.
- A curly arrow from the **ring** to the NO_2^+ forms a bond, giving an unstable positively charged **intermediate** (the delocalisation is partly broken).
- A curly arrow from the **C–H bond** back into the ring restores the delocalised ring and releases **H^+**.
- The catalyst is regenerated: $H^+ + HSO_4^- \rightarrow H_2SO_4$.

4 Diazonium compounds and azo dyes

Spec reference: CD(h).

- A **primary aromatic amine** (e.g. phenylamine) reacts with **nitrous acid** (HNO_2, made in situ from $NaNO_2$ and HCl) at a **low temperature (below 10 °C)** to form a **diazonium salt** (containing $-N{\equiv}N^+$).
- The diazonium ion then **couples** with another aromatic compound, such as a phenol, to form a brightly coloured **azo dye** containing the **azo group –N=N–**.
- The extended delocalisation across the azo group and the two rings is the **chromophore** that gives the colour. Azo dyes are stable and cover a wide range of colours.

Common pitfall

The diazonium salt must be kept **cold** (below about 10 °C); above this it decomposes, releasing nitrogen gas. Make it and use it at once.

5 Carbonyl compounds

Spec references: CD(i), CD(k). Practical: PAG7.

Carbonyl compounds contain the C=O group: **aldehydes** (−CHO, at the end of the chain) and **ketones** (C=O within the chain).

Reactions and tests CD(i)

Reagent	Aldehyde	Ketone
Acidified dichromate(VI), reflux	oxidised to a **carboxylic acid** (orange to green)	no reaction
Fehling's solution (warm)	**brick-red** precipitate	no change
Tollens' reagent (warm)	**silver mirror**	no change
Cyanide ions, HCN	both add CN across the C=O to form a **cyanohydrin** (a hydroxynitrile)	

Nucleophilic addition mechanism — carbonyl + CN^- (CD(k))

- The C=O bond is **polar** ($C^{\delta+}=O^{\delta-}$).
- A curly arrow from the **lone pair on CN^-** to the **δ+ carbon** forms a bond; at the same time the **C=O π bond breaks**, its electrons moving onto the oxygen.
- This gives a negatively charged **alkoxide** intermediate, which is then **protonated** (by H_2O or H^+) to give the −OH of the cyanohydrin.

6 Fats and oils

Spec reference: CD(c).

- Fats and oils are mainly **mixed esters** (triesters) of **propane-1,2,3-triol** (glycerol) with long-chain carboxylic (fatty) acids. 'Mixed' means the three acid chains can be different.
- The **degree of unsaturation** sets the melting point: **saturated** chains (no C=C) pack well and give solid **fats**; **unsaturated** chains (one or more C=C) cannot pack as well and give liquid **oils**. More C=C means a lower melting point.

7 Organic synthesis and mechanisms

Spec references: CD(f), CD(j), CD(l). Practical: PAG7.

Polyfunctional molecules CD(f)

- A molecule may contain **several functional groups**. Name each group, then predict the molecule's properties from the groups it contains.
- **Test** for the groups using reactions met in the course, for example: bromine water for C=C, iron(III) chloride for a phenol, Fehling's or Tollens' for an aldehyde, and sodium carbonate (fizzing) for a carboxylic acid.

Synthetic routes CD(j)

- Plan a **multi-step synthesis** by linking the reactions and conditions met across the course, working back from the target molecule. The Data Sheet gives further reactions you can use.

Classifying and explaining reactions CD(l)

- Be able to **classify** any reaction as **addition, condensation, elimination, substitution, oxidation, reduction** or **hydrolysis**.
- For an **unfamiliar mechanism**, use **curly arrows and partial charges** from the information given: an arrow starts at a lone pair or a bond and points to where the new bond forms.

8 Gas–liquid chromatography

Spec reference: CD(n).

Gas–liquid chromatography (GLC) separates a mixture of **volatile** compounds.

- The **sample is injected** into a stream of **inert carrier gas** (the mobile phase).
- The **column** contains a **high-boiling liquid** on a porous solid support (the stationary phase).
- Components travel at **different rates**, so they emerge separately and are **detected** (sometimes using mass spectrometry).
- Each compound has a characteristic **retention time** (the time to pass through the column), used to identify it; the **peak areas** give the relative amounts.

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
Carbonyl tests (PAG7)	use Fehling's solution, Tollens' reagent and acidified dichromate to identify an aldehyde and distinguish it from a ketone
Identifying functional groups (PAG7)	carry out test-tube reactions to identify or distinguish unknown organic compounds by their functional groups
Reactions of aromatic compounds	carry out and interpret reactions involving aromatic compounds
Dye making and dyeing	form a diazonium salt, couple it to make an azo dye, and use it to dye a fabric

Exam tip — distinguishing aldehydes and ketones

Only **aldehydes** give a positive result with **Fehling's** (brick-red), **Tollens'** (silver mirror) and **acidified dichromate** (orange to green). A ketone gives **no change** with all three.

Spec coverage checklist — can you do every point?

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

CD(a)	How dyes attach to fibres (intermolecular, ionic and covalent bonding) — §1
CD(b)	The structure of a dye: chromophore and modifying, solubilising and bonding groups — §1
CD(c)	Fats and oils as mixed esters of propane-1,2,3-triol; unsaturation — §6
CD(d)	Arenes, delocalisation, and why they substitute rather than add — §2
CD(e)	The two representations of benzene; shape, bonding and enthalpy of hydrogenation — §2
CD(f)	Naming, predicting and testing functional groups in a polyfunctional molecule — §7
CD(g)	Electrophilic substitution of arenes, including the nitration mechanism — §3
CD(h)	Diazonium compounds and coupling to form azo dyes — §4
CD(i)	Reactions of carbonyl compounds: oxidation, Fehling's, Tollens', cyanohydrin — §5
CD(j)	Suggesting and explaining synthetic routes — §7
CD(k)	The nucleophilic addition mechanism of a carbonyl with CN^- — §5
CD(l)	Classifying reactions and using curly arrows for unfamiliar mechanisms — §7
CD(m)	The origins of colour and UV absorption in organic molecules — §1
CD(n)	The principles of gas–liquid chromatography — §8