Chapter: 3: Bonding and structure
Book/PDF: Chapter-03.pdf
Pages: 30–53
Exam level: Cambridge IGCSE (0610)

1) Big-picture overview

This chapter explains how atoms join together to form the substances all around us. You'll learn about the three main types of chemical bonds: **ionic**, **covalent**, and **metallic**. Ionic bonds form when atoms transfer electrons, creating charged particles (ions) that attract each other, typically between metals and non-metals. Covalent bonds form when non-metal atoms share electrons. Metallic bonds are found in metals, where outer electrons are free to move, holding a lattice of positive ions together. Understanding these bonds is crucial because they determine a substance's properties, such as its melting point, solubility, and whether it can conduct electricity. The chapter also introduces redox reactions—the process of electron loss (oxidation) and gain (reduction)—which are fundamental to ionic bonding.

2) Syllabus mapping

Outcome description	Where covered (page)
Describe the formation of ionic bonds between metals and non-metals.	30–31
Draw dot-and-cross diagrams for simple ionic compounds.	31–32
Describe the properties of ionic compounds (melting point, solubility, conductivity).	34
Explain the properties of ionic compounds in terms of their giant lattice structure.	34
Describe the formation of covalent bonds between non-metal atoms.	38
Draw dot-and-cross diagrams for simple covalent molecules, including those with multiple bonds.	38–42

Outcome description	Where covered (page)
Describe the properties of simple molecular covalent compounds.	43
Explain the properties of simple covalent compounds (low m.p./b.p.) in terms of weak intermolecular forces.	43
Describe the giant covalent structures of diamond, graphite, and silicon(IV) oxide.	44, 46–47
Relate the structures and bonding of diamond and graphite to their different uses.	47
Describe metallic bonding as a lattice of positive ions in a 'sea' of delocalised electrons.	50
Explain the properties of metals (conductivity, malleability) in terms of their structure and bonding.	50
Define oxidation and reduction in terms of electron transfer (OIL RIG).	31
Define oxidation and reduction in terms of change in oxidation number.	36
Identify redox reactions, oxidising agents, and reducing agents.	36–37
Deduce the formula of an ionic compound from the charges on its ions.	35

3) Key terms and definitions

Term	One-sentence definition	First appears (page)	Example/application
Ionic bond	[cite_start]The strong electrostatic attraction between oppositely charged ions[cite: 59].	31	[cite_start]The bond holding Na^+ and Cl^- ions together in salt[cite: 56].

Term	One-sentence definition	First appears (page)	Example/application
Ionisation	[cite_start]The process in which an atom becomes an ion by losing or gaining electrons[cite: 30].	31	[cite_start]A sodium atom is ionised to a Na^+ ion by losing one electron[cite: 30].
Oxidation	[cite_start]A process involving the loss of electrons [cite: 49] [cite_start]or an increase in oxidation number[cite: 233].	31	$Na \rightarrow Na^+ + e^-$
Reduction	[cite_start]A process involving the gain of electrons [cite: 50] [cite_start]or a decrease in oxidation number[cite: 233].	31	$Cl + e^- \rightarrow Cl^-$
Redox reaction	[cite_start]A reaction where oxidation and reduction occur simultaneously[cite: 51].	31	[cite_start]The reaction of sodium and chlorine to form sodium chloride[cite: 47].
Oxidation number	[cite_start]A number assigned to an atom or ion to show how oxidised or reduced it is[cite: 198].	35	In $MgCl_2$, Mg has an oxidation number of +2; [cite_start]Cl has -1[cite: 196, 201].
Oxidising agent	[cite_start]A substance that oxidises another substance and is itself reduced[cite: 263].	36	[cite_start]Acidified potassium manganate(VII) [cite: 238, 243].
Reducing agent	[cite_start]A substance that reduces another substance and is itself oxidised[cite: 264].	36	[cite_start]Iron(II) ions [cite: 243] [cite_start]or magnesium metal[cite: 261].
Covalent bond	[cite_start]A bond formed when a pair of electrons is shared between two atoms[cite: 286].	38	[cite_start]The H-H bond in a hydrogen molecule[cite: 289, 290].

Term	One-sentence definition	First appears (page)	Example/application
Intermolecular forces	[cite_start]Weak forces of attraction between simple molecules[cite: 484].	43	[cite_start]The forces holding iodine molecules together in a solid crystal[cite: 489].
Allotropy	[cite_start]When an element can exist in more than one physical form in the same state[cite: 513].	44	[cite_start]Carbon exists as diamond and graphite[cite: 516, 538].
Metallic bond	[cite_start]The electrostatic force of attraction between the giant lattice of positive ions and the 'sea' of delocalised electrons[cite: 637, 638].	50	[cite_start]The bonding in copper, iron, or any metal[cite: 632].
Malleable	[cite_start]The ability of a metal to be bent or hammered into different shapes[cite: 643].	50	A sheet of aluminium foil has been hammered flat.
Ductile	[cite_start]The ability of a metal to be pulled out into thin wires[cite: 644].	50	Copper is used for electrical wiring because it is ductile.

4) Core concepts explained

3.1 Ionic Bonding (p. 30)

- [cite_start]Ionic bonds form between **metals and non-metals**[cite: 13].
- The metal atom **loses** its outer shell electrons to form a **positive ion** (cation). [cite_start]This is **oxidation**[cite: 14, 45].
- The non-metal atom **gains** these electrons to form a **negative ion** (anion). [cite_start]This is **reduction**[cite: 14, 46].
- [cite_start]Both ions now have a stable, full outer shell of electrons, like a noble gas[cite: 15, 26].

- [cite_start]The strong electrostatic force of attraction between these oppositely charged ions is the ionic bond[cite: 56, 59].
- [cite_start]In the solid state, ions are arranged in a regular, repeating 3D pattern called a **giant ionic lattice**[cite: 140, 143]. [cite_start]For example, in NaCl, each Na^+ is surrounded by 6 Cl^- ions, and each Cl^- by 6 Na^+ ions (p. 33 [cite: 144]).

Properties of Ionic Compounds (p. 34)

Feature	Property	Explanation
State	[cite_start]Solid at room temperature[cite: 151].	[cite_start]Strong electrostatic forces in the giant lattice require a lot of energy to overcome[cite: 152, 153].
Melting/Boiling Points	[cite_start]High[cite: 151].	[cite_start]A large amount of thermal energy is needed to break down the strong lattice structure[cite: 153].
Solubility in water	[cite_start]Usually soluble[cite: 155].	[cite_start]Water molecules can surround the ions, breaking down the lattice[cite: 155, 156].
Electrical Conductivity	[cite_start]**Do not** conduct when solid[cite: 161]. [cite_start]**Do** conduct when molten or dissolved in water (aqueous)[cite: 158].	[cite_start]In the solid state, ions are fixed in the lattice and cannot move[cite: 161]. [cite_start]When molten or in solution, the ions are free to move and carry charge[cite: 159].

Redox and Oxidation Numbers (p. 31, 35–37)

- [cite_start]**Redox** is a reaction involving both **Red**uction and **Ox**idation[cite: 47, 51].
- [cite_start]A simple way to remember electron transfer is **OIL RIG**: **O**xidation **I**s **L**oss, **R**eduction **I**s **G**ain (of electrons) (p. 31 [cite: 49, 50]).
- **Oxidation Number** tracks electron control.
  - [cite_start]Oxidation is an **increase** in oxidation number (e.g., $Fe^{2+} \rightarrow Fe^{3+}$ is an increase from +2 to +3)[cite: 230].
  - [cite_start]Reduction is a **decrease** in oxidation number (e.g., $Cl_2 \rightarrow 2Cl^-$ is a decrease from 0 to -1)[cite: 231].
- [cite_start]An **oxidising agent** gets reduced itself (it takes electrons), while a **reducing agent** gets oxidised itself (it gives electrons)[cite: 234, 235].

3.2 Covalent Bonding (p. 38)

- [cite_start]Covalent bonds form between **non-metal atoms**[cite: 304].
- [cite_start]Atoms **share** one or more pairs of outer-shell electrons to achieve a stable, full outer shell (like a noble gas)[cite: 303, 305].
- [cite_start]A shared pair of electrons forms a strong covalent bond[cite: 286].
- [cite_start]**Single bond**: one shared pair of electrons (e.g., H-H in H_2)[cite: 290].
- [cite_start]**Double bond**: two shared pairs of electrons (e.g., O=O in O_2)[cite: 446, 461].
- [cite_start]**Triple bond**: three shared pairs of electrons (e.g., N≡N in N_2)[cite: 462, 463].

Covalent Structures and Their Properties (p. 43)

Feature	Simple Molecular Structure	Giant Covalent Structure
Structure	[cite_start]Made of small, discrete molecules (e.g., H_2O, CO_2, I_2)[cite: 483, 488].	[cite_start]A huge network of atoms joined by strong covalent bonds (e.g., diamond, graphite) [cite: 493, 494].
Bonds	**Strong** covalent bonds *within* molecules (intramolecular). [cite_start]**Weak** forces *between* molecules (intermolecular)[cite: 484].	[cite_start]**Strong** covalent bonds throughout the entire structure[cite: 493].
Melting/Boiling Points	**Low**. [cite_start]Only a small amount of energy is needed to overcome the weak intermolecular forces[cite: 496, 497].	**Very high**. [cite_start]A large amount of energy is needed to break the many strong covalent bonds[cite: 498].
Conductivity	**Do not** conduct electricity. [cite_start]Molecules have no overall charge and there are no free electrons or ions[cite: 500, 501].	[cite_start]**Do not** conduct (e.g., diamond), *except for graphite*[cite: 557, 576].

Allotropes of Carbon (p. 45–47)

Feature	Graphite	Diamond	Exam Note
Structure	[cite_start]Layers of hexagonal rings[cite: 559].	[cite_start]A rigid, tetrahedral lattice[cite: 573, 574].	You must be able to describe and sketch

Feature	Graphite	Diamond	Exam Note
			these structures.
Bonding	[cite_start]Each C atom is bonded to **3** others[cite: 560].	[cite_start]Each C atom is bonded to **4** others[cite: 573].	This difference in bonding is the key to their properties.
Properties	[cite_start]Soft and slippery (layers slide over each other due to weak forces between them)[cite: 557, 561]. [cite_start]Conducts electricity (has delocalised electrons between layers)[cite: 557, 563].	[cite_start]Very hard (strong covalent bonds throughout) [cite: 557, 575]. [cite_start]Does not conduct electricity (all outer electrons are used in bonding)[cite: 557, 576].	Link properties directly to structure. "Graphite is soft because the layers can slide" is a key marking point.
Uses	[cite_start]Lubricant, pencil 'leads', electrodes[cite: 571].	[cite_start]Jewellery, cutting tools (glass cutters, drill bits) [cite: 571].	Uses are a direct result of the properties.

[cite_start]**Silicon(IV) Oxide (SiO_2)**, found in sand and quartz, has a giant covalent structure similar to diamond, giving it a very high melting point and making it very hard (p. 44[cite: 494, 511], p. [cite_start]52 [cite: 703]).

3.3 Metallic Bonding (p. 50)

- [cite_start]Describes the bonding in metals[cite: 632].
- [cite_start]Metal atoms lose their outer shell electrons, which become **delocalised** (free to move) [cite: 633, 634].
- [cite_start]This creates a regular lattice of **positive metal ions**[cite: 635].
- [cite_start]The metallic bond is the strong electrostatic attraction between these positive ions and the "sea" of negative delocalised electrons that surrounds them[cite: 637, 638].

Properties of Metals (p. 50)

- [cite_start]**Good electrical conductors**: The delocalised electrons are free to move and carry charge through the structure[cite: 658, 659].

- [cite_start]**Malleable and ductile**: When a force is applied, layers of ions can slide over one another without breaking the metallic bond, which reforms in the new positions[cite: 640, 641, 642].
- [cite_start]**High melting/boiling points**: A lot of energy is needed to overcome the strong attraction between the positive ions and the electron sea[cite: 645].
- [cite_start]**High density**: The ions are packed closely together in a regular lattice[cite: 665].

5) Diagrams and micrographs (figures)

- **Ionic Bonding in NaCl (Fig 3.2, p. 31)**: Shows a sodium atom (2,8,1) transferring its single outer electron to a chlorine atom (2,8,7). This results in a Na^+ ion (2,8) and a Cl^- ion (2,8,8), both with full outer shells.
- **Giant Ionic Lattice of NaCl (Fig 3.6d, p. 33)**: A 3D cube-like structure showing small orange spheres (Na^+) and larger green spheres (Cl^-) arranged in a regular, alternating pattern. Each ion is surrounded by 6 of the opposite ion.
- **Covalent Bonding in Methane, CH_4 (Fig 3.15, p. 39)**: A central carbon atom shares one pair of electrons with each of four hydrogen atoms. The diagram shows the outer shells overlapping, with crosses for carbon's electrons and dots for hydrogen's.
- **Structure of Graphite (Fig 3.28a, p. 46)**: Shows flat layers of carbon atoms arranged in interconnected hexagons. The layers are shown stacked on top of each other with space in between, representing weak intermolecular forces.
- **Structure of Diamond (Fig 3.29a, p. 46)**: Shows each carbon atom at the center of a tetrahedron, strongly bonded to four other carbon atoms. This creates a rigid, repeating 3D network.
- **Metallic Bonding Model (Fig 3.34, p. 50)**: A diagram showing positive ions (circles with '+' signs) arranged in a regular pattern, surrounded by a 'sea' of tiny delocalised electrons (dots with '-' signs) moving freely among them.

6) Processes and cycles

Process: Forming an Ionic Bond (e.g., Sodium Chloride)

1. [cite_start]**Approach**: A sodium atom (metal) comes into contact with a chlorine atom (non-metal) during a reaction (p. 30 [cite: 16]).

2. [cite_start]**Electron Transfer**: The sodium atom transfers its single outer electron to the chlorine atom (p. 30 [cite: 23]).
3. **Ion Formation**:
    - [cite_start]Sodium, having lost an electron, becomes a positive sodium ion (Na^+)[cite: 30, 34]. [cite_start]This is oxidation[cite: 45].
    - [cite_start]Chlorine, having gained an electron, becomes a negative chloride ion (Cl^-)[cite: 45]. [cite_start]This is reduction[cite: 46].
4. [cite_start]**Electrostatic Attraction**: The oppositely charged Na^+ and Cl^- ions are now strongly attracted to each other, forming an ionic bond[cite: 56, 57].
5. [cite_start]**Lattice Formation**: Millions of ions pack together in a regular giant ionic lattice structure[cite: 143].

- [cite_start]**Word Equation:** Sodium + Chlorine → Sodium chloride [cite: 17]

7) Formulae and calculations

Deducing Ionic Formulae

[cite_start]To find the formula of an ionic compound, the total positive charge must balance the total negative charge[cite: 193]. You can use the oxidation numbers (valencies) of the ions.

Quantity	Formula/Method	Units	Typical values	Worked example
Chemical Formula	1. Identify ions and their charges (oxidation numbers). 2. Balance the charges to find the ratio of ions.	n/a	From Table 3.1 (p. 35): Mg^{2+}, Na^+, O^{2-}, NO_3^-	**Find the formula for magnesium nitrate.** 1. [cite_start]Ions: Magnesium (Mg^{2+}) and Nitrate (NO_3^-)[cite: 209]. 2. Charges: Mg is +2, NO_3 is -1. 3. Balance: We need two -1 charges to balance one +2 charge. So, one Mg^{2+} ion combines with two NO_3^- ions. 4. [cite_start]Formula: **$Mg(NO_3)_2$**[cite: 209]. The brackets show that the subscript

Quantity	Formula/Method	Units	Typical values	Worked example
				'2' applies to the entire nitrate ion.
Ratio of Atoms	Count the atoms of each element in the final chemical formula.	n/a	Simple whole numbers.	[cite_start]**Find the ratio of atoms in $Mg(NO_3)_2$.** Mg: 1 N: 1 × 2 = 2 O: 3 × 2 = 6 Ratio = **1 Mg : 2 N : 6 O** [cite: 212]

8) Required practicals / experiments

Testing the Electrical Conductivity of Substances (p. 44–45)

- [cite_start]**Aim**: To investigate whether ionic and covalent compounds conduct electricity when dissolved in water[cite: 524].
- [cite_start]**Apparatus**: 6V power supply, wires, a bulb (or ammeter), a beaker, and two inert electrodes (e.g., graphite)[cite: 524, 526, 532].
- **Method**:
    i. [cite_start]Set up the circuit as shown in the diagram, with the electrodes dipped into a beaker[cite: 524].
    ii. [cite_start]Pour the first test solution (e.g., potassium chloride solution) into the beaker[cite: 525].
    iii. Turn on the power supply and observe whether the bulb lights up. [cite_start]Record the result[cite: 531].
    iv. Turn off the power, rinse the electrodes and beaker with distilled water, and dry them.
    v. [cite_start]Repeat steps 2-4 for each of the other test solutions (e.g., glucose solution, ethanol, pure water)[cite: 525, 531].
- **Variables**:
    - **Independent Variable (IV)**: The substance dissolved in the water.
    - **Dependent Variable (DV)**: Whether the bulb lights up (a measure of conductivity).
    - **Control Variables**: Voltage of the power supply, concentration of solutions, distance between electrodes.
- **Safety**: Wear eye protection. [cite_start]Handle solutions with care, as some can be irritants[cite: 521].

- **Sources of Error**: Electrodes not cleaned properly between tests, leading to cross-contamination. Inconsistent concentration of solutions.
- **Improvements**: Use an ammeter for a quantitative reading of current instead of just observing a bulb. Ensure all solutions are the same concentration.
- **Expected Results**:
  - [cite_start]**Ionic solutions** (potassium chloride, calcium chloride, copper(II) sulfate) will conduct electricity, and the **bulb will light up**[cite: 531].
  - [cite_start]**Covalent solutions** (glucose, ethanol) and pure water will not conduct, and the **bulb will not light up**[cite: 531].

9) Data handling and graphing

[cite_start]This chapter primarily uses **results tables** to display qualitative data, such as in the conductivity experiment (p. 45 [cite: 531]).

- **Table Interpretation**:
  - The table has columns for the 'Solution', 'Does the bulb light?', 'Does it conduct?', and 'Bonding type'.
  - You are expected to fill in the last two columns based on the observation in the second column.
  - **Trend**: A 'Yes' in the 'Bulb light?' column corresponds to 'Yes' for conductivity and 'Ionic' for bonding. A 'No' corresponds to 'No' for conductivity and 'Covalent' for bonding.
- **Typical Exam Prompts**:
  - "Copy and complete the table."
  - "Explain the results for potassium chloride solution." (Answer: It is an ionic compound, so in solution, its ions are free to move and carry charge).
  - "Predict the result for solid potassium chloride and explain your answer." (Answer: The bulb would not light because in a solid, the ions are in fixed positions in the lattice and cannot move) [cite_start][cite: 536, 161].

10) Common misconceptions and exam tips

- **Misconception**: "Ionic compounds are made of molecules."
  - **Correct Understanding**: Ionic compounds form giant ionic lattices, not separate molecules. The formula NaCl just represents the 1:1 ratio of ions in the lattice.

- **Tip**: Remember 'lattice' for ionic, 'molecule' for simple covalent.
- **Misconception**: "Covalent bonds are weak."
  - **Correct Understanding**: The covalent bonds *within* a molecule (intramolecular) are very strong. It is the *intermolecular* forces of attraction *between* the molecules that are weak.
  - **Tip**: To melt ice, you break the weak forces *between* H_2O molecules, not the strong covalent bonds *inside* them.
- **Misconception**: "Graphite is soft because its covalent bonds are weak."
  - **Correct Understanding**: Graphite's softness comes from the weak forces *between its layers*, allowing them to slide easily. The covalent bonds within the layers are very strong.
  - **Tip**: Think of graphite as a stack of paper. The paper itself is strong (the layers), but the sheets slide over each other easily.
- **Misconception**: "In a metal, electrons jump from one atom to another."
  - **Correct Understanding**: The outer electrons are delocalised, meaning they don't belong to any single atom but move freely as a 'sea' throughout the entire structure.
  - **Tip**: Visualise the electrons as a fluid flowing around fixed positive ions.

11) Exam-style practice

Multiple-Choice Questions

1. Which substance has a giant covalent structure?
   A) Sodium chloride
   B) Carbon dioxide
   C) Diamond
   D) Copper
   Answer: C. Diamond is an allotrope of carbon with a giant covalent lattice.
2. Why can metals be bent and shaped?
   A) They have weak metallic bonds.
   B) The atoms are in layers that can slide.
   C) They have a low density.
   D) The ions are in layers that can slide over one another.
   Answer: D. The layers of positive ions can slide without breaking the overall metallic bond.
3. Which statement about ionic compounds is correct?
   A) They have low melting points.
   B) They conduct electricity when solid.
   C) They are formed by sharing electrons.

D) They are typically formed between a metal and a non-metal.

Answer: D. Ionic bonds involve the transfer of electrons from a metal to a non-metal.

4. In the reaction $Zn + Cu^{2+}$
$rightarrow Zn^{2+} + Cu$, what has happened to the zinc?
   A) It has been reduced.
   B) It has been oxidised.
   C) It has acted as an oxidising agent.
   D) It has gained two protons.
   Answer: B. Zinc has lost two electrons (its oxidation number increased from 0 to +2), which is oxidation.
5. Which molecule contains a double covalent bond?
   A) H_2
   B) Cl_2
   C) O_2
   D) N_2
   Answer: C. An oxygen atom (6 outer electrons) needs to share two pairs of electrons to get a full outer shell.

(Note: The following MCQs are created to supplement the prompt's requirements and are not from the text.)

6. A substance has a low melting point and does not conduct electricity. What is its likely structure?
   A) Ionic lattice
   B) Simple molecular
   C) Giant covalent
   D) Metallic
   Answer: B. Simple molecular structures have weak intermolecular forces, leading to low melting points.
7. How many electrons are shared in a molecule of ammonia, NH_3?
   A) 2
   B) 3
   C) 6
   D) 8
   Answer: C. Nitrogen shares one pair of electrons with each of the three hydrogen atoms, making 3 pairs or 6 electrons in total.
8. Why does graphite conduct electricity?
   A) It contains mobile ions.
   B) It has weak bonds between layers.
   C) It has delocalised electrons.

D) It is a non-metal.
Answer: C. Each carbon atom in graphite has one delocalised electron that is free to move between the layers.

9. What is the correct formula for aluminium oxide? (Al has charge 3+, O has charge 2-)
   A) AlO
   B) Al_2O
   C) AlO_2
   D) Al_2O_3
   Answer: D. Two Al^{3+} ions (total charge +6) are needed to balance three O^{2-} ions (total charge -6).
10. What is the definition of reduction?
    A) Loss of electrons.
    B) Gain of protons.
    C) Gain of electrons.
    D) Loss of neutrons.
    Answer: C. Reduction Is Gain (RIG) of electrons.

Short-Answer Questions

1. **Define** the term 'ionic bond'.
   - *Marking points:* A strong electrostatic force of attraction [1] between oppositely charged ions [1].
2. **Explain** why sodium chloride has a high melting point but iodine (I_2) has a low melting point.
   - *Marking points:* NaCl has a giant ionic lattice structure [1] with strong electrostatic forces between ions [1] which require a lot of energy to overcome [1]. Iodine is a simple molecule [1] with weak intermolecular forces [1] which require little energy to overcome [1].
3. **Draw** a dot-and-cross diagram to show the bonding in a water molecule (H_2O). Show outer shells only.
   - *Marking points:* Oxygen atom with 6 outer electrons (e.g., crosses) [1]. Two hydrogen atoms, each with 1 outer electron (e.g., dots) [1]. One pair of electrons shared between oxygen and each hydrogen [1]. Oxygen has two non-bonding pairs of electrons shown [1].
4. In the reaction $Mg(s) + H\_2SO\_4(aq)$ $rightarrowMgSO\_4(aq) + H\_2(g)$, **identify** the substance that is oxidised and the substance that is reduced. **Explain** your answer in terms of oxidation numbers.
   - *Marking points:* Magnesium (Mg) is oxidised [1]. Its oxidation number increases from 0 (in Mg) to +2 (in $MgSO_4$) [1]. Hydrogen (H) is reduced [1]. Its oxidation number decreases from +1 (in H_2SO_4) to 0 (in H_2) [1].
5. **Describe** the structure and bonding in a typical metal.

- *Marking points:* A regular/giant lattice [1] of positive ions [1]. Surrounded by a 'sea' of delocalised electrons [1]. Held together by the electrostatic attraction between the positive ions and negative electrons [1].

Structured Questions

1. Calcium (Ca) is in Group 2 of the Periodic Table. Chlorine (Cl) is in Group 7.
   a) **Explain**, in terms of electrons, how calcium and chlorine atoms form ions. [2]
   b) **State** the formula of the ions formed. [2]
   c) **Deduce** the chemical formula of calcium chloride. [1]
   d) **Predict** two physical properties of calcium chloride. [2]
   - *Model Answer:*
     a) A calcium atom **loses** two outer shell electrons [1]. Each of two chlorine atoms **gains** one electron [1].
     b) Calcium ion is Ca^{2+} [1]. Chloride ion is Cl^- [1].
     c) $CaCl_2$ [1].
     d) Any two from: high melting/boiling point; soluble in water; conducts electricity when molten/aqueous; solid at room temperature [2].
2. Graphite and diamond are two allotropes of carbon.
   a) **Describe** the structure of diamond. [2]
   b) **Explain** why diamond is extremely hard. [2]
   c) **Explain** why graphite, unlike diamond, can conduct electricity. [2]
   - *Model Answer:*
     a) Each carbon atom is covalently bonded to **four** other carbon atoms [1], forming a rigid, **tetrahedral** giant lattice [1].
     b) The structure is held together by many **strong covalent bonds** throughout [1], which require a large amount of energy to break [1].
     c) In graphite, each carbon atom is bonded to only **three** others [1]. This leaves one **delocalised electron** per atom which is free to move and carry charge [1]. In diamond, all electrons are used in bonding and are not free.

12) Quick revision checklist

- [ ] I can describe an ionic bond as the electrostatic attraction between oppositely charged ions.
- [ ] I can draw dot-and-cross diagrams for ionic compounds like NaCl and $MgCl_2$.
- [ ] I can explain why ionic compounds have high melting points and only conduct electricity when molten or aqueous.

- ☐ I can describe a covalent bond as a shared pair of electrons.
- ☐ I can draw dot-and-cross diagrams for simple molecules like H_2O, CH_4, O_2, and CO_2.
- ☐ I can explain the difference between simple molecular and giant covalent structures.
- ☐ I can explain why simple covalent substances have low melting points.
- ☐ I can describe the structures of diamond and graphite.
- ☐ I can relate the properties of diamond (hard) and graphite (soft, conductive) to their structures and uses.
- ☐ I can describe metallic bonding as a lattice of positive ions in a sea of delocalised electrons.
- ☐ I can explain why metals are malleable and good electrical conductors.
- ☐ I can define oxidation as electron loss and reduction as electron gain (OIL RIG).
- ☐ I can identify the oxidising and reducing agents in a redox reaction.
- ☐ I can determine the formula of an ionic compound given the charges of the ions.

13) Flashcards (ready-to-use)

Question	Answer
What is an ionic bond?	[cite_start]The strong electrostatic force of attraction between oppositely charged ions (p. 31 [cite: 59]).
How are positive ions formed?	[cite_start]When a metal atom loses one or more electrons (p. 30 [cite: 14]).
What is oxidation?	[cite_start]The loss of electrons, or an increase in oxidation number (p. 31[cite: 49], p. [cite_start]36 [cite: 233]).
What is reduction?	[cite_start]The gain of electrons, or a decrease in oxidation number (p. 31[cite: 50], p. [cite_start]36 [cite: 233]).
Why do solid ionic compounds not conduct electricity?	[cite_start]The ions are held in fixed positions in the lattice and are not free to move (p. 34 [cite: 161]).
What is a covalent bond?	[cite_start]A pair of electrons shared between two non-metal atoms (p. 38 [cite: 286]).
Why do simple molecules like methane have low boiling points?	[cite_start]Because of the weak intermolecular forces between the molecules, which require little energy to overcome (p. 43 [cite: 497]).

Question	Answer
What is a giant covalent structure?	[cite_start]A structure containing many hundreds of thousands of atoms joined by strong covalent bonds (p. 43 [cite: 493]).
How many other atoms is each carbon atom bonded to in diamond?	[cite_start]Four (p. 47 [cite: 573]).
How many other atoms is each carbon atom bonded to in graphite?	[cite_start]Three (p. 47 [cite: 560]).
Why is graphite a good lubricant?	[cite_start]It has a layered structure, and the weak forces between layers allow them to slide over each other easily (p. 47 [cite: 561]).
Why do metals conduct electricity?	[cite_start]They have delocalised electrons that are free to move through the structure and carry charge (p. 50 [cite: 658, 659]).
What does malleable mean?	[cite_start]It can be hammered or bent into shape (p. 50 [cite: 643]).
What does ductile mean?	[cite_start]It can be pulled into a wire (p. 50 [cite: 644]).
What is the formula for magnesium oxide?	[cite_start]MgO (Mg is 2+, O is 2-) (p. 32 [cite: 79]).

14) 60-second recap

This chapter covers the three ways atoms bond: ionic, covalent, and metallic. Ionic bonding involves the transfer of electrons from metals to non-metals, creating a strong lattice of oppositely charged ions with high melting points. Covalent bonding involves the sharing of electrons between non-metals, forming either simple molecules with low melting points due to weak intermolecular forces, or giant structures like diamond and graphite which have very high melting points. Diamond is hard because of its rigid 3D lattice, while graphite is soft and conductive due to its layered structure and delocalised electrons. Metallic bonding involves a lattice of positive ions in a 'sea' of mobile electrons, which explains why metals are conductive and malleable. All these bonding types are ways for atoms to achieve a stable, full outer electron shell.

15) References to pages

16) Excluded "Going further" sections (not summarized)

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The 'cross-over method'	38
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