

IB Chemistry – Structure 3: Classification of Matter

IB Chemistry SL & HL (2023+ syllabus) · Total marks: 43 · Answers on the last page

This worksheet covers periodicity (Structure 3.1), functional groups (Structure 3.2) and, in Section B, transition elements (Structure 3.1 HL). A calculator is not required. Questions marked HL extend beyond the SL syllabus.

Section A – Periodicity

- Define first ionisation energy.
 - Explain why the first ionisation energy generally increases across Period 3 (Na to Ar), despite the increasing number of electrons. [4]
- Explain why the first ionisation energy of aluminium is lower than that of magnesium, even though aluminium has a greater nuclear charge. [2]
- Describe how atomic radius changes across Period 3 from sodium to argon.
 - Explain this trend. [3]
- Sodium, magnesium and aluminium are metals with giant metallic structures, whereas sulfur (S_8) and chlorine (Cl_2) are simple molecular substances.
 - State and explain the trend in melting point from sodium to aluminium.
 - Explain why the melting point of sulfur is much higher than that of chlorine, even though both are simple molecular substances. [4]

Section B – Transition elements (HL) (Higher Level only)

- Write the full electron configuration of an iron atom (Fe, $Z = 26$).
 - Write the electron configurations of the ions Fe^{2+} and Fe^{3+} .
 - Explain why the 4s electrons are removed before the 3d electrons when iron atoms form ions. [5]
- Define the term 'transition element' and explain why scandium and zinc are usually excluded from the transition elements. [3]
- Aqueous copper(II) sulfate is a pale blue solution. When excess ammonia solution is added, a deep blue solution containing $[Cu(NH_3)_4(H_2O)_2]^{2+}$ forms.
 - Explain, in terms of d-orbitals, why transition metal complexes such as $[Cu(H_2O)_6]^{2+}$ are coloured.
 - Explain why changing the ligand from water to ammonia changes the colour observed. [4]
- State two catalytic properties of transition metals or their compounds, giving one named industrial example for each: (a) a transition metal used as a heterogeneous catalyst, and (b) a transition metal ion used as a homogeneous catalyst. [3]

Section C – Functional groups (Exam-style)

- For each compound, name the functional group present and give the class of organic compound:
 - CH_3CH_2COOH , (b) CH_3CH_2CHO , (c) CH_3COCH_3 , (d) $CH_3CH_2NH_2$. [4]

10. Compound X has the structural formula $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$.
- (a) Give the IUPAC name of X.
 - (b) State whether X is a primary, secondary or tertiary alcohol, and explain your answer.
 - (c) X has an isomer that is a tertiary alcohol. State whether this is possible, giving a reason. [4]
11. Ethanoic acid reacts with ethanol in the presence of a small amount of concentrated sulfuric acid catalyst.
- (a) Write the equation for this reaction, including state symbols.
 - (b) Name the organic product and state the type of reaction occurring.
 - (c) State the role of the concentrated sulfuric acid. [4]
12. But-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$, exists as two stereoisomers.
- (a) Name the type of stereoisomerism shown and explain, in terms of bonding, why it arises.
 - (b) Draw-by-description the two isomers and state which has the higher boiling point, giving a reason based on molecular polarity. [3]

Answers

Check your working against these. If an answer does not match, try the question again before looking for the method.

- (a) First ionisation energy is the energy required to remove one mole of electrons from one mole of gaseous atoms in their ground state, forming one mole of gaseous $1+$ ions.

(b) Across Period 3 the nuclear charge increases while electrons are added to the same principal energy level (shielding stays roughly constant), so effective nuclear charge increases and outer electrons are held more strongly, requiring more energy to remove.
- Magnesium's outer electron is removed from a full $3s$ subshell, while aluminium's outer electron is in the higher-energy $3p$ subshell, which is less tightly bound (slightly further from the nucleus and shielded by the $3s$ electrons), so less energy is needed despite the higher nuclear charge.
- (a) Atomic radius decreases across the period.

(b) Nuclear charge increases while the number of occupied shells stays the same and shielding is approximately constant, so the increased effective nuclear charge pulls the outer electrons closer to the nucleus.
- (a) Melting point increases from Na to Al because the metallic bonding strengthens: each atom contributes more delocalised electrons (Na^+ , Mg^{2+} , Al^{3+}) and the ionic radius decreases, so electrostatic attraction between the metal cations and the delocalised electron sea increases.

(b) Sulfur exists as larger S_8 molecules with more electrons than Cl_2 , giving stronger London (dispersion) forces between molecules, so more energy is needed to overcome these forces and melt sulfur.
- (a) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

(b) Fe^{2+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$; Fe^{3+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$

(c) In transition metal atoms, once occupied, the $3d$ subshell is lower in energy than the $4s$ subshell (the $4s$ electrons are, on average, further from the nucleus and more shielded), so the $4s$ electrons are lost first on ionisation.
- A transition element is a d-block element that forms at least one stable ion with a partially filled d subshell. Scandium only forms the Sc^{3+} ion, which has an empty d subshell ($3d^0$), and zinc only forms Zn^{2+} , which has a full d subshell ($3d^{10}$); neither has a partially filled d subshell, so they are excluded.
- (a) Ligands bonded to the central metal ion cause the five degenerate d orbitals to split into two energy levels. Electrons can absorb visible light and be excited from the lower to the higher d level; the complementary colour of the light absorbed is transmitted/reflected, giving the complex its colour.

(b) Ammonia is a different (stronger-field) ligand from water, producing a different degree of splitting between the d orbital energy levels. This changes the energy (and hence wavelength/colour) of light absorbed, so a different colour is observed.
- (a) Iron is used as a heterogeneous catalyst in the Haber process for the synthesis of ammonia, $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$.

(b) $\text{Fe}^{2+}/\text{Fe}^{3+}$ ions act as a homogeneous catalyst in the reaction between iodide and peroxodisulfate ions (or: Co^{2+} catalysing the decomposition of hydrogen peroxide), exploiting the variable oxidation states of the transition metal.
- (a) Carboxyl group, $-\text{COOH}$; carboxylic acid.

(b) Carbonyl/aldehyde group, $-\text{CHO}$; aldehyde.

(c) Carbonyl group, $\text{C}=\text{O}$, bonded to two carbons; ketone.

(d) Amine group, $-\text{NH}_2$; (primary) amine.

10. (a) Butan-2-ol
(b) Secondary alcohol, because the carbon bonded to the —OH group is itself bonded to two other carbon atoms.
(c) Not possible for a $\text{C}_4\text{H}_{10}\text{O}$ alcohol with a straight-chain skeleton; a tertiary alcohol isomer, 2-methylpropan-2-ol, does exist because it has a branched skeleton where the —OH -bearing carbon is bonded to three other carbons.
11. (a) $\text{CH}_3\text{COOH(l)} + \text{C}_2\text{H}_5\text{OH(l)} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5\text{(l)} + \text{H}_2\text{O(l)}$
(b) The product is ethyl ethanoate, an ester; the reaction is esterification (a condensation reaction).
(c) Concentrated sulfuric acid acts as a catalyst (and dehydrating/water-removing agent), increasing the rate and yield of the reversible reaction.
12. (a) Cis-trans (E/Z) isomerism, which arises because rotation about the $\text{C}=\text{C}$ double bond is restricted (the π bond prevents free rotation), and each double-bond carbon has two different groups attached.
(b) In the cis (Z) isomer both —CH_3 groups are on the same side of the double bond, giving the molecule an overall dipole; in the trans (E) isomer the —CH_3 groups are on opposite sides, and the molecule is non-polar (dipoles cancel). The cis isomer has the higher boiling point because its molecules experience additional permanent dipole-dipole forces in addition to London dispersion forces.

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