Cambridge IGCSE · Chemistry 0620 · Notes

Covalent bonding and giant covalent structures

Read online at **pastopic.com/cambridge/chemistry-0620/notes/covalent-bonding**

Last checked 30 September 2026

Read first: **Elements, compounds and atomic structure**, **Ionic and metallic bonding**

What you need to know

By the end of this topic you should be able to:

1. **State what a covalent bond is**: a pair of electrons shared between two atoms, which gives both atoms a noble-gas electronic configuration.
2. **Describe how covalent bonds form in simple molecules** such as H_2, Cl_2, H_2O, CH_4, NH_3 and HCl, and draw dot-and-cross diagrams of these and similar molecules.
3. **Describe the properties of simple molecular compounds** in terms of their structure and bonding: low melting and boiling points, and poor electrical conductivity.
4. **Describe the giant covalent structures of graphite and diamond.**
5. **Relate the structures of graphite and diamond to their uses**: graphite as a lubricant and as an electrode; diamond in cutting tools.
6. **Extended only:** describe the covalent bonds in molecules such as CH_3OH, C_2H_4, O_2, CO_2 and N_2 (including double and triple bonds), with dot-and-cross diagrams of these and similar molecules.
7. **Extended only:** explain the low melting and boiling points of simple molecular compounds in terms of weak intermolecular forces (you don't need the names of the types of force), and explain their poor electrical conductivity.
8. **Extended only:** describe the giant covalent structure of silicon(IV) oxide, SiO_2.
9. **Extended only:** describe how the properties of silicon(IV) oxide are like those of diamond, and relate this to their structures.

Understand it

Sharing electrons

In the note on ionic bonding, a metal atom gave electrons to a non-metal atom. When **two non-metal atoms** meet, neither will give electrons away: both need to **gain** electrons to fill their outer shell. Instead, they **share** them.

Each atom puts **one electron** into the space between the two atoms. That **pair of shared electrons** counts towards the outer shell of **both** atoms at once, and it holds the two atoms together. This is a **covalent bond**:

a covalent bond is a **pair of electrons shared between two atoms**, which gives the atoms **noble-gas electronic configurations**.

A covalent bond is **one pair** (two electrons) shared by **two atoms**, no more. A group of atoms joined by covalent bonds is a **molecule**. Molecules have **no charge**: nothing has been gained or lost, only shared.

How many bonds does an atom form?

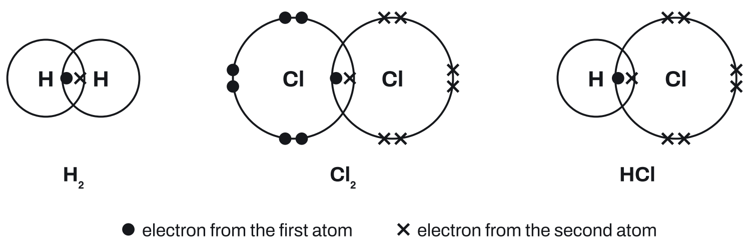
An atom forms enough bonds to fill its outer shell: **8** electrons, or **2** for hydrogen (its only shell holds two). Each bond adds one electron to the atom's count, so:

Atom	Group	Outer electrons	Electrons needed	Covalent bonds formed	Non-bonding (lone) pairs left
H	I	1	1	1	0
C, Si	IV	4	4	4	0
N, P	V	5	3	3	1
O, S	VI	6	2	2	2
F, Cl, Br, I	VII	7	1	1	3

The outer electrons that are not in bonds sit in pairs on the atom: these are **non-bonding pairs** (lone pairs). You need them in every dot-and-cross diagram.

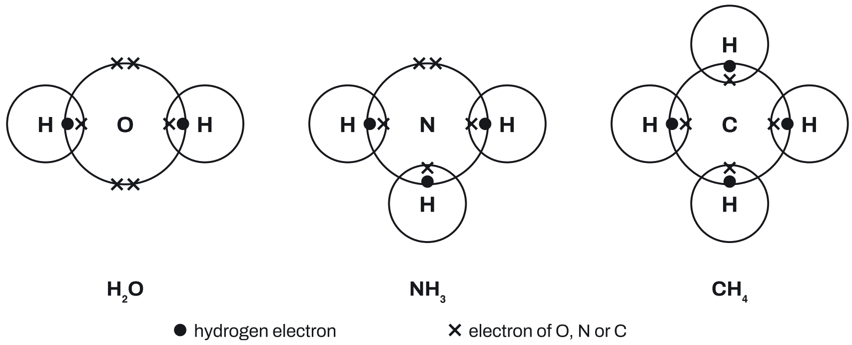
Dot-and-cross diagrams of molecules

Draw each atom's outer shell as a circle. Where two atoms bond, their circles **overlap**, and the shared pair goes in the overlap: **one electron from each atom**. Electrons of one atom are dots and those of the other are crosses, so you can see where each came from. Use just dots and crosses, never a third symbol. If the key gives two bonded atoms the same symbol (in diagram 4 below, C and O are both crosses), their shared pair shows two of that symbol; that is still one electron from each atom.



Check every diagram by counting: each atom's circle must hold **8** electrons (bonding and non-bonding together), or **2** for hydrogen. In HCl, chlorine has 2 in the overlap plus 6 in three lone pairs, which is 8; hydrogen has just the 2 in the overlap.

The same idea gives the three molecules you must know with a central atom:



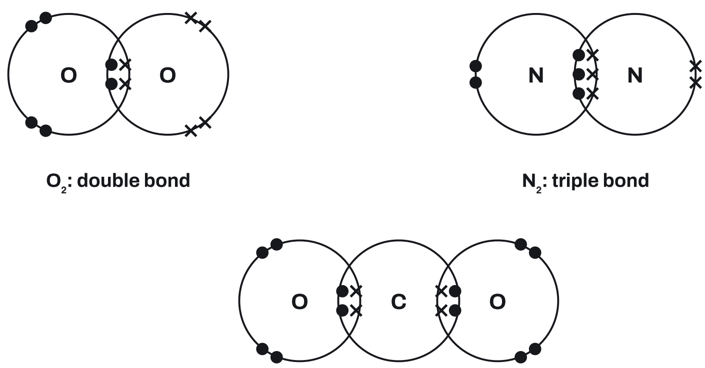
- **Water, H_2O**: 2 bonds, and **2 lone pairs** on oxygen (4 non-bonding electrons).
- **Ammonia, NH_3**: 3 bonds, and **1 lone pair** on nitrogen.
- **Methane, CH_4**: 4 bonds, and **no lone pairs**: carbon uses all four of its outer electrons in bonds.

"Similar molecules" follow the same pattern. Hydrogen sulfide, H_2S, is drawn like water (S is in Group VI); PCl_3 and NCl_3 are drawn like ammonia, but each Cl also has its 3 lone pairs; F_2, Br_2 and I_2 are drawn like Cl_2.

Double and triple bonds

Extended only. Some atoms share **two** or **three** pairs with the same partner:

- A **double bond** is **two shared pairs** (4 electrons). An oxygen atom needs 2 more electrons, so in O_2 the two atoms share two pairs.
- A **triple bond** is **three shared pairs** (6 electrons). A nitrogen atom needs 3 more electrons, so in N_2 the two atoms share three pairs.
- In **carbon dioxide**, carbon needs 4 electrons and each oxygen needs 2, so carbon forms a **double bond to each oxygen**: O=C=O.



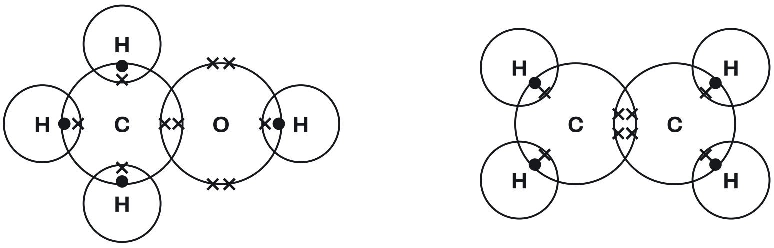
O_2: double bond

N_2: triple bond

CO_2: two double bonds

Count again: in O_2 each atom has 4 bonding + 4 non-bonding = 8; in N_2, 6 + 2 = 8; in CO_2 carbon has 4 + 4 = 8 and no lone pairs.

Two organic molecules are on the syllabus. In the diagrams below, hydrogen electrons are dots and the electrons of carbon and oxygen are crosses. In **ethene, C_2H_4**, the two carbon atoms share a **double bond** and each carbon bonds to two hydrogens. In **methanol, CH_3OH**, carbon bonds to three H atoms and the O atom; the oxygen bonds to carbon and one H, and keeps **2 lone pairs**.



CH_3OH **C_2H_4**
● hydrogen electron ✕ electron of C or O

Simple molecular substances

A **simple molecular** substance, such as water, chlorine, methane or carbon dioxide, is made of **small, separate molecules**. There are two kinds of attraction in it, and they are very different:

- **Inside** each molecule, the atoms are held by **covalent bonds**, which are **strong**.
- **Between** the molecules there are **intermolecular forces** (forces of attraction between molecules), which are **weak**.

When the substance melts or boils, the molecules move apart, so only the **weak forces between molecules** are overcome. The covalent bonds are **not** broken: steam is still H_2O molecules. Little energy is needed, so:

1. **Low melting and boiling points.** Many simple molecular substances are gases or liquids at room temperature (methane, chlorine, water); some are solids that melt easily, such as sulfur or iodine.
   - **Extended only, why:** the **intermolecular forces are weak**, so **little energy** is needed to overcome them.
2. **Poor electrical conductivity**, as a solid, as a liquid and in most cases in solution.
   - **Extended only, why:** a current needs charged particles that can move. Molecules have **no overall charge**, and there are **no ions** and **no delocalised (mobile) electrons** to carry the current: all the electrons are held in bonds or lone pairs.

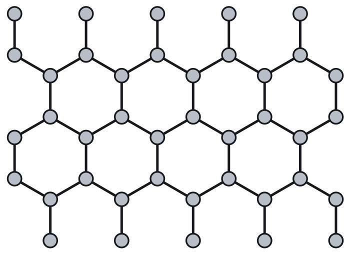
Poor conductivity **on its own** does not show that a substance is simple molecular: diamond, silicon(IV) oxide and solid ionic compounds don't conduct either. What marks out a simple molecular substance is its **low melting and boiling points**.

Breaking a molecule apart (**decomposing** it into its elements) is different from boiling it: that would mean breaking the **strong covalent bonds** between the atoms, which needs far more energy. So a simple molecular compound can boil at a low temperature without decomposing.

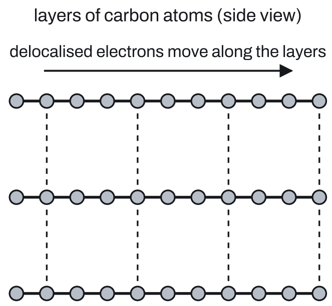
Giant covalent structures

In a **giant covalent** structure there are no separate molecules: **every atom is joined by covalent bonds** to its neighbours in a network that goes on through the whole solid. To melt it you must break **very many strong covalent bonds**, so giant covalent substances have **very high melting and boiling points** and are **insoluble** in water. Diamond and graphite are both giant covalent forms of the element **carbon**.

Graphite



one layer: each C bonded to 3 others



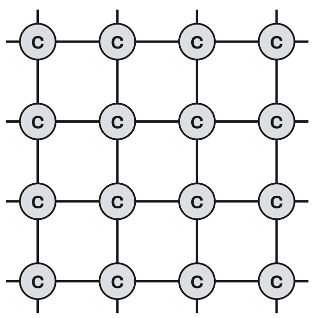
dashed: weak forces between layers, so the layers can slide over each other

- Each carbon atom forms **3 covalent bonds**, making flat **layers of hexagons**.
- Carbon has 4 outer electrons, so each atom has **one electron left over**. These electrons are **delocalised**: they are free to **move along the layers**.
- The layers are held to each other only by **weak forces**, so they **slide over each other** easily.

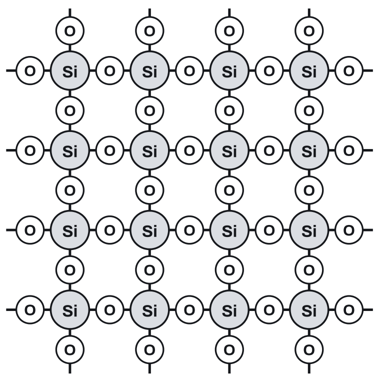
These explain its uses:

- **Lubricant**: the **layers slide over each other** because the forces between them are weak, so graphite is soft and slippery.
- **Electrode** (in electrolysis): the **delocalised electrons move** through the structure, so graphite **conducts electricity**; it also has a very high melting point. It is the only non-metal element on the syllabus that conducts.

Diamond



diamond: each C bonded to 4 C



SiO_2: each Si bonded to 4 O, each O to 2 Si

- Each carbon atom forms **4 covalent bonds** to four other carbon atoms (arranged in 3D, pointing to the corners of a tetrahedron; the drawing flattens it).
- This makes a rigid **three-dimensional** network of strong bonds, so diamond is **very hard** and has a very high melting point.
- All four outer electrons of each atom are in bonds, so there are **no delocalised electrons**: diamond **does not conduct** electricity.

Its use: **cutting tools** (and drill tips), because it is **very hard**. It is also used in jewellery, but the syllabus use is cutting.

	Diamond	**Graphite**
Bonds per carbon atom	4	3
Shape	rigid 3D network	flat layers of hexagons
Delocalised electrons?	no	yes, one per atom
Hard or soft?	very hard	soft, slippery
Conducts electricity?	no	yes
Use	cutting tools	lubricant, electrodes
Melting point	very high	very high

Silicon(IV) oxide

Extended only. Silicon(IV) oxide, SiO_2 (silica, the main compound in sand), is a **giant covalent** compound, not a simple molecule like CO_2:

- Each **silicon atom** is bonded by single covalent bonds to **4 oxygen atoms**.
- Each **oxygen atom** is bonded to **2 silicon atoms**, forming a bridge between them.
- The network goes on in three dimensions. There is no SiO_2 molecule: the formula gives the ratio. Each Si has 4 O, but each O is shared by 2 Si, so there are $4 \div 2 = 2$ oxygen atoms per silicon atom.

It contains atoms, not ions: there is no Si^{4+} or O^{2-} in it. (The "(IV)" in the name is silicon's oxidation number, +4; in the same way, chlorine(I) oxide, Cl_2O, has chlorine at +1.)

Because its structure is **like diamond's** (a 3D network where every atom is held by strong covalent bonds, and no delocalised electrons), SiO_2 has **similar properties** to diamond:

- **very hard**;
- **very high melting and boiling points** (many strong covalent bonds must be broken);
- **does not conduct electricity** (no ions and no delocalised electrons);
- **insoluble** in water.

Telling the structures apart

Structure	Particles	Melting point	Conducts when solid	Conducts when molten	Examples
Simple molecular	small molecules	low	no	no	H_2O, CO_2, CH_4, Cl_2, S_8, I_2
Giant covalent	atoms in a network	very high	no (graphite: yes)	no	diamond, graphite, SiO_2
Giant ionic	ions	high	no	yes	NaCl, MgO
Giant metallic	positive ions + delocalised electrons	usually high	yes	yes	Cu, Fe (Hg is a liquid)

Each type has one property the others don't share, and that is the one to use as your reason:

- **Low melting point**: only simple molecular substances.
- **Conducts when molten but not when solid**: only ionic compounds.
- **Very high melting point, and no conduction even when molten**: only giant covalent substances (graphite is the exception that conducts).
- **Conducts when solid and when molten**: metals (and graphite when solid).

"Does not conduct when solid" fits three of the four types, so it never picks out a type by itself.

Key facts and formulas

Nothing for this topic is printed in the exam except the **Periodic Table**, which gives each element's group (and so its number of outer electrons). Everything else is **Learn it**.

Formula	Status
Group number of each element, from the Periodic Table (outer electrons = group number)	Given
Covalent bond = a pair of electrons shared between two atoms, giving noble-gas configurations	Learn it
Bonds formed = $8 - \text{group number}$ (hydrogen: 1)	Learn it
Single bond: 1 shared pair (2 electrons); double: 2 pairs (4); triple: 3 pairs (6)	Learn it
Simple molecular: low melting and boiling points; poor conductors	Learn it
Extended only: low melting point because intermolecular forces are weak; poor conductor because there are no ions and no mobile electrons	Learn it

Formula	Status
Diamond: each C bonded to 4 others, very hard, no conduction, cutting tools	Learn it
Graphite: each C bonded to 3 others in layers, delocalised electrons, layers slide; lubricant and electrodes	Learn it
Extended only: SiO_2: each Si bonded to 4 O, each O to 2 Si; hard, high melting point, non-conductor, like diamond	Learn it

How to do it

In the questions we have tagged for this topic (183 questions, 2021–2025, on Papers 1–4), the types came up this often. 27 of the 183 questions mix types, so the counts add up to more than 183.

Question type	Questions
Dot-and-cross diagrams of molecules	61
Diamond and graphite: structure, properties and uses	48
Properties of simple molecular substances, and explaining them	30
Identifying the type of structure from names or data	24
Counting shared pairs, bonds and electrons	24
Silicon(IV) oxide	16
What a covalent bond is, and which substances are covalent	14

1. Dot-and-cross diagrams of molecules (61 questions)

Usually "complete the dot-and-cross diagram... show outer shell electrons only", worth 2 or 3 marks, or (Papers 1 and 2) "which diagram shows the arrangement of outer shell electrons?"

1. **Find the outer electrons** of each atom from its group.
2. **Work out the bonds**: each atom forms $8 - \text{group}$ bonds (H forms 1). Put the atom that forms the most bonds in the middle.
3. **Draw the shared pairs**: in each overlap, one pair per bond, with one electron from each atom (a dot and a cross, or two of the same symbol if the key gives both atoms that symbol); two pairs for a double bond, three for a triple bond.
4. **Add the lone pairs**: the leftover outer electrons of each atom, **in pairs**, in that atom's own symbol.
5. **Count**: 8 around every atom (2 around each H). Nothing extra on the hydrogens.

Variations you will meet:

- **Core molecules**: H_2, Cl_2, HCl, H_2O, NH_3, CH_4. Water has **2** lone pairs on O (not 3); ammonia has **1** lone pair on N (not 0 or 2).
- **Extended molecules**: O_2 (double bond, 2 lone pairs on each O), N_2 (triple bond, 1 lone pair on each N), CO_2 (two double bonds, none on C), C_2H_4 (C=C), CH_3OH (2 lone pairs on O).
- **"Similar" molecules** built the same way: NCl_3, PCl_3 or NF_3 like ammonia with 3 lone pairs on each halogen; Cl_2O and SCl_2 like water with 3 lone pairs on each Cl; $SiCl_4$ and $SnCl_4$ like methane with 3 lone pairs on each Cl; H_2S like water; $COCl_2$ with a C=O double bond and two C–Cl single bonds; hydrazine, N_2H_4, with an N–N single bond, two H on each N and one lone pair on each N; methanoic or ethanoic acid, with a C=O double bond and an O–H bond, and 2 lone pairs on each O; an ester, with a C=O double bond and a C–O–C link, and 2 lone pairs on each O.
- **The symbols are given** in the diagram ("Cl N Cl"): add only the electrons. If the question says which atom gets dots, follow it.
- **"Inner shells have been drawn"**: add only the outer shell electrons.
- **Choosing a diagram**: count each atom's electrons in every option. The wrong ones usually have lone pairs on H, a missing lone pair, or three electrons in one bond.

2. Diamond and graphite: structure, properties and uses (48 questions)

1. **Diamond**: giant covalent; each C bonded to **4** others; **no delocalised electrons**; very hard; high melting point; does not conduct; **cutting tools**.
2. **Graphite**: giant covalent; each C bonded to **3** others, in **layers** of hexagons; **delocalised electrons** move along the layers, so it conducts; **weak forces between layers**, so the layers slide; **lubricant** and **electrodes**.
3. For "explain" answers, link the **use** to the **structure**: lubricant because **layers slide over each other**; electrode because **electrons can move**; cutting because it is **very hard**, with each atom held by **four strong covalent bonds** in a rigid network.

Variations you will meet:

- **Statement or row questions** ("which statements about graphite are correct?"): reject 4 bonds for graphite, 3 bonds or layers for diamond, "ionic", "simple molecular", "low melting point", and "diamond conducts".
- **A diagram of two structures**: the one with layers and "weak attraction" between them is graphite; the rigid 3D network is diamond.
- **"Why is graphite used as an electrode?"** It has **mobile (delocalised) electrons**. "It has a giant covalent structure" is true but does not explain the use.
- **An unfamiliar substance "with a structure like diamond"** (boron nitride, silicon): predict **very hard**, **high melting point**, **does not conduct**, not a lubricant.
- **"Name the type of bonding in diamond"**: covalent. **"Describe its structure"**: giant covalent, each carbon atom bonded to four others.
- **Uses**: graphite is also used in pencils; diamond also in jewellery and drill tips. If asked for **one other use**, don't repeat the one in the question.

- **Why both have high melting points**: very many strong covalent bonds must be broken.

3. Properties of simple molecular substances, and explaining them (30 questions)

1. **State**: low melting point, low boiling point, poor electrical conductivity (any two if asked for two).
2. **Extended only: explain the low melting or boiling point**: weak **forces of attraction between molecules** (intermolecular forces); **little energy** needed to overcome them.
3. **Explain poor conductivity**: **no ions** and **no mobile electrons**; molecules are uncharged.

Variations you will meet:

- **Comparing with an ionic compound** (NaCl and Cl_2, SnO and $SnCl_4$, Li_3N and NF_3): name the particles and forces in **both**, and say which is stronger. Ionic: strong attraction between oppositely charged ions in a giant lattice. Simple molecular: weak attraction between molecules. So much more energy is needed for the ionic compound.
- **Comparing with a giant covalent substance** (graphite and O_2, SiO_2 and $SiCl_4$): in the giant structure, **strong covalent bonds** between atoms must be broken; in the molecules, only **weak intermolecular forces**.
- **Boiling versus decomposing**: boiling overcomes the weak forces between molecules; decomposing into elements would break the strong covalent bonds inside them.
- **Row questions** ("low melting point because the forces between sulfur **molecules** are weak"): the forces that matter are **between molecules**, not between atoms, and they are weak, not strong.
- **Volatility and solubility** (pentane compared with sodium chloride): simple molecular substances with low boiling points are **volatile**; many (such as pentane) are **insoluble in water**.
- **Which has the lowest melting point** from a list: the simple molecular one (such as methanol).

4. Identifying the type of structure from names or data (24 questions)

1. **From a name**: diamond, graphite, silicon(IV) oxide are **giant covalent**; compounds of non-metals only (water, ammonia, CO_2, methane, ethanol) are **simple molecular**; a metal with a non-metal is **ionic**; a metal element is **metallic**.
2. **From data**, use the table in "Telling the structures apart":

Melting point	Conducts when solid?	Conducts when molten?	Type
low	no	no	simple molecular
very high	no	no	giant covalent (diamond, SiO_2)
very high	yes	—	graphite (a non-metal element)
high	no	yes	ionic
any	yes	yes	metal

3. **State at 25 °C**: solid if 25 °C is below the melting point, liquid if between the melting and boiling points, gas if above the boiling point.

4. **Give reasons from the table**: quote the property ("melting point −182 °C, which is low"; "does not conduct when molten").

Variations you will meet:

- **"A compound with a giant covalent structure"** from a list: silicon(IV) oxide (graphite and diamond are **elements**). **"An element with a giant covalent structure"**: graphite or diamond.
- **"A non-metallic element that conducts"**: graphite.
- **"Which two are simple molecules?"** Choose the two with **low melting points**; that is the reason that separates them from giant covalent and ionic substances. For the second reason write **"does not conduct when molten"**, which rules out ionic compounds and metals. "Does not conduct" alone is also true of diamond and SiO_2, so it only works alongside the low melting point.
- **"Which is giant covalent?"** Two reasons: a **very high melting (or boiling) point**, and **poor conduction when solid and when molten**.
- **"Which is ionic?"** One reason: it **conducts only when molten** (not when solid).
- **"Macromolecule"** is an older word for a giant covalent structure.

5. Counting shared pairs, bonds and electrons (24 questions)

1. **Count the bonds** from the formula (use the table in "How many bonds does an atom form?").
2. **Shared pairs** = single bonds + 2 × double bonds + 3 × triple bonds.
3. **Shared electrons** = 2 × shared pairs.

Molecule	Bonds	Shared pairs	Shared electrons	Lone pairs on the central atom
Cl_2, HCl	1	1	2	3 (on each Cl)
H_2O	2	2	4	2
NH_3	3	3	6	1
CH_4	4	4	8	0
O_2	1 double	2	4	2 (on each O)
N_2	1 triple	3	6	1 (on each N)
CO_2	2 double	4	8	0 on C
C_2H_4	1 double + 4 single	6	12	0 on C
CH_3OH	5 single	5	10	2 on O

Variations you will meet:

- **"Which molecule has only two shared pairs?"** H_2O. **"Four shared pairs?"** CH_4. **"Three shared pairs?"** NH_3 or N_2. **"Six shared electrons?"** NH_3 (or N_2).
- **"Which atoms use all their outer electrons in bonding?"** Only atoms with **no lone pairs**: C in CH_4, H in any molecule. Cl, O and N keep lone pairs.

- **Differences**: ethene has 12 shared electrons and nitrogen 6, so ethene has 6 more.
- **Total electrons in a molecule** (not just outer ones): add the proton numbers. NH_3 has $7 + 3 \times 1 = 10$.
- **Methanal, CH_2O**: carbon forms two C–H bonds and a **double bond** to oxygen, so carbon and oxygen **share four electrons**.
- **Choosing a displayed formula**: CO_2 is **O=C=O** (two double bonds), not O–C–O or O≡C≡O.
- **"An element with a triple bond"**: N_2. **"A double bond between two atoms of the same element"**: ethene (C=C) or O_2; CO_2's double bonds join different elements.

6. Silicon(IV) oxide (16 questions)

Extended only.

1. **Structure**: giant covalent; each **Si bonded to 4 O**; each **O bonded to 2 Si**; single covalent bonds (one shared pair each).
2. **Like diamond**: very hard, very high melting point, does not conduct, insoluble.
3. **Explain**: many strong covalent bonds in a 3D network must be broken; no ions or delocalised electrons.

Variations you will meet:

- **"Which structure does SiO_2 most closely resemble?"** Diamond (not CO_2, not graphite, not sodium chloride).
- **Completing a diagram** with Si and O symbols: an atom with **4 bonds** is Si; an atom with **2 bonds** is O. Write plain "Si" and "O", with no charges.
- **Statements**: reject "ions in a lattice", "conducts", "simple molecule", "layers like graphite", "double bonds" and "one Si with four O atoms in a molecule".
- **SiO_2 compared with $SiCl_4$**: $SiCl_4$ is simple molecular (weak forces between **molecules**); SiO_2 is giant covalent (many strong covalent bonds).

7. What a covalent bond is, and which substances are covalent (14 questions)

1. **Define**: a covalent bond is **a pair of electrons** (B1) **shared between two atoms** (B1).
2. **Which elements bond covalently**: **non-metals with non-metals**. A metal with a non-metal is ionic; noble gases (such as argon) form no bonds.

Variations you will meet:

- **"Which substances contain shared pairs?"** Molecules such as methane and chlorine, not argon or a metal oxide.
- **"Which element forms covalent bonds with hydrogen?"** A non-metal (nitrogen), not a metal or a noble gas.
- **Gap fills**: covalent bonds form when electrons are **shared**; most covalent compounds have **low** electrical conductivity.

- **"Which statement about bonding is correct?"** In CH_4, NH_3 and H_2O, **every atom** has a noble-gas configuration.
- **"Diatomic"** means two atoms per molecule (H_2, N_2, O_2, Cl_2; HCl is a diatomic compound).

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **B1** mark for a correct result on its own, with no method needed.

Example 1

Hydrogen sulfide, H_2S, is a simple molecular compound. Sulfur is in Group VI.

(a) State what is meant by a covalent bond. **[2]**

(b) Complete the dot-and-cross diagram of a molecule of H_2S. Show outer shell electrons only. **[2]**

(c) H_2S melts at −86 °C and boils at −60 °C. State its physical state at 25 °C. **[1]**

(d) Explain why liquid H_2S does not conduct electricity. **[1]**

(a) A **pair of electrons B1 shared between two atoms**. **B1**

(b) Sulfur has 6 outer electrons and needs 2 more, so it forms 2 bonds. One dot-and-cross pair in the overlap between S and each H, with nothing else on the H atoms; **B1 2 non-bonding pairs** (4 electrons) on the S atom, making 8 in total. **B1**

(c) Gas: 25 °C is above its boiling point, −60 °C. **B1**

(d) It is made of uncharged molecules: there are **no ions and no mobile electrons** to carry the charge. **B1**

Example 2

Extended. Phosphorus trichloride, PCl_3, melts at −94 °C. Magnesium chloride, $MgCl_2$, melts at 714 °C.

(a) Draw the dot-and-cross diagram of a molecule of PCl_3. Use dots for phosphorus electrons and crosses for chlorine electrons. Show outer shell electrons only. **[3]**

(b) Explain, in terms of structure and bonding, why PCl_3 has a much lower melting point than $MgCl_2$. **[3]**

(c) When PCl_3 boils, are its covalent bonds broken? Explain. **[1]**

(a) Phosphorus (Group V) forms 3 bonds, like nitrogen in ammonia.

- **3 bonding pairs**, one dot and one cross between P and each Cl. **B1**
- **1 non-bonding pair** of dots on P. **B1**
- **3 non-bonding pairs** of crosses on each Cl. **B1**

(b) PCl_3 is made of **simple molecules** with **weak attractions between the molecules** (intermolecular forces). **B1** $MgCl_2$ is a **giant ionic lattice** with **strong electrostatic attractions between oppositely charged ions**. **B1** Much **less energy** is needed to overcome the weak intermolecular forces in PCl_3 than the ionic bonds in $MgCl_2$. **B1**

(c) No: boiling only overcomes the weak forces **between** the molecules; the covalent bonds inside them stay. **B1**

Example 3

Extended. Carbon disulfide, CS_2, has the same type of bonding as carbon dioxide.

(a) Draw the dot-and-cross diagram of a molecule of CS_2, using dots for carbon and crosses for sulfur. Show outer shell electrons only. **[3]**

(b) State the total number of shared electrons in one molecule of CS_2. **[1]**

(c) How many more shared electrons are there in a molecule of ethene, C_2H_4, than in a molecule of CS_2? **[1]**

(a)

- **Two shared pairs** (a double bond: 2 dots and 2 crosses) between carbon and **each** sulfur atom. **B1**
- **Two non-bonding pairs** of crosses on each sulfur atom. **B1**
- **No non-bonding electrons** on carbon (it has 8 from the two double bonds). **B1**

(b) $2 \text{ double bonds} \times 4 =$ **8** electrons. **B1**

(c) Ethene: one C=C (2 pairs) and four C–H (4 pairs), so 6 pairs = 12 electrons. $12 - 8 =$ **4** more. **B1**

Example 4

The table gives data for five substances, V to Z. Y is a non-metal element.

Substance	Melting point / °C	Boiling point / °C	Conducts when solid?	Conducts when molten?
V	801	1413	no	yes
W	1700	2950	no	no
X	–23	77	no	no
Y	3600	4800	yes	not tested
Z	114	184	no	no

(a) State which substance is a liquid at 25 °C. **[1]**

(b) Identify the two substances that have simple molecular structures. Give two reasons from the table. **[3]**

(c) A student says that W must be a simple molecular substance because it does not conduct electricity. Explain why the student is wrong, and name the type of structure W has. **[2]**

(d) Identify Y and explain why it conducts electricity. **[3]**

(e) **Extended.** W is silicon(IV) oxide. Describe its structure and explain why it has a high melting point. **[4]**

(a) X: 25 °C is between its melting point (–23 °C) and its boiling point (77 °C). **B1**

(b) X and Z. **B1**

- **Low melting points** (–23 °C and 114 °C). **B1** This is the reason that does the work: V, W and Y all melt above 800 °C, because their particles are held by strong bonds throughout a giant structure.
- They **do not conduct when molten**. **B1** This rules out an ionic compound (V conducts when molten) and a metal.

(c) Not conducting does not prove a structure is simple molecular: giant covalent substances such as diamond, and ionic compounds when solid, don't conduct either. W melts at 1700 °C, which is far too high for a simple molecular substance, whose weak forces between molecules are overcome at low temperatures. **B1** A very high melting point with no conduction, solid or molten, means W is **giant covalent**. **B1**

(d) Graphite: a non-metal element that conducts when solid and has a very high melting point. **B1** Each carbon atom forms only 3 bonds, so it has **delocalised electrons**, **B1** which **move** along the layers and carry the current. **B1**

(e) Giant covalent structure; **B1** each **silicon atom bonded to four oxygen atoms** and each oxygen atom to two silicon atoms. **B1 Many strong covalent bonds B1** must be broken to melt it, which needs **a lot of energy**. **B1**

Common mistakes

- **Putting lone pairs on hydrogen.** A hydrogen atom holds only **2** electrons, the bonding pair. This is the error examiners report most often, in water, ammonia and hydrogen chloride.
- **The wrong number of lone pairs**: three on oxygen in water, none or two on nitrogen in ammonia, or leaving out the non-bonding electrons on Cl, F or O in bigger molecules. Count to 8 around every atom, and **draw non-bonding electrons in pairs** so they are easy to count.
- **Three electrons in one bond**, or both electrons of a pair taken from the same atom. Every shared pair has **one electron from each atom**: a dot and a cross, unless the key gives both atoms the same symbol. Use only dots and crosses, not a third symbol.
- **A double bond in N_2** or a single bond in O_2. Nitrogen needs 3 electrons (triple bond); oxygen needs 2 (double bond).
- **Defining a covalent bond as "two or more pairs" or "between two or more atoms".** One covalent bond is **one pair** shared by **two** atoms.

- **"Intermolecular forces between atoms"**, or "weak covalent bonds" in chlorine. Intermolecular forces are **between molecules**; covalent bonds are strong and are **not** broken on melting or boiling.
- **Describing an ionic compound with molecular words** in a comparison ("LiCl has weaker intermolecular forces than NCl_3"). Ionic compounds have **ions and ionic bonds**, not molecules. Name the substance in each half of a comparison, and say which attraction is **stronger**.
- **Using "does not conduct" as the only sign of a simple molecular substance.** Diamond, SiO_2 and solid ionic compounds don't conduct either. The giveaway is the **low melting point**; if you also use conductivity, say "does not conduct **when molten**".
- **Explaining graphite's use as an electrode with its structure alone.** "It is giant covalent" or "it has layers" doesn't explain conduction; say it has **delocalised electrons that move**.
- **Describing diamond without covalent bonding.** Say **giant covalent**, with **each carbon atom bonded to four others**. "Dense" or "does not corrode" does not explain cutting tools: it is **very hard**.
- **Calling diamond or SiO_2 ionic**, or drawing SiO_2 with ions (Si^{4+}, O^{2-}). They contain atoms joined by covalent bonds; in SiO_2, Si has 4 bonds and O has 2.
- **Choosing a compound when an element is asked for** (or the reverse): graphite and diamond are elements; SiO_2 is a compound.
- **Repeating the example in the question** when it asks for "one **other** use" or "another material".

How to get the marks

- **Definitions are marked on key words.** Covalent bond: "pair of electrons" + "shared between two atoms" (one mark each).
- **Dot-and-cross diagrams** usually give one mark for the **bonding pairs** (right number, one electron from each atom) and one for the **non-bonding electrons** on each kind of atom. Draw the atoms the question labels, and keep the key it gives.
- **"Explain in terms of structure and bonding"** for a simple molecular substance needs: **simple molecules**, **weak attraction between molecules** (intermolecular forces), **little energy** needed to overcome them. For a giant covalent substance: **giant structure**, **many strong covalent bonds**, **a lot of energy** to break them. In a comparison, include **both** substances and a comparative word ("weaker", "much more energy").
- **Conductivity answers** name the particle and say it **moves**: graphite conducts because **electrons move**; simple molecules don't because there are **no ions and no mobile electrons**. Both reasons are needed when two are asked for.
- **Uses must be linked to properties** when the question says "explain": lubricant — layers slide; electrode — conducts; cutting — very hard.
- **"State"** needs a short answer ("graphite", "covalent"). **"Describe"** needs the features of the structure (bonds per atom, layers or 3D network). **"Explain"** needs the reason, with the particles and forces named. **"Suggest"** means apply what you know to an unfamiliar substance.
- **Data-table questions** reward a **reason from the data** for each choice, and the reason must fit that type only: "low melting point" for simple molecules, "conducts when molten but not when solid" for ionic, "high melting point and does not conduct when solid or molten" for giant covalent. Say **when** it conducts (solid

or molten).

- **Multiple-choice questions** hinge on one word: 3 or 4 bonds, between or within molecules, strong or weak, atoms or ions, element or compound. Check every part of the row.

Quick check

1. For each molecule, give the number of covalent bonds and the number of non-bonding pairs on the atom named: NH_3 (N), H_2O (O), CH_4 (C), HCl (Cl).
2. **Extended.** How many shared electrons are there in one molecule of each: C_2H_4, N_2, CO_2, CH_3OH?
3. Explain why graphite is used as a lubricant and as an electrode.
4. **Extended.** Hydrogen cyanide, H–C≡N, is a simple molecule. How many shared electrons does it have, and how many non-bonding pairs are on the nitrogen atom and on the carbon atom?
5. **Extended.** Give three properties that silicon(IV) oxide shares with diamond and explain them in terms of structure.

Answers

1. NH_3: **3** bonds, **1** lone pair on N. H_2O: **2** bonds, **2** lone pairs on O. CH_4: **4** bonds, **0** lone pairs on C. HCl: **1** bond, **3** lone pairs on Cl.
2. C_2H_4: 6 pairs, **12** electrons. N_2: 3 pairs, **6**. CO_2: 4 pairs, **8**. CH_3OH: 5 pairs, **10**.
3. **Lubricant**: graphite has layers held together only by weak forces, so the **layers slide over each other**. **Electrode**: each carbon forms 3 bonds, leaving **delocalised electrons that can move** along the layers and carry a current (and graphite has a very high melting point).
4. One C–H bond (1 pair) and one C≡N bond (3 pairs): 4 pairs, **8** shared electrons. Nitrogen: $5-3=2$ electrons left, so **1** lone pair. Carbon: $4-1-3=0$, so **no** lone pairs.
5. **Very hard**, **very high melting point**, **does not conduct** (also insoluble in water). Both are giant covalent 3D networks where every atom is held by strong covalent bonds (C to 4 C in diamond; Si to 4 O, O to 2 Si in SiO_2): many strong bonds must be broken to melt or scratch them, and neither has ions or delocalised electrons.

Past questions to try

- **0620/43/M/J/22 Q3**: the bonding in nitrogen, why nitrogen has a low melting point and doesn't conduct, and the dot-and-cross diagram of hydrazine, N_2H_4.
- **0620/43/M/J/23 Q3**: parts (b) and (c): the dot-and-cross diagram of $SiCl_4$ and why SiO_2 has a much higher melting point.
- **0620/43/O/N/21 Q3**: the dot-and-cross diagram of CO_2, and why lead(II) oxide melts at a much higher temperature than CO_2.
- **0620/21/O/N/23 Q9**: which statements about graphite's structure, uses and conductivity are correct.