# Question Bank 1

# IB Chemistry HL

# 1000 Exam Questions with Solutions

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## Current Structure and Reactivity syllabus

First assessment 2025
Questions 1 to 1000 with answer key and worked solutions

This worksheet is designed for Higher Level revision. It covers the shared syllabus and HL extensions through conceptual questions, calculations, experimental evaluation and extended reasoning. Work through a unit after studying it, then use mixed sets to practise making connections.

The problems are original practice material aligned to current IB HL response styles. The six units include the shared foundations and additional HL chemistry. Suggested marks guide the depth of each response.

### How to use this worksheet

Use the current IB Chemistry data booklet and a calculator. Show substitutions, units, sensible significant figures and balanced equations in written answers. Draw structures and mechanisms where requested. Use separate paper for full working; the spaces here are for brief annotations.

The bank contains 100 related practice sets, each with ten numbered problems. Questions within each set cover different tasks; numerical methods recur with new chemical data when useful for practice. Each set has four multiple-choice questions, two data or experimental questions, three focused written questions and one extended question. Subparts within a numbered item count as one problem.

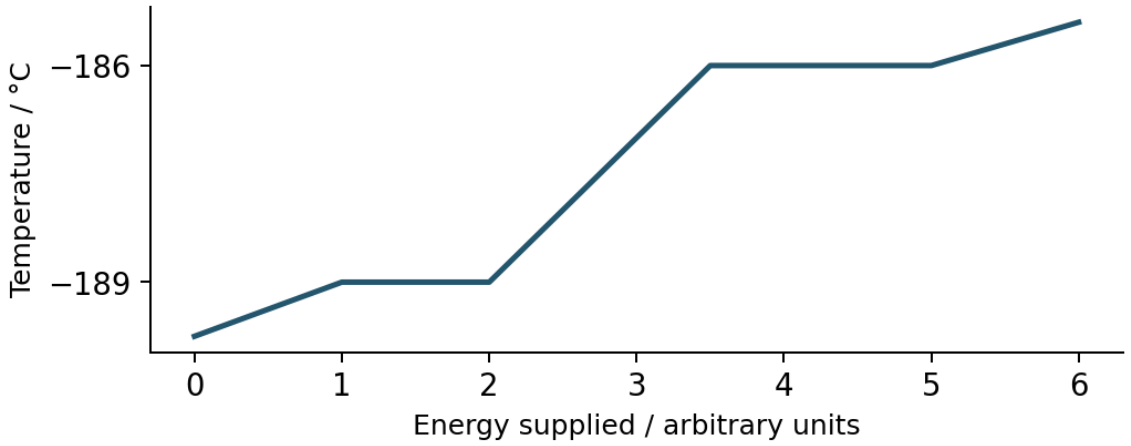
Format labels: 1A = multiple choice; 1B = data or experimental work; 2S = focused written response; 2E = extended response. The marks shown are suggested practice marks, not an official markscheme. Extended items range across linked topics; their filing unit is their main focus.

Reference conditions: use 298 K and 100 kPa when standard conditions are explicitly requested, unless a question states otherwise. Keep gas-law units consistent. For equilibrium, omit pure solids, pure liquids and the bulk solvent from variable concentration terms; include changing dissolved species. Graphs and numerical measurements use teaching data unless identified as reference values; schematic spectra are labelled.

# Structure 1.1 Set 4

## States and particle models for argon

At 100 kPa, argon melts at -189 °C and boils at -186 °C. A pure sample is heated slowly at constant pressure. A temperature probe has uncertainty ±0.2 °C. Assume no decomposition.




Idealized heating curve for argon at fixed pressure

**0031 1A [1 mark]** Which sample contains more than one element but is not a mixture?

A A copper–zinc alloy
B Pure carbon dioxide
C A nitrogen–oxygen gas sample
D Oxygen gas

**0032 1A [1 mark]** What is diffusion in a gas?

A Only gravitational settling
B Directed movement of all particles at the same speed
C Net spreading caused by random particle motion
D Conversion of molecules into atoms

**0033 1A [1 mark]** At equal temperature, how do mean translational kinetic energies of Ar and Ne compare?

A Ar is twice as large
B They are inversely proportional to molar mass
C Ne is twice as large
D They are equal

**0034 1A [1 mark]** Which observation best supports the existence of spaces between gas particles?

A A gas volume decreases greatly under pressure
B A solid has a fixed composition
C An element has a line spectrum
D A crystal has a definite shape

## Structure 1.2 Set 5 continued

Use the preceding set information where relevant; additional substances and datasets are specified in individual questions.

**0045 1B [3 marks]** For the cl dataset above, calculate the relative atomic mass from the spectrum. Report to two decimal places.

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**0046 1B [3 marks]** The abundance detector has a constant background signal added to both peaks. Explain why normalizing the peak heights may still give a biased atomic mass.

_____

**0047 2S [3 marks]** Deduce the abundance of isotope 35 from a measured mean mass of 35.48, assuming only these two isotopes. Allow rounding.

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**0048 2S [3 marks]** Predict the m/z of the doubly positive ion of isotope 37.

_____

**0049 2S [3 marks]** Distinguish relative atomic mass from the mass number of an isotope.

_____

**0050 2E [6 marks]** A hypothetical diatomic molecule $Cl_2$ is formed by random pairing of these atoms. Predict its three molecular-ion m/z values and percentage abundances; explain the central peak.

_____

_____

# Structure 1.3 Set 10

## Electron arrangements and spectra of Mg

Neutral Mg has atomic number 12, ground-state configuration [Ne] $3s^2$, and first two ionization energies 738 and 1451 kJ $mol^{-1}$. A line in an emission spectrum has wavelength 460 nm. Use h = $6.626 \times 10^{-34}$ J s and c = $2.998 \times 10^8$ m $s^{-1}$.

**0091 1A [1 mark]** Which configuration is the ground state of $Mg^{2+}$?

A $1s^2 2s^2 2p^4$
B $1s^2 2s^2 2p^6 3p^2$
C $1s^2 2s^2 2p^6 3s^2$
D $1s^2 2s^2 2p^6$

**0092 1A [1 mark]** Which subshell contains five orbitals?

A s
B d
C p
D f

**0093 1A [1 mark]** Which orbital occupancy violates the Pauli principle?

A An empty p orbital
B One electron in each p orbital
C Two opposite-spin electrons in one orbital
D Two same-spin electrons in one orbital

**0094 1A [1 mark]** Which electronic transition absorbs the most energy in an atom?

A The lowest-frequency emission
B Any transition within one level
C The largest upward energy gap
D The smallest downward energy gap

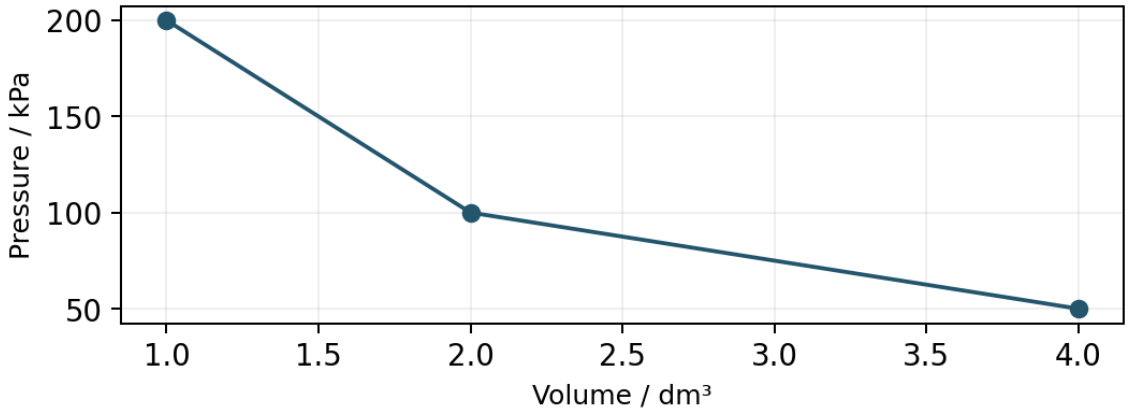
**0095 1B [3 marks]** For the mg dataset above, calculate the energy of one photon of the 460 nm emission line.

_____

## Structure 1.5 Set 18 continued

Use the preceding set information where relevant; additional substances and datasets are specified in individual questions.

**0176 1B [4 marks]** An isothermal gas gives (V, p) values (1.00 dm³, 200 kPa), (2.00, 100) and (4.00, 50.0). Identify a linear plot and calculate its gradient.




Isothermal pressure and volume measurements

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**0177 2S [4 marks]** An ideal gas occupies 2.50 dm³ at 95.0 kPa and 298 K. Calculate n using R = 8.314 kPa dm³ $mol^{-1}$ $K^{-1}$.

_____

**0178 2S [4 marks]** A sealed gas has 120 kPa at 300 K. Find its pressure at 350 K in the same rigid vessel.

_____

**0179 2S [4 marks]** Explain why $CO_2$ can deviate more than He from ideal behaviour near condensation.

_____

**0180 2E [8 marks]** A 0.250 g volatile liquid becomes 120.0 cm³ of vapour at 100.0 kPa and 373 K. Calculate molar mass and evaluate the effects of an air leak and incomplete vaporization.

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## Structure 2.1 Set 22

### Ionic structure and properties of KBr

KBr consists of $K^+$ and $Br^-$. Their ionic radii are 138 and 196 pm. The melting point is approximately 734 °C. In a teaching experiment, conductance in arbitrary units is 0.3 for the solid and 78 for the molten substance; use these as illustrative measurements.

**0211 1A [1 mark]** What formula balances $Mg^{2+}$ and $NO_3^-$ charges?

A $MgNO_3$
B $Mg_2(NO_3)_3$
C $Mg_2NO_3$
D $Mg(NO_3)_2$

**0212 1A [1 mark]** Which is the electron configuration of $O^{2-}$?

A $1s^2 2s^2 2p^2$
B $1s^2 2s^2 2p^6 3s^2$
C $1s^2 2s^2 2p^6$
D $1s^2 2s^2 2p^4$

**0213 1A [1 mark]** Which pair is expected to have the strongest attraction at the same separation?

A $Li^+$ and $F^-$
B $Mg^{2+}$ and $O^{2-}$
C $Na^+$ and $Cl^-$
D $K^+$ and $Br^-$

**0214 1A [1 mark]** Which statement distinguishes ionic bonding from electron transfer?

A Bonding is only the instant an electron moves
B Bonding has no electrostatic basis
C Bonding requires uncharged molecules
D Bonding is the subsequent attraction between ions

**0215 1B [4 marks]** For the kbr dataset above, calculate the approximate nearest-neighbour ion-centre separation and the molten to solid conductance ratio.

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## Structure 2.3 Set 30

### Metallic bonding and alloys of aluminium

A aluminium sample has density 2.7 g $cm^{-3}$. Illustrative room-temperature conductivities of the pure metal and one alloy are 3.77 and 2.450 × $10^{7}$ S $m^{-1}$. For a simple particle model take 3 delocalized electron(s) per metal atom; this is a simplified bonding model.

**0291 1A [1 mark]** What is the main current carrier in an aluminium wire?

A Electrons
B Protons
C $Al^{3+}$ ions flowing through the solid
D Neutral aluminium atoms

**0292 1A [1 mark]** Why do metals usually conduct heat well?

A Mobile electrons transfer energy through the solid
B Only nuclear reactions release heat
C Their ions have no mass
D Each metal atom becomes a gas

**0293 1A [1 mark]** Which observation supports non-directional metallic bonding?

A A copper sheet can be bent without immediately shattering
B Copper becomes an insulator on melting
C Copper has no valence electrons
D Copper exists only as diatomic molecules

**0294 1A [1 mark]** What usually happens to a metal's resistance when temperature rises?

A It must become zero
B It becomes independent of wire length
C It always halves
D It increases

**0295 1B [3 marks]** For the aluminium dataset above, calculate the percentage decrease in conductivity on alloying.

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## Structure 3.2 Set 44

### Functional groups and isomers of butan-2-one

Compound P is $CH_3COCH_2CH_3$, named butan-2-one, with molecular formula $C_4H_8O$ and molar mass 72.1 g $mol^{-1}$. A 1.00 g sample is burned completely. Use $M(CO_2) = 44.01$ g $mol^{-1}$. For the structural questions, use the displayed atom connectivity, not only the molecular formula.

**0431 1A [1 mark]** Which pair are enantiomers?

A Two compounds with different atom connectivity
B Any two molecules with the same mass
C Non-superimposable mirror images
D Two conformers related only by simple bond rotation

**0432 1A [1 mark]** Which general formula fits an acyclic saturated monocarboxylic acid?

A $C_nH_{2n+2}O_2$
B $C_nH_{2n+2}$
C $C_nH_{2n}O_2$
D $C_nH_{2n-2}$

**0433 1A [1 mark]** What is the IUPAC name of $CH_3CH_2NHCH_3$?

A Ethyl methanoate
B N-Methylethanamine
C Propanamide
D Trimethylamine

**0434 1A [1 mark]** Which molecule cannot have a tetrahedral chiral carbon?

A Butan-2-ol
B Propan-2-one
C 2-Chlorobutanoic acid
D 2-Bromobutane

**0435 1B [3 marks]** For the butan-2-one dataset above, calculate the amount of $CO_2$ formed by complete combustion of the 1.00 g sample.

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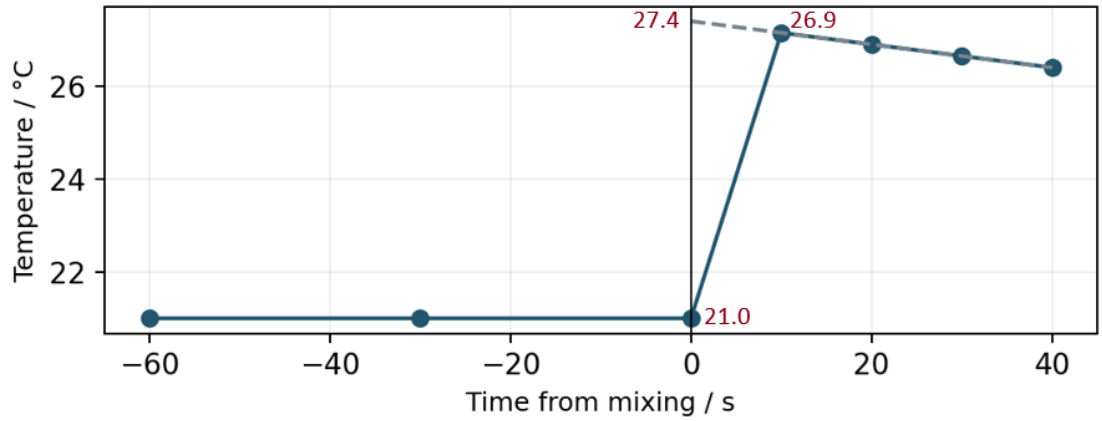
## Reactivity 1.1 Set 50 continued

Use the preceding set information where relevant; additional substances and datasets are specified in individual questions.

**0496 1B [4 marks]** A cooling line extrapolates to 27.4 °C at mixing time; the measured peak is 26.9 °C and initial temperature 21.0 °C. For 100.0 g solution with c = 4.18, find corrected q and the heat missed by using the peak.




Cooling-line extrapolation to mixing time

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**0497 2S [4 marks]** A 60.0 g solution cools by 3.00 K when a salt dissolves. Calculate q(solution) using c = 4.18 and infer q(dissolution), neglecting the cup.

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**0498 2S [4 marks]** Calculate molar enthalpy if 0.0200 mol reacts and releases 1.10 kJ.

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**0499 2S [4 marks]** Explain why heat gained by the thermometer itself can bias a result if ignored.

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**0500 2E [8 marks]** A calorimeter has heat capacity 80.0 J $K^{-1}$. A reaction warms 100.0 g of solution by 5.00 K. Calculate heat released including the calorimeter, compare with ignoring it, and explain the resulting molar-enthalpy bias. Use c = 4.18 J $g^{-1}$ $K^{-1}$.

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# Reactivity 1.4 Set 64

## Entropy and feasibility case 4

A hypothetical reaction has $\Delta H^\circ = 55.0$ kJ mol$^{-1}$ and $\Delta S^\circ = -80.0$ J mol$^{-1}$ K$^{-1}$. Evaluate it at 328 K and assume both values are temperature independent over the range discussed. Use $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. These are illustrative thermodynamic data.

**0631 1A [1 mark]** What is the slope of $\Delta G^\circ$ versus T if $\Delta H^\circ$ and $\Delta S^\circ$ are constant?

A $-\Delta S^\circ$
B $+\Delta H^\circ$
C $\Delta H^\circ/\Delta S^\circ$
D $-\Delta H^\circ$

**0632 1A [1 mark]** Which entropy comparison is normally correct for the same amount of a substance?

A All entropies are zero at 298 K
B S(solid) > S(liquid) > S(gas)
C S(gas) > S(liquid) > S(solid)
D All are exactly equal

**0633 1A [1 mark]** Why may a system's entropy decrease in a feasible process?

A The second law concerns only the system
B Entropy is not affected by heat
C The surroundings' entropy can increase by a larger amount
D The surroundings always have zero entropy change

**0634 1A [1 mark]** What does $\Delta G = 0$ mean for the actual reacting mixture?

A It is at equilibrium
B Its standard-state K must be zero
C Every concentration must equal one
D Its forward rate must be zero

**0635 1B [4 marks]** For the entropy and feasibility case 4 dataset above, calculate $\Delta G^\circ$ at the stated temperature and interpret its sign for standard-state feasibility.

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# Reactivity 2.2 Set 69

## Initial rates and mechanism case 1

For A + B → products at fixed temperature, initial-rate data are: trial 1, [A] = 0.100, [B] = 0.200, rate = 0.003; trial 2, [A] = 0.200, [B] = 0.200, rate = 0.006; trial 3, [A] = 0.100, [B] = 0.400, rate = 0.006. Concentrations are mol $dm^{-3}$ and rates mol $dm^{-3}$ $s^{-1}$. Use rate = $k[A]^m[B]^n$.

**0681 1A [1 mark]** What is the order in A?

A 1
B 0
C 3
D 2

**0682 1A [1 mark]** What is the order in B?

A 1
B 2
C 0
D 3

**0683 1A [1 mark]** What is the overall reaction order?

A 3
B 2
C 1
D 4

**0684 1A [1 mark]** Which statement about rate laws is correct?

A They must be established experimentally or from a valid mechanism
B They are independent of temperature in every reaction
C They cannot include zero orders
D They always follow the overall balanced coefficients

**0685 1B [5 marks]** For the initial rates and mechanism case 1 dataset above, deduce the rate law and calculate k with units.

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# Reactivity 3.3 Set 95

## Radical chlorination of propane

propane, $C_3H_8$, reacts with $Cl_2$ under ultraviolet light. Consider the chain producing $CH_3CH_2CH_2Cl$; other substitution products may also form. The irradiation wavelength is 350 nm. Use $h = 6.626 \times 10^{-34}$ J s, $c = 2.998 \times 10^8$ m $s^{-1}$, $N_a = 6.022 \times 10^{23}$ $mol^{-1}$ and Cl–Cl bond enthalpy 243 kJ $mol^{-1}$. R• for the specified chain is $CH_3CH_2CH_2$•.

**0941 1A [1 mark]** What is a propagation step in methane bromination?

A $CH_3$• + $Br_2$ → $CH_3Br$ + Br•
B $Br_2$ → 2Br•
C Br• + Br• → $Br_2$
D $CH_3$• + Br• → $CH_3Br$

**0942 1A [1 mark]** Which change favours repeated halogen substitution?

A A large alkane excess with limited halogen
B Lower conversion alone
C A large halogen excess
D Immediate separation of the first product

**0943 1A [1 mark]** What product results when two ethyl radicals combine?

A Ethane
B Propane
C Butane
D Ethene

**0944 1A [1 mark]** Why is UV light useful in alkane halogenation?

A It makes the reaction atom economy 100%
B Photons can initiate halogen homolysis
C It eliminates all termination steps
D It directly removes every hydrogen nucleus

**0945 1B [4 marks]** For the propane dataset above, calculate the energy per photon and the molar photon energy. Compare with Cl–Cl bond enthalpy.

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| | | |
|---|---|---|
| 0033 | 1A | D  They are equal |
| 0034 | 1A | A  A gas volume decreases greatly under pressure |
| 0035 | 1B | -186.0 °C; half-range 0.2 °C; consistent. |
| 0036 | 1B | 240 J $g^{-1}$. |
| 0037 | 2S | Most of the gas volume is interparticle space. |
| 0038 | 2S | Helium spreads faster under comparable conditions. |
| 0039 | 2S | Ar is an element; $CO_2$ is a compound; air is a mixture. |
| 0040 | 2E | The colder container has twice as many particles; the warmer particles have twice the mean kinetic energy; total translational energy is equal. |
| 0041 | 1A | B  20 |
| 0042 | 1A | A  16 |
| 0043 | 1A | B  They have the same electron configuration |
| 0044 | 1A | B  Mass to charge ratio |
| 0045 | 1B | 35.48 |
| 0046 | 1B | The weaker peak is increased by a larger relative fraction; normalized abundances shift toward 50:50. |
| 0047 | 2S | Approximately 75.8%. |
| 0048 | 2S | 18.5 |
| 0049 | 2S | Relative atomic mass is an abundance-weighted relative mean; mass number counts nucleons in one isotope. |
| 0050 | 2E | m/z 70, 72, 74; abundances 57.46%, 36.69%, 5.86%. |
| 0051 | 1A | C  $^{79}Br$ and $^{81}Br$ |
| 0052 | 1A | D  44 |
| 0053 | 1A | D  −1 |
| 0054 | 1A | D  The lower-mass ion |
| 0055 | 1B | 79.99 |
| 0056 | 1B | 79.44; relative areas determine the abundance-weighted mean. |
| 0057 | 2S | 35 protons, 46 neutrons, 36 electrons. |
| 0058 | 2S | 63.5. |
| 0059 | 2S | Three isotope peaks separated by two mass units can appear in an approximate 9:6:1 pattern. |
| 0060 | 2E | $Br_2$ peaks are approximately 1:2:1; doubly charged atomic peaks occur at half the isotope mass. |
| 0061 | 1A | B  2 |
| 0062 | 1A | C  Neutron |
| 0063 | 1A | B  10.5 |
| 0064 | 1A | B  Increasing the heavier-isotope fraction |
| 0065 | 1B | 10.80 |
| 0066 | 1B | x = 0.20 ± 0.02, or 20 ± 2 percentage points. |
| 0067 | 2S | 30.0%. |
| 0068 | 2S | It changes nuclear mass while leaving proton number fixed. |
| 0069 | 2S | A mass-40 doubly charged ion also has m/z 20. |
| 0070 | 2E | Different isotope abundances; x = (11 − Ar)/(11 − 10), and 10 ≤ Ar ≤ 11 under this two- |

| | | |
|---|---|---|
| 0580 | 2E | Complete $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$; incomplete $C_2H_5OH + 2O_2 \rightarrow 2CO + 3H_2O$. |
| 0581 | 1A | A Mass $CO_2$ per useful kJ |
| 0582 | 1A | D A smaller heat release per mole than for complete combustion |
| 0583 | 1A | C Their storage densities differ |
| 0584 | 1A | D Energy used in production and transport |
| 0585 | 1B | 26.9 kJ; $\Delta T = 20.9$ K. |
| 0586 | 1B | A: 0.100 g $kJ^{-1}$; B: 0.0833 g $kJ^{-1}$; B is lower on this measure. |
| 0587 | 2S | $CH_3OH + O_2 \rightarrow CO + 2H_2O$. |
| 0588 | 2S | 24.0 kJ $cm^{-3}$, or $2.40 \times 10^4$ kJ $dm^{-3}$. |
| 0589 | 2S | It converts chemical free energy directly into electrical work. |
| 0590 | 2E | 171.6 kJ $mol^{-1}$ useful; anode $H_2 \rightarrow 2H^+ + 2e^-$; cathode $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$. |
| 0591 | 1A | A $O_2$ with $H^+$ and electrons |
| 0592 | 1A | C It makes apparent fuel consumption exceed fuel actually burned |
| 0593 | 1A | C Renewable origin alone does not guarantee zero net emissions |
| 0594 | 1A | D $CO_2$ and $H_2O$ |
| 0595 | 1B | 28.9 kJ; $\Delta T = 22.5$ K. |
| 0596 | 1B | 23.5 kJ $g^{-1}$. |
| 0597 | 2S | 17.6 g. |
| 0598 | 2S | Direct vehicle exhaust can be zero while generation-related emissions remain. |
| 0599 | 2S | Flame appearance depends on mixing, oxygen supply and heat transfer as well as energy release. |
| 0600 | 2E | Both produce $CO_2$ and water on complete combustion; feedstock and process history change net emissions. |
| 0601 | 1A | A Negative |
| 0602 | 1A | C Vaporization |
| 0603 | 1A | C It can still be extremely slow |
| 0604 | 1A | C Zero |
| 0605 | 1B | -35.3 kJ $mol^{-1}$; feasible in the forward direction under standard-state conditions. |
| 0606 | 1B | ±1.49 kJ $mol^{-1}$. |
| 0607 | 2S | Crossover 533 K; feasible below it. |
| 0608 | 2S | Total entropy includes both system and surroundings. |
| 0609 | 2S | Heat capacities and phase changes can change $\Delta H°$ and $\Delta S°$. |
| 0610 | 2E | Intercept -80 kJ $mol^{-1}$; slope 0.15 kJ $mol^{-1}$ $K^{-1}$. |
| 0611 | 1A | C $\Delta H < 0$ and $\Delta S > 0$ |
| 0612 | 1A | A 0.125 |
| 0613 | 1A | C $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ |
| 0614 | 1A | D −10 kJ $mol^{-1}$ |
| 0615 | 1B | -4.28 kJ $mol^{-1}$; feasible in the forward direction under standard-state conditions. |
| 0616 | 1B | 0.0 ± 2.5 kJ $mol^{-1}$; the sign is unresolved. |
| 0617 | 2S | −6.50 kJ $mol^{-1}$. |
| 0618 | 2S | 400 K. |
| 0619 | 2S | The gases can occupy more spatial arrangements when distributed through the combined volume. |

# Worked solutions

Each entry corresponds to one numbered problem. For design, sketch and mechanism questions, use the prose to construct the requested drawing or procedure. Numerical data in the question take priority over reference values from other sources.

## Structure 1.1 Solutions for set 1

### States and particle models for bromine

**0001 B Liquid.** At 25.8 °C bromine is above −7.2 °C but below 58.8 °C, so the stable bulk phase at the stated pressure is liquid.

**0002 A Mean separation of particles increases.** Energy overcomes attractions between particles while the temperature remains constant.

**0003 D It has a fixed chemical composition.** Both elements and compounds may be pure; composition distinguishes them from mixtures.

**0004 D Condensation.** Condensation forms stronger attractions and releases energy to the surroundings.

**0005 58.8 °C; half-range 0.2 °C; consistent.** The three-reading mean is (58.6 + 58.8 + 59.0)/3 = 58.8 °C. For bromine, half-range = (59.0 − (58.6))/2 = 0.2 °C; the accepted 58.8 °C value is consistent with the interval.

**0006 Systematic error; reported boiling point is 1.0 °C high; calibrate and subtract the offset.** A constant zero offset shifts every result in the same direction. More repeats reduce random scatter but do not remove this offset.

**0007 Widely separated particles move rapidly and randomly.** Above the boiling point the material is a gas. Its particles move in all directions; collisions continually change their velocities.

**0008 Supplied energy increases potential energy by overcoming interparticle attractions.** Temperature measures mean kinetic energy. During the phase change the energy changes particle separation rather than increasing mean kinetic energy.

**0009 Heterogeneous; pure substance.** There are two physical phases with different properties, making the system heterogeneous. Both phases have the same chemical identity, so it remains a pure substance.

**0010 Plot temperature against time; locate melting and boiling regions; control pressure and heating power; heat slowly and stir.** Use a calibrated probe and record temperature at equal time intervals. Keep pressure and sample mass fixed. Slow heating and stirring reduce temperature gradients. Sloping regions indicate rising mean kinetic energy; plateaus indicate changes in attractions and phase proportions. Repeat to assess precision.

## Structure 1.1 Solutions for set 2

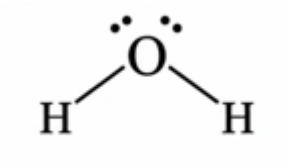
### States and particle models for ethanol

**0011 C Homogeneous mixture.** Both molecular species are distributed throughout one phase; a uniform appearance does not imply chemical purity.

**0012 D Heating it from 20 to 40 °C.** Raising temperature increases the average kinetic energy; energy supplied during a constant-temperature phase transition mainly changes potential energy.

**0013 C Fractional distillation.** Different volatilities allow repeated vaporization and condensation to enrich one component.

**0257 Two O–H bonds and two oxygen lone pairs.** O supplies six valence electrons and the two H atoms supply two; four electrons form bonds and four remain nonbonding on oxygen.

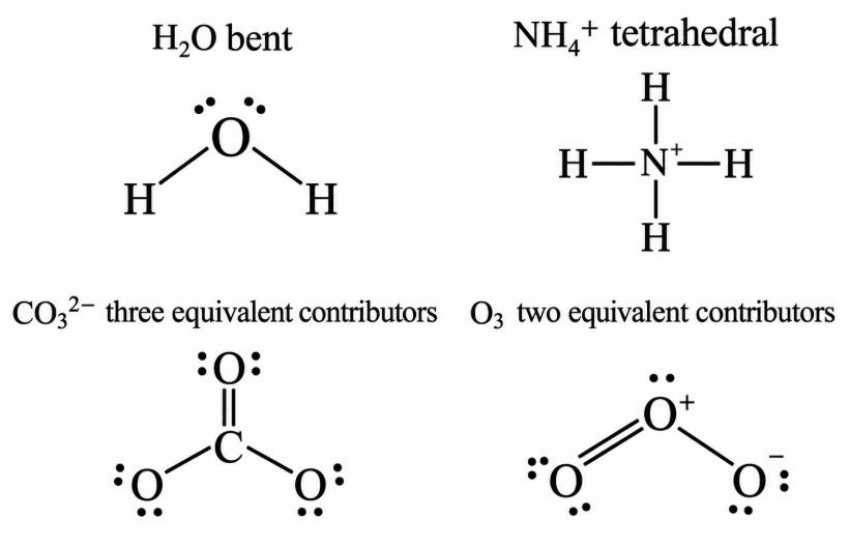


Two O–H bonds and two oxygen lone pairs

**0258 Tetrahedral, approximately 109.5°.** Four bonding domains surround nitrogen with no central lone pair, so the molecular and electron-domain geometries coincide.

**0259 N–H bonds are strongly polar and nitrogen has a suitable lone pair.** The strong N/O/F-type hydrogen-bond interaction is not predicted simply from the presence of any X–H bond; phosphine lacks the same donor polarity.

**0260 $H_2O$ bent; $NH_4^+$ tetrahedral; $CO_3^{2-}$ trigonal planar; $O_3$ bent.** Water has four domains and two lone pairs. Ammonium has four bonding domains and no central lone pairs. Carbonate has three bonding domains and delocalized pi bonding represented by three equivalent contributors. Ozone has three domains around the central oxygen and two main resonance contributors. The actual electron density is delocalized; resonance drawings are bookkeeping models of one structure.




Representative Lewis contributors move the double-bond position for the other resonance forms

## Structure 2.2 Solutions for set 27

### Covalent bonding in $CO_2$

**0261 C C≡C.** Greater bond order normally gives greater electron density between the nuclei and a shorter bond.

**0262 B $SO_2$.** Bent $SO_2$ has polar bonds whose vectors do not cancel.

**0263 D Its lone pair repels bonding domains more strongly.** The lone-pair domain compresses the H–N–H angles relative to the ideal tetrahedral value.

**0264 B B in $BF_3$.** Boron has three bonding pairs and six surrounding electrons in planar $BF_3$.

## Structure 3.1 Solutions for set 38

### Periodic classification and Mg

**0371 D Mg.** Magnesium has an n = 3 valence shell with two 3s electrons.

**0372 D $Al_2O_3$.** Aluminium oxide can react with both acids and strong bases.

**0373 A Oxidizing strength decreases.** Increasing distance and shielding make electron gain less favourable down the halogen group under comparable conditions.

**0374 D +6.** Solving $2x + 7(-2) = -2$ gives $x = +6$.

**0375 10.6% decrease.** The Mg-to-Al contraction is $(160 - 143)/160 \times 100 = 10.6\%$. Moving from Mg to Al adds nuclear charge while the occupied outer shell remains n = 3, giving stronger effective attraction.

**0376 36.6% decrease.** The change is $(186 - 118)/186 \times 100$. Valence electrons enter the same main shell while effective nuclear attraction generally increases across these elements.

**0377 $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$.** Chlorine gains two electrons while two bromide ions each lose one; charges and halogen atoms balance.

**0378 Nuclear attraction increases with little additional inner-shell shielding.** The added valence electron enters the same main shell, so the greater proton number contracts the outer electron cloud.

**0379 $MgO(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2O(l)$.** Oxide accepts protons to form water; the balanced equation consumes two $H^+$ per oxide ion.

**0380 $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$; bromine does not normally displace chloride.** Chlorine is the stronger oxidizing agent and gains electrons more readily than bromine under comparable aqueous conditions. Its smaller atomic size and less shielding support the group trend. Bromide is oxidized and chlorine reduced. Observe bromine formation using an appropriate colour comparison or extraction test; colour alone can be obscured by excess halogen.

## Structure 3.1 Solutions for set 39

### Periodic classification and Al

**0381 D 6.** Six water oxygen donors bind directly to the metal centre.

**0382 C $Fe^{2+}$.** $Fe^{2+}$ is $[Ar]3d^6$, whereas $Zn^{2+}$ has a filled $3d^{10}$ subshell and the main-group ions have none.

**0383 C S.** Sulfur oxides react with bases and can contribute to acidic aqueous systems.

**0384 A A ligand donor atom.** The ligand's occupied lone-pair orbital supplies the pair to a suitable metal acceptor orbital.

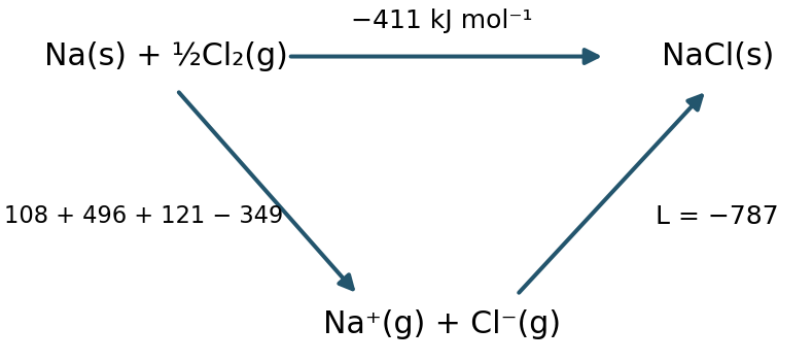
**0385 17.5% decrease.** The Al-to-Si contraction is $(143 - 118)/143 \times 100 = 17.5\%$. Moving from Al to Si adds nuclear charge while the occupied outer shell remains n = 3, giving stronger effective attraction.

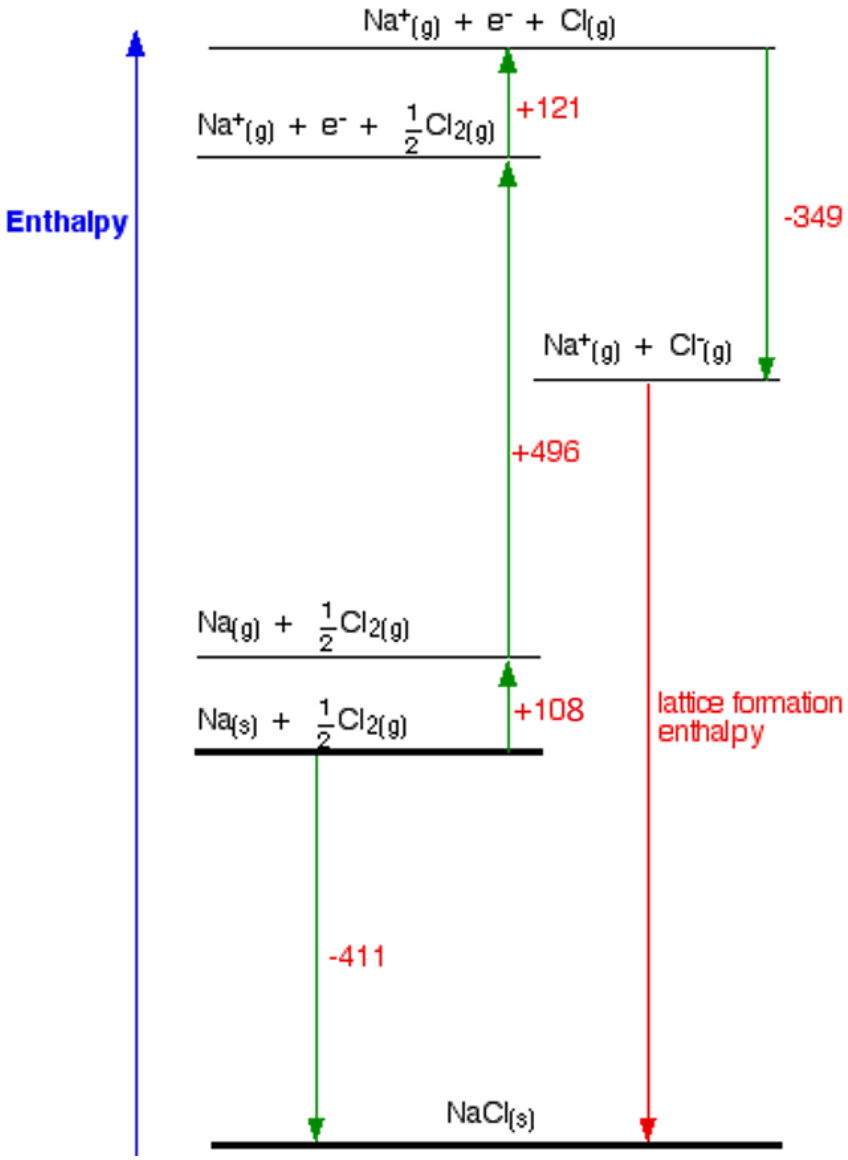
**0386 0.750 mol $dm^{-3}$.** The diluted sample is $0.375/2.50 = 0.150$ mol $dm^{-3}$; multiply by five to recover the original concentration under the linear model.

**0387 Fe is +3; coordination number is 6.** Six $CN^-$ ligands contribute −6 charge, so iron must be +3 for total −3; each ligand donates through one atom.

**0388 Its 3d subshell is full.** A $d^{10}$ configuration lacks the usual partly occupied split d-level pattern that gives many transition-metal d–d absorptions; other absorption mechanisms remain possible.

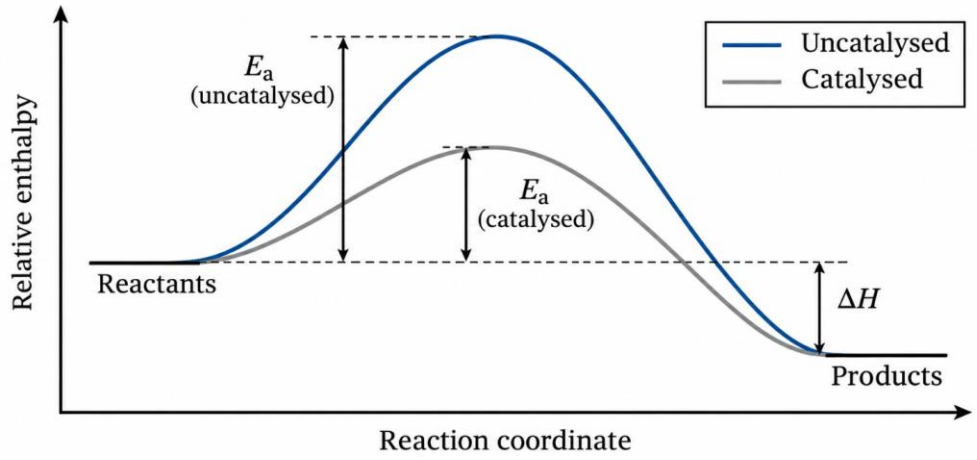
**0530 Lattice formation enthalpy = −787 kJ mol⁻¹.** Atomize Na(s) and half a mole of $Cl_2$ to gaseous atoms; these steps are endothermic. Removing an electron from Na absorbs 496; attaching it to Cl releases 349. Hess law gives −411 = 108 + 496 + 121 − 349 + L. Therefore L = −787. Formation of the ionic lattice releases energy through electrostatic attraction.




Born–Haber formation cycle for sodium chloride

**0730 Same reactant and product energy levels; lower maximum barrier on a catalysed route.** Label activation energies and the common reaction enthalpy. A lower barrier generally increases the rate constant, though A can also change with pathway. The catalyst speeds approach to equilibrium in both directions. Because the initial and final thermodynamic states are unchanged, it does not change the equilibrium constant at fixed temperature.




Same endpoints and reaction enthalpy with different activation barriers

## Reactivity 2.2 Solutions for set 74

### Arrhenius analysis case 2

**0731 B 0.693.** The Arrhenius two-temperature form uses the natural logarithm, so the relevant value is ln 2.

**0732 D ln A.** The logarithmic equation is ln k = ln A − (Ea/R)(1/T).

**0733 D To make Ea/(RT) dimensionless.** Consistent energy units cancel in the exponential; mixing kJ and J introduces a thousandfold numerical error.

**0734 D The one with larger Ea if other assumptions match.** The exponent in the two-temperature ratio is proportional to activation energy.

**0735 55 kJ mol$^{-1}$.** The measured ratio is 0.00830577/0.00200 = 4.15289. In Ea = 8.314 ln($k_2/k_1$)/(1/295 − 1/315), the reciprocal-temperature difference is positive. Substitution yields 55000 J mol$^{-1}$, equivalent to 55.0 kJ mol$^{-1}$ for this case.

**0736 54.0 ± 1.7 kJ mol$^{-1}$.** Multiply both the gradient magnitude and its uncertainty by R/1000. Reporting more precise activation energy than the gradient supports would be misleading.

**0737 49.9 kJ mol$^{-1}$.** Multiplying the gradient magnitude by R gives 49884 J mol$^{-1}$, then divide by 1000.

**0738 4.85 × 10$^8$ s$^{-1}$.** The intercept is ln A, so A = e$^{20}$; the dimensionless exponential does not alter the rate-constant unit.

**0739 The equation requires absolute temperature, and reciprocal Celsius is not proportional to reciprocal kelvin.** A temperature difference alone is also insufficient because both absolute reciprocals appear in ln($k_2/k_1$).

**0740 Ea = 59.9 kJ mol$^{-1}$; A = 7.20 × 10$^{10}$ s$^{-1}$; k300 = 2.72 s$^{-1}$.** Slope = −Ea/R, so Ea = 7200 × 8.314 J mol$^{-1}$. Intercept is ln A, so A = exp(25.0). At 300 K, ln k = 25.0 − 7200/300 = 1.00, so k = e. The time unit is inherited from the rate-constant values used to construct the graph.

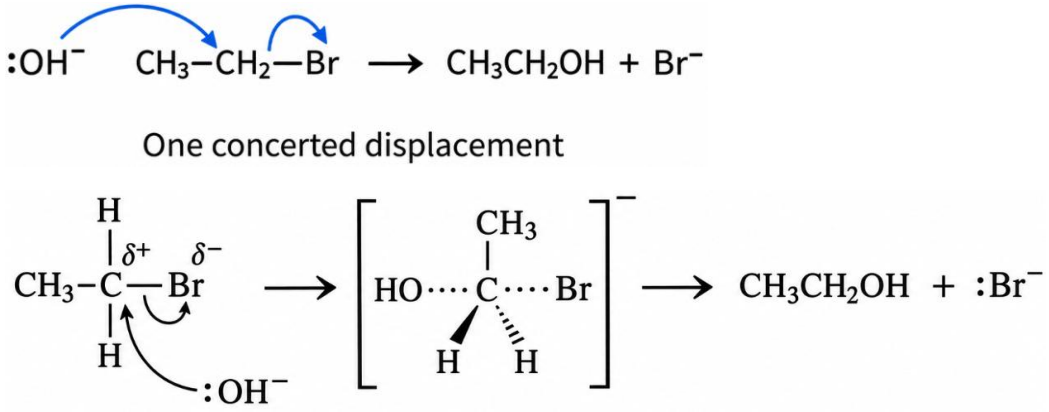
**0966 Solvent composition changes nucleophile reactivity and ion stabilization.** Hold the solvent composition, ionic conditions and temperature constant while varying one concentration. Solvent changes can alter both the rate constant and the dominant mechanism, so the data no longer isolate concentration dependence.

**0967 ethanol; RBr + $OH^-$ → ROH + $Br^-$.** Replace the Br substituent with OH while retaining the carbon skeleton. For an SN1 reaction in aqueous medium, water attack and subsequent deprotonation may be the more detailed solvent-level description.

**0968 Hot ethanolic base; ethene.** Heating with ethanolic hydroxide favours loss of H and Br from neighbouring carbons to form a double bond. Aqueous conditions are commonly used to favour substitution.

**0969 Movement of an electron pair; the tail begins at a lone pair or bond.** The arrowhead points to where that electron pair goes. It must not begin at a positive charge with no electrons; single-headed arrows are reserved for single-electron movement.

**0970 Dominant pathway: SN2.** For SN2, draw $OH^-$ lone-pair attack at the carbon bearing Br and simultaneous C–Br bond cleavage to $Br^-$. Show a single transition state with partial O–C and C–Br bonds, no carbocation intermediate. Steric crowding slows backside attack. Both pathways give the named alcohol. Substrate substitution and solvent polarity/proticity can change which pathway dominates.




SN2 at bromoethane  pair donation and leaving-bond cleavage occur together.

## Reactivity 3.4 Solutions for set 98

### Electron-pair mechanisms for 1-bromopropane

**0971 A At an oxygen lone pair.** The arrow tracks an existing pair of electrons donated by the nucleophile.

**0972 D Steric hindrance to backside approach.** Bulky groups obstruct the nucleophile's approach along the C–leaving-group axis.

**0973 D A carbocation.** An electron-deficient positive carbon can accept an electron pair.

**0974 A rate = k[haloalkane].** The slow bond-ionization step involves the substrate alone, before nucleophile capture.

**0975 0.008 mol $dm^{-3}$ $s^{-1}$.** For 1-bromopropane, the measured substrate order is one and $OH^-$ order is 1. Its 0.0020 initial rate is multiplied by $2^1 \times 2^1 = 4$, giving 0.0080 mol $dm^{-3}$ $s^{-1}$ after both concentrations are doubled.

**0976 First order in $OH^-$; more mechanistic evidence is required.** The doubling ratio gives exponent one, but substrate order, stereochemical behaviour and solvent effects are needed to distinguish alternative multistep possibilities.