IB DP CHEMISTRY

Structure 3 · Classification of Matter

MARK SCHEME

S3.1 The Periodic Table: Classification of Elements

S3.2 Functional Groups: Classification of Organic Compounds

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Chemistry course (first assessment 2025)

Section A — Multiple Choice: Answer Key (15 marks)

1. Answer: **B** — Electronegativity is a measure of the relative ability of an atom (in a covalent bond) to attract the shared pair of bonding electrons towards itself.

2. Answer: **D** — Electronegativity generally increases across a period as nuclear charge increases (with similar shielding), so chlorine, at the right-hand end of Period 3 (excluding the noble gas), has the highest electronegativity.

3. Answer: **B** — Down Group 1, atomic radius increases and the outer electron is progressively further from (and more shielded from) the nucleus, so first ionization energy decreases, making it easier to lose the outer electron and react.

4. Answer: **B** — Period 3 oxides change from strongly basic (Na_2O, MgO) through amphoteric (Al_2O_3) to acidic (SO_3), reflecting the change from metallic to non-metallic character across the period.

5. Answer: **B** — Metalloids, found along the 'staircase' boundary of the periodic table, have properties intermediate between metals and non-metals, and many (such as silicon) behave as semiconductors.

6. Answer: **B** — A horizontal row of the periodic table is called a period; a vertical column is called a group.

7. Answer: **B** — Metallic character decreases across a period (as elements become more non-metallic/electronegative) and increases down a group (as ionization energy decreases and atoms more readily lose electrons).

8. Answer: **C** — Sulfur is located on the right-hand side of the periodic table (Group 16) and is a non-metal; Mg, Al and Na are all metals.

9. Answer: **C** — The −OH functional group characteristic of alcohols is called the hydroxyl group.

10. Answer: **B** — A homologous series is a family of compounds with the same functional group and general formula, in which successive members differ by a CH_2 unit and show a gradual trend in physical properties.

11. Answer: **B** — Alkanes are saturated hydrocarbons with the general formula C_nH_{2n+2}.

12. Answer: **B** — Isomers are compounds that share the same molecular formula but differ in the arrangement of their atoms (structural isomers) or in spatial arrangement (stereoisomers).

13. Answer: **B** — Carboxylic acids contain the carboxyl functional group, −COOH.

14. Answer: **C** — Longer alkane chains have more electrons and greater molar mass, increasing the strength of London (dispersion) forces between molecules, so more energy is required to separate them, raising the boiling point.

15. Answer: **A** — The −OH group in propan-1-ol allows hydrogen bonding between molecules (in addition to London forces), which are much stronger than the London forces alone that act between non-polar propane molecules, giving propan-1-ol a much higher boiling point.

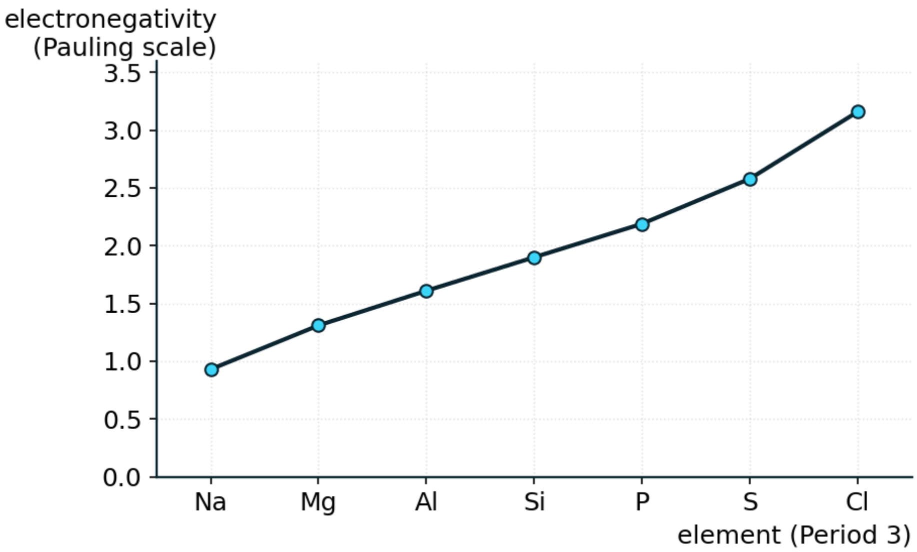
Section B — Structured Questions: Worked Solutions (65 marks)

Mark-scheme notation: M = method mark, A = accuracy mark (dependent on the preceding M mark), R = reasoning mark.

S3.1 The Periodic Table

Question 1 [7 marks]

The graph shows the electronegativity (Pauling scale) of the Period 3 elements from sodium to chlorine.



Electronegativity across Period 3 (given data).

(a) Using the graph, identify the elements with the highest and lowest electronegativity shown. **[2]**

Highest electronegativity = **chlorine** (3.16); lowest electronegativity = **sodium** (0.93). **A1 A1**

(b) Describe and explain the general trend in electronegativity across Period 3. **[3]**

Electronegativity **increases** across Period 3 from Na to Cl. Nuclear charge increases across the period while the outer electrons remain in the same shell (similar shielding), so the nucleus attracts the shared pair of bonding electrons more strongly, increasing electronegativity. **A1 R1 R1**

(c) Explain why the noble gas argon is usually omitted from electronegativity trends and data tables. **[2]**

Argon has a full outer shell and does not readily form covalent bonds under normal conditions, so it does not have a meaningful electronegativity value on the Pauling scale (which is defined in terms of bonding behaviour). **R1 R1**

Question 2 [6 marks]

The Group 1 metals (lithium, sodium, potassium) react with water with increasing vigour going down the group.

(a) Describe how the reactivity of Group 1 metals with water changes going down the group. **[2]**

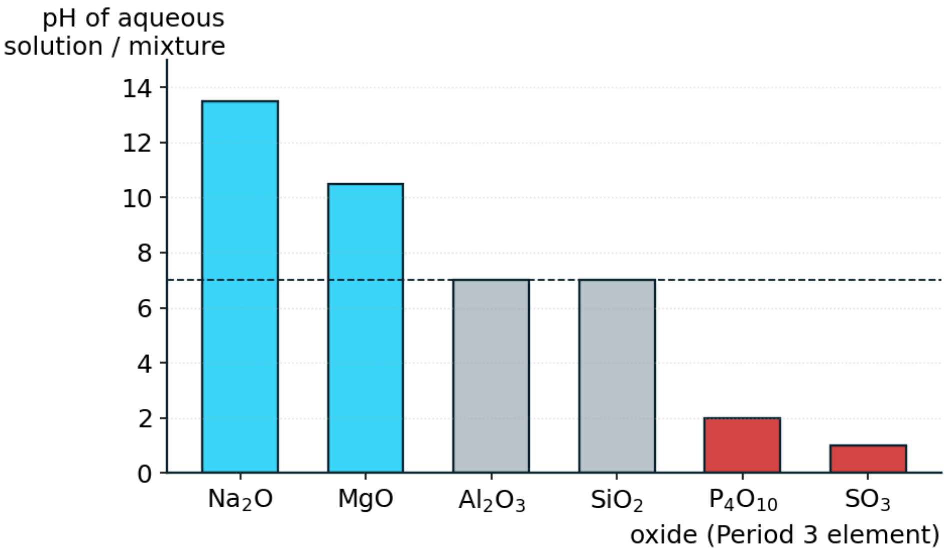
Reactivity with water **increases** going down Group 1: lithium reacts steadily, sodium reacts vigorously, and potassium reacts violently (often igniting). **A1 A1**

(b) Explain this trend in reactivity in terms of atomic structure. **[4]**

Going down Group 1, atomic radius **increases** and the single outer-shell electron is progressively further from the nucleus and more shielded by inner electron shells. This means **less energy** is required to remove the outer electron, so first ionization energy **decreases** down the group. Since reaction with water involves the metal atom losing its outer electron to form a positive ion, this electron loss becomes easier down the group, making the metal more reactive. **R1 R1 R1 A1**

Question 3 [7 marks]

The graph shows the approximate pH of the aqueous solutions (or mixtures) formed by the oxides of the Period 3 elements.



Approximate pH of Period 3 oxide solutions/mixtures (given data).

(a) Using the graph, identify one basic oxide and one acidic oxide from Period 3. **[2]**

Basic oxide, e.g. **Na_2O** (or MgO), pH ≥ 10.5. Acidic oxide, e.g. **SO_3** (or P_4O_{10}), pH ≤ 2. **A1 A1**

(b) Explain the general trend from basic to acidic oxides across Period 3, in terms of metallic/non-metallic character. **[3]**

Period 3 changes from strongly **metallic** character (Na, Mg) to strongly **non-metallic** character (P, S, Cl) across the period. Metal oxides are generally basic (react with acids to form salts and water), while non-metal oxides are generally acidic (react with bases and dissolve in water to form acidic solutions), so the oxides become progressively less basic and more acidic across the period as metallic character decreases. **R1 R1 A1**

(c) Al_2O_3 has a pH close to neutral in the graph. Classify its behaviour and explain what this means. **[2]**

Al_2O_3 is **amphoteric**: it can react with both acids (acting as a base) and with bases (acting as an acid), reflecting aluminium's intermediate position between strongly metallic and non-metallic character. **A1 R1**

Question 4 [6 marks]

Silicon (Si, Group 14) lies on the boundary between metals and non-metals in the periodic table.

(a) Classify silicon and state one physical property that justifies this classification. **[2]**

Silicon is a **metalloid (semi-metal)**. It behaves as a **semiconductor** — its electrical conductivity is intermediate between that of a typical metal and a typical non-metal, and increases with temperature (unlike a true metal). **A1 A1**

(b) Describe how metallic character changes (i) across a period and (ii) down a group of the periodic table. **[2]**

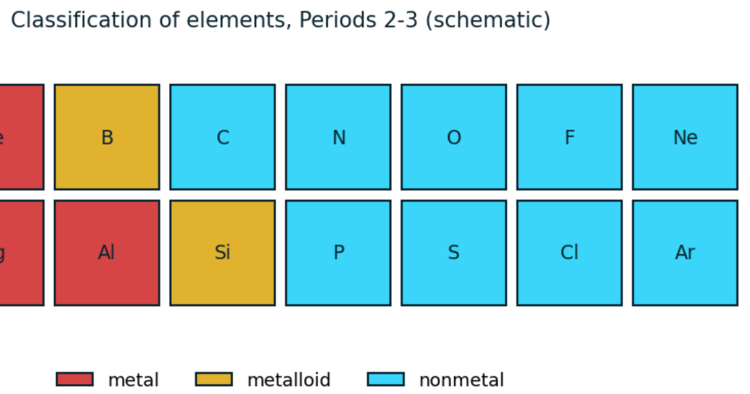
(i) Metallic character **decreases** across a period (from left to right). (ii) Metallic character **increases** down a group. **A1 A1**

(c) Using the trends in part (b), suggest whether tin (Sn), directly below silicon in Group 14, would be expected to show more or less metallic character than silicon. **[2]**

Tin would be expected to show **more** metallic character than silicon, since metallic character increases down a group; tin is indeed classified as a metal, unlike silicon which is a metalloid. **R1 A1**

Question 5 [6 marks]

The diagram shows a simplified classification of some Period 2 and Period 3 elements as metals, metalloids, or non-metals.



Classification of elements, Periods 2-3 (schematic).

(a) Using the diagram, identify one metal, one metalloid, and one non-metal from Period 3. **[2]**

Metal, e.g. **Na, Mg or Al**. Metalloid: **Si**. Non-metal, e.g. **P, S or Cl**. **A1 A1**

(b) Describe the general position of the metalloids in the periodic table, based on the diagram. **[2]**

The metalloids lie along a **diagonal 'staircase' line** that separates the metals (to the left) from the non-metals (to the right) of the periodic table, e.g. running from boron (B) down through silicon (Si). **A1 A1**

(c) State one physical property that generally differs between a metal and a non-metal element shown in the diagram. **[2]**

Metals are generally good **conductors of electricity** (and heat), whereas non-metals are generally poor conductors (insulators). (Other valid answers: metals are typically malleable/lustrous solids, while many non-metals are brittle solids, liquids, or gases at room temperature.) **A1 R1**

S3.2 Functional Groups

Question 6 [6 marks]

Alkanes form a homologous series of saturated hydrocarbons.

(a) Define the term 'homologous series'. **[2]**

A homologous series is a family of compounds with the **same functional group** (or general structure) and the **same general formula**, in which successive members differ by a CH_2 unit and show a gradual trend in physical properties. **A1 A1**

(b) State the general formula of the alkanes, and use it to deduce the molecular formula of the alkane with 6 carbon atoms. **[2]**

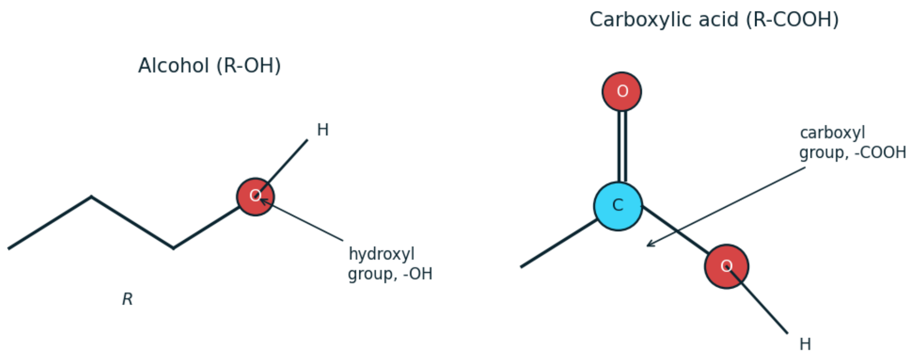
General formula: $\mathbf{C_nH_{2n+2}}$. For n = 6: $C_6H_{(2\cdot6)+2}$ = $\mathbf{C_6H_{14}}$. **A1 A1**

(c) Identify the functional group present in ethanol, CH_3CH_2OH. **[2]**

Ethanol contains the **hydroxyl group, −OH**, so it belongs to the homologous series of alcohols. **A1 A1**

Question 7 [7 marks]

The diagrams show the structures of two important functional groups found in organic compounds.



Functional groups: alcohol (hydroxyl) and carboxylic acid (carboxyl), schematic.

(a) Identify the functional group and name the homologous series shown in each diagram. **[2]**

Left diagram: the **hydroxyl group, −OH**, characteristic of the **alcohols**. Right diagram: the **carboxyl group, −COOH**, characteristic of the **carboxylic acids**. **A1 A1**

(b) State the general formula for a straight-chain, saturated carboxylic acid in terms of n (number of carbon atoms). **[2]**

General formula: $\mathbf{C_nH_{2n}O_2}$ (equivalently written $C_nH_{2n+1}COOH$ for the alkyl chain plus −COOH). **A1 A1**

(c) Describe a simple chemical test that could be used to distinguish a carboxylic acid from an alcohol. **[3]**

Add a small amount of a carbonate (e.g. sodium hydrogencarbonate) to each substance. The **carboxylic acid** reacts, producing visible **effervescence (bubbles) of carbon dioxide gas**; the **alcohol** does not react, and no effervescence is observed. **M1 A1 A1**

Question 8 [6 marks]

Consider the straight-chain alcohol with the structural formula $CH_3CH_2CH_2OH$.

(a) Give the IUPAC name of this compound. **[2]**

This is a 3-carbon chain with the −OH group on carbon 1: the IUPAC name is **propan-1-ol**. **A1 A1**

(b) Draw or describe the structure of a structural isomer of this compound that is also an alcohol. **[2]**

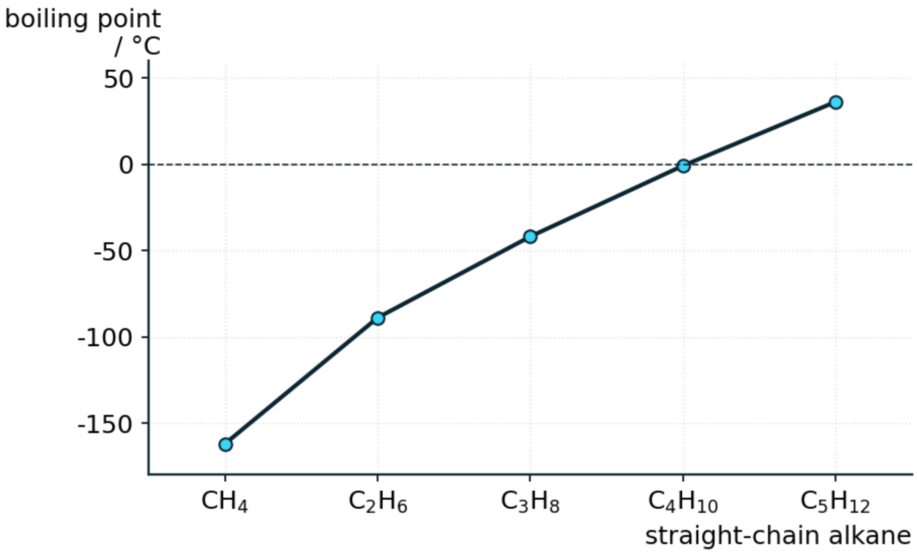
Propan-2-ol, $CH_3CH(OH)CH_3$, in which the −OH group is on the central (2nd) carbon atom instead of the end carbon — same molecular formula (C_3H_8O), different structural arrangement. **A1 A1**

(c) State the type of isomerism shown between propan-1-ol and propan-2-ol. **[2]**

This is **structural (positional) isomerism** — the two compounds have the same molecular formula but the −OH functional group is attached at a different position along the carbon chain. **A1 A1**

Question 9 [7 marks]

The graph shows the boiling points of the first five members of the straight-chain alkane homologous series.



Boiling point vs chain length, straight-chain alkanes (given data).

(a) Describe the trend in boiling point shown in the graph as the number of carbon atoms increases. **[2]**

Boiling point **increases steadily** as the number of carbon atoms (chain length) increases, from −162°C for CH_4 up to 36°C for C_5H_{12}. **A1 A1**

(b) Explain this trend in terms of intermolecular forces. **[3]**

Alkanes are non-polar, so only **London (dispersion) forces** act between molecules. As chain length increases, the number of electrons and the molar mass of the molecule increase, strengthening the London forces between molecules. More energy is therefore required to separate the molecules and overcome these forces, so boiling point increases with chain length. **R1 R1 A1**

(c) Using the trend in the graph, predict the boiling point of hexane, C_6H_{14} (the next member of the series). **[2]**

The boiling point increases by about 37°C between C_4H_{10} (−1°C) and C_5H_{12} (36°C). Extrapolating this gradient: predicted boiling point of hexane ≈ 36 + 37 = **73°C** (the accepted literature value is 69°C, so this simple linear extrapolation gives only an approximate estimate). **M1 A1**

Question 10 [7 marks]

Ethanol (CH_3CH_2OH, boiling point 78°C) and ethane (CH_3CH_3, boiling point −89°C) have similar molar masses but very different boiling points. Ethanoic acid (CH_3COOH, boiling point 118°C) has a functional group related to that of ethanol.

(a) Explain why ethanol has a much higher boiling point than ethane. **[3]**

Ethanol contains a polar −OH group, which allows **hydrogen bonding** to form between ethanol molecules, in addition to London forces. Ethane is non-polar and can only form weak London forces between molecules. Hydrogen bonds are much stronger than London forces, so significantly more energy is required to separate ethanol molecules, giving ethanol a much higher boiling point. **R1 R1 A1**

(b) Explain why ethanoic acid has an even higher boiling point than ethanol. **[2]**

Ethanoic acid's carboxyl group (−COOH) contains two oxygen atoms and can form **more extensive/stronger hydrogen bonding** between molecules than the single −OH group in ethanol (carboxylic acid molecules can form strong hydrogen-bonded dimers). This requires more energy to overcome, giving ethanoic acid a higher boiling point than ethanol. **R1 A1**

(c) State the functional group responsible for the hydrogen-bonding capability of both ethanol and ethanoic acid. **[2]**

Both contain an **O−H bond** (the hydroxyl part of the −OH group in ethanol, and part of the −COOH group in ethanoic acid); the highly electronegative oxygen atom bonded to hydrogen allows hydrogen bonding to form between molecules. **A1 A1**