Unit 12 · Basic Concepts of Organic Chemistry

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Organic Chemistry (Units 12–15 together): 18 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** short: the homologous series of alcohols: mass difference of neighbors, a member's molar mass, boiling point and solubility along the series
- **MCQ (1 mark)**: 4 valence electrons bond; catenation (CH_3–CH_3); count secondary carbons; name a functional group (ester); homologs (16, 30, 44 u); octane number 75; TEL anti-knock; cracking from its products; heptane 0; Berzelius; urea first; $C_3H_6O_3$ from CH_2O and 90; knocking from poor petrol
- **Short (5 marks, in parts)**
  - why study organic compounds separately (five reasons); five differences, organic vs inorganic
  - vital force theory and its fall; how urea was first made
  - tetracovalency: σ and π bonds of CH_4, C_2H_6, C_2H_4, C_2H_2; classification with a chart
  - homologous series: first five alcohols, 14 u; why HCOOH differs; characteristics
  - structural vs contracted formula; C_6H_6, C_6H_{12}, C_3H_7OH drawn
  - reforming vs cracking; octane and cetane numbers; octane number of a 40% heptane mix
- **Long (8 marks)**: three members (HCOOH, X, CH_3CH_2COOH or HCHO, X, CH_3CH_2CHO): X, its mass and name, highest b.p., why the first differs; a knocking engine and TEL; –OH and $-NH_2$ compounds of 2–5 carbons; octane vs cetane (three alike, three different); classification chart with examples; functional groups in urea, chlorophyll, heme

Key terms

Organic chemistry: the chemistry of **hydrocarbons and their derivatives** (H replaced by other atoms or groups).

Vital force theory (Berzelius): organic compounds only made in living things by a "vital force".

Catenation: carbon atoms joining one another into chains and rings of any length.

Tetracovalency: carbon forms four covalent bonds (valency 4).

Isomerism: same molecular formula, different structures (ethanol and methoxymethane, C_2H_6O).

Alkyl group (R–): alkane less one H, C_nH_{2n+1}–; -ane → -yl (methyl, ethyl, *n*-propyl, isopropyl).

Functional group: atom or group that decides a compound's chemical properties (–OH, –CHO, –COOH…).

Homologous series: same functional group, members differing by $-CH_2-$ (14 u); each a **homolog**.

Heteroatom: a ring atom other than carbon (N, O, S).

Cracking: breaking large hydrocarbons into smaller ones by heat, with or without a catalyst.

Reforming (aromatization, platforming): C_6–C_8 alkanes → aromatic hydrocarbons over Pt.

Knocking: the compressed fuel–air mixture exploding by itself before the flame reaches it; metallic rattle.

Octane number: % by volume of **iso-octane** in an iso-octane + heptane mixture that knocks like the petrol.

Cetane number: % by volume of **cetane** in a cetane + 1-methylnaphthalene mixture that ignites like the diesel.

Organic compounds

- vital force theory fell: **Wöhler 1828** urea from ammonium cyanate; Kolbe 1845 acetic acid from its elements; Berthelot 1856 methane
- $NH_4Cl + KCNO \xrightarrow{\text{heat}} NH_4CNO + KCl$; $NH_4CNO \xrightarrow{\text{heat}} NH_2CONH_2$ (same atoms, CH_4N_2O, rearranged)
- not organic: CO, CO_2, CS_2, carbonates and hydrogencarbonates, cyanides, cyanates, carbides
- studied separately: very many compounds; own properties; carbon's catenation

	Organic	Inorganic
elements	C essential, usually H	any
bonding	covalent	ionic, covalent, coordinate
m.p., b.p.	low, volatile	high
solubility	organic solvents	often water
conduct (solution)	no	usually yes
reactions	between molecules, slow	ions, very fast
burn	yes → $CO_2 + H_2O$	generally not
isomerism	common	rare (some complexes)
catenation	chains, rings	rare

Tetracovalency and catenation

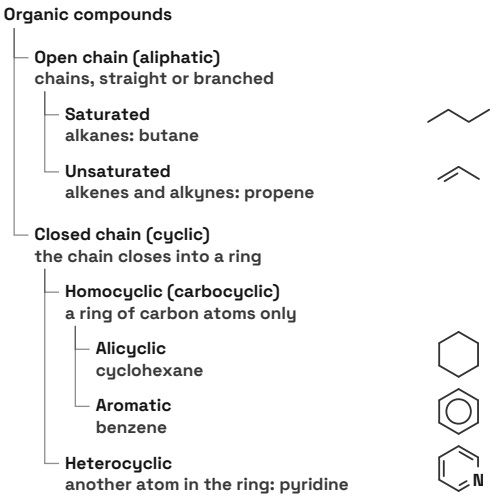
- C $1s^2\ 2s^2\ 2p^2$: two unpaired; one 2s electron promoted → **four** unpaired → four bonds (shares, never gains or loses 4)
- single bond σ; double $\sigma + \pi$; triple $\sigma + 2\pi$

Carbon has	σ	π	Example
4 single	4	0	CH_4, C_2H_6
1 double + 2 single	3	1	C_2H_4
1 triple + 1 single	2	2	C_2H_2
2 double	2	2	O=C=O

- whole molecules: C_2H_6 7σ; C_2H_4 $5\sigma + 1\pi$; C_2H_2 $3\sigma + 2\pi$

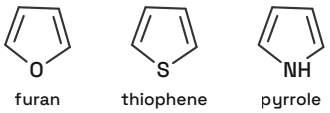
- catenation because the C–C bond is **strong** (346 kJ/mol vs Si–Si 226, N–N 160, O–O 146); C small, four bonds
- chains straight (each C joined to ≤ 2 others; zigzag in space) or branched; rings; single, double, triple bonds

Classification



Organic compounds sorted by their carbon skeleton; in the small drawings each corner and line end is a carbon.

- **open chain (aliphatic)**: straight or branched; saturated (alkanes) or unsaturated (alkenes C=C, alkynes C≡C)
- **closed chain (cyclic)**
  - **homocyclic** (carbocyclic, ring of C only): **alicyclic** (behave like aliphatic: cyclopropane, cyclohexane, cyclohexene) and **aromatic** (benzene ring, flat, π electrons shared all round: benzene, toluene, phenol, naphthalene, anthracene; sooty flame; substitution rather than addition)
  - **heterocyclic** (heteroatom in the ring): oxirane, THF (non-aromatic); pyridine, furan, thiophene, pyrrole (aromatic)



Heterocyclic: furan, thiophene and pyrrole, five-membered rings with O, S or N.

Functional groups

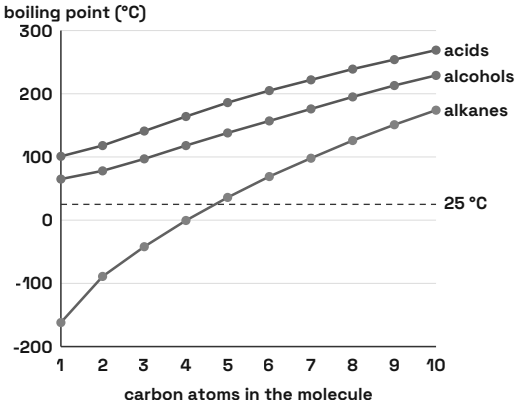
Group	Class	Example	Group	Class	Example
–X	haloalkanes	CH_3CH_2Cl chloroethane	–CO–O–CO–	anhydrides	$(CH_3CO)_2O$
–OH	alcohols	CH_3CH_2OH ethanol	–COOR′	esters	CH_3COOCH_3 methyl ethanoate
–O–	ethers	CH_3OCH_3 methoxymethane	$–NO_2$	nitro	$CH_3CH_2NO_2$ nitroethane
–CHO	aldehydes	CH_3CHO ethanal	$–NH_2$	amines	$CH_3CH_2NH_2$ ethanamine
–CO–	ketones	CH_3COCH_3 propanone	–C≡N	nitriles	CH_3CN ethanenitrile
–COOH	carboxylic acids	CH_3COOH ethanoic acid	$–SO_3H$	sulphonic acids	CH_3SO_3H
–COX	acid halides	CH_3COCl ethanoyl chloride	–N=N–	azo	$CH_3N{=}NCH_3$
$–CONH_2$	amides	CH_3CONH_2 ethanamide			

- R–G: R the **molecular body** (decides physical properties with G), G the **active site** (decides reactions)
- functional groups are the basis of classification, naming (-ol, -al, -one, -oic acid) and reactions
- urea $H_2N–CO–NH_2$: C=O + two $–NH_2$ (amide); chlorophyll: two esters (–COOR), ring ketone, C=C, four ring N holding Mg^{2+}; heme: two –COOH, vinyl C=C, four ring N holding Fe^{2+}
- –OH series: ethanol, propan-1-ol, butan-1-ol, pentan-1-ol; $–NH_2$: ethanamine, propan-1-amine, butan-1-amine, pentan-1-amine

Homologous series

1. same functional group, **similar chemical properties**
2. neighbors differ by **$–CH_2–$, 14 u**
3. one **general formula**: alkanes C_nH_{2n+2}, alkenes C_nH_{2n}, alkynes C_nH_{2n-2}, alcohols $C_nH_{2n+1}OH$, haloalkanes $C_nH_{2n+1}X$, acids $C_nH_{2n+1}COOH$
4. same general methods of preparation
5. **physical properties change gradually**: b.p. and m.p. rise with mass (larger van der Waals forces)
6. the **first member differs**: HCOOH has no alkyl group, its H–C=O also reacts like an aldehyde (reduces Tollens' reagent); HCHO has H on both sides

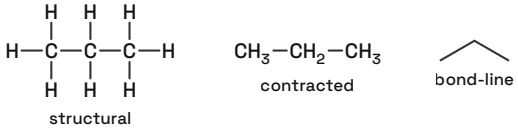
- alcohols: CH_3OH 32, C_2H_5OH 46, C_3H_7OH 60, C_4H_9OH 74, $C_5H_{11}OH$ 88 (each +14)
- along the alcohol series: b.p. **rises**, solubility in water **falls** (–OH bonds to water, the growing alkyl part doesn't): methanol to propanol mix fully, pentanol hardly
- HCOOH, **CH_3COOH** (60, ethanoic acid), CH_3CH_2COOH; fourth $CH_3CH_2CH_2COOH$ (butanoic acid); highest b.p. propanoic acid (largest)
- HCHO, **CH_3CHO** (44, ethanal), CH_3CH_2CHO; highest b.p. propanal



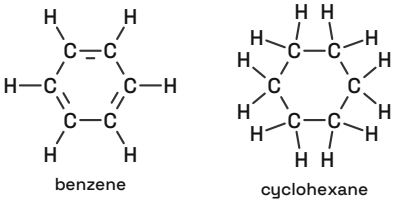
Boiling points of the first ten alkanes, alcohols and acids climb with every –CH_2–; the dashed line is 25 °C.

Formulas

- **empirical**: simplest ratio: $C_2H_4 \rightarrow CH_2$; $C_6H_{12}O_6 \rightarrow CH_2O$
- **molecular** = (empirical)$_n$, $n = \frac{\text{molecular mass}}{\text{empirical formula mass}}$: CH_2, 42 → n = 3, C_3H_6; CH_2O, 90 → $C_3H_6O_3$; 180 → $C_6H_{12}O_6$
- **structural** (graphic): every atom and bond; tells isomers apart
- **contracted** (condensed): CH_3CH_2OH, $CH_2{=}CHCH_3$, $CH_3CH(CH_3)CH_3$ (branch in brackets); multiple bonds shown
- **bond-line**: zigzag; each corner and end a C; H on C not shown; other atoms written



Propane three ways: structural, contracted and bond-line.



Structural formulas of benzene, C_6H_6, and cyclohexane, C_6H_{12}.

Petrol

Cracking (big → small; always an alkane + an alkene)

- $C_7H_{16} \longrightarrow C_5H_{12} + C_2H_4$; $C_8H_{18} \longrightarrow C_4H_{10} + C_4H_8$; hexane → $C_6H_{12} + H_2$ too
- **thermal** (pyrolysis): 450–750 °C, pressure, no catalyst → ethene, propene
- **catalytic**: about 500 °C, SiO_2–Al_2O_3 (zeolites today) → more petrol, more branched (better)

Reforming (aromatization, platforming), Pt on alumina, about **773 K** (500 °C), pressure

- $C_6H_{14} \longrightarrow C_6H_{12} + H_2$, $C_6H_{12} \longrightarrow C_6H_6 + 3\,H_2$ (hexane → benzene, 4 H_2 lost)
- $C_7H_{16} \longrightarrow C_7H_{14} + H_2$, $C_7H_{14} \longrightarrow C_7H_8 + 3\,H_2$ (heptane → toluene)

	Cracking	Reforming
molecule	broken into smaller	same carbons, closed into a ring
products	alkane + alkene	aromatics + H_2
catalyst	none or SiO_2–Al_2O_3	Pt

Knocking: more compression → more efficiency; too much → mixture explodes ahead of the flame → rattle, power lost, piston damaged; a **low-octane** petrol, not a faulty engine; fix: higher-octane petrol

- octane number: heptane **0** (straight), iso-octane (2,2,4-trimethylpentane) **100**; 40% heptane → **60**; 75 → 75% iso-octane + 25% heptane
- octane rises: straight < cyclic < branched < unsaturated < aromatic (toluene over 100); so cracking, reforming raise it
- cetane number: cetane (hexadecane, straight) **100**, 1-methylnaphthalene **0**
- **TEL** $(C_2H_5)_4Pb$: $(C_2H_5)_4Pb \longrightarrow Pb + 4\,C_2H_5^{\bullet}$; its lead oxide **mops up radicals** that set off early explosion; scavenger 1,2-dibromoethane → volatile $PbBr_2$ out with the exhaust; **banned** for road vehicles (2021, lead poisons); today: branched and aromatic hydrocarbons, ethanol, MTBE

	Octane number	Cetane number
fuel	petrol (spark)	diesel (compression)
good fuel	resists self-ignition	ignites easily
100	iso-octane, branched	cetane, straight
0	heptane, straight	1-methylnaphthalene, aromatic
raised by	branching, aromatics	straight chains

- alike: both % by volume of a reference mix; both compare a fuel in a test engine; both measure combustion quality

COMMON MISTAKES

✗ ethene's molecular formula is CH_2
✓ C_2H_4; CH_2 is its **empirical** formula.

✗ oxirane has a C=C in its ring
✓ oxirane is a **saturated** three-membered ring, C–C–O.

✗ reforming at 670 K
✓ about **773 K** (500 °C) over platinum.

✗ TEL's ethyl radicals branch the petrol's chains
✓ TEL's lead oxide **destroys radicals**, checking early ignition.

✗ inorganic compounds never show isomerism
✓ **rare** in inorganic compounds (some complexes).

✗ aldehyde group –COH
✓ **–CHO**.

✗ a five-line zigzag has 5 carbons
✓ **6** (every corner and both ends).