# Unit 7 · Chemical Bonding

**ANSWER KEY · FOR TEACHERS**

Full marks 44

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

## 1 Key words

1. covalent bond
2. lone pair
3. sigma bond
4. pi bond
5. coordinate covalent bond
6. donor
7. Avogadro number
8. molar volume

Each carries 0.5 mark. K · 4

## 2 Multiple choice

**i.** **d.** p–p sideways K · 1

A $\pi$ bond is the sideways overlap of two parallel p orbitals. The other three are head-on overlaps, which give $\sigma$ bonds.

**ii.** **c.** 1 $\sigma$ and 2 $\pi$ U · 1

N≡N is a triple bond. Two atoms are joined by only one $\sigma$ bond; the other two bonds are $\pi$ bonds.

**iii.** **c.** $NH_4^+$ U · 1

In $NH_4^+$ the nitrogen of ammonia gives its lone pair to an $H^+$ ion. The others have only ordinary covalent bonds.

**iv.** **b.** 1 mol of ammonia, $NH_3$ A · 1

1 mol $NH_3$ has 4 mol of atoms (1 N and 3 H in each molecule): $4 \times 6.022 \times 10^{23}$. 1 g of $H_2$ is 0.5 mol of molecules, 1 mol of atoms; 1 mol $O_2$ is 2 mol of atoms; 12 g of carbon is 1 mol of atoms.

**v.** **b.** 32 A · 1

$M(SO_2) = 32 + 2 \times 16 = 64$, and VD $= \frac{M}{2} = 32$. (64 is the molecular mass, not the vapor density.)

## 3 Label the diagram

1. s + s → $\sigma$ H–H in $H_2$
2. p + p head-on → $\sigma$ Cl–Cl in $Cl_2$
3. s + p → $\sigma$ H–Cl in HCl
4. p + p side by side → $\pi$ the second bond of O=O

Each carries 1 mark. K · 4

## 4 Very short answers

**a.** MARKING SCHEME K · 1

✓ Equal volumes of all gases at the same temperature and pressure contain equal numbers of molecules.

**b.** MARKING SCHEME A · 1

✓ 2 $\sigma$ and 2 $\pi$.

**c.** MARKING SCHEME U · 1

✓ A lone pair of a water molecule's oxygen bonds to it at once, giving $H_3O^+$.



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**d.** MARKING SCHEME K · 1

✓ Donor: a lone pair; acceptor: an empty orbital.

## 5 Short answers

**a.** MARKING SCHEME U · 2

✓ A $\sigma$ bond is a large head-on overlap, with the shared pair right between the two nuclei.

✓ A $\pi$ bond is a smaller sideways overlap, above and below the axis, so it is weaker.

**b.** MARKING SCHEME U · 2

✓ A current needs charged particles that can move: free electrons or free ions.

✓ Covalent compounds are neutral molecules with their electrons held in bonds, and give no ions.

**c.** MARKING SCHEME A · 2

✓ A coordinate bond differs from a covalent bond only in where its electrons came from.

✓ Once formed it is a shared pair like the other three, so all four have the same length and strength.

**d.** MARKING SCHEME A · 2

✓ Organic compounds are covalent molecules held to one another by weak forces, so little heat separates them.

✓ In salt each ion is held by strong attraction to the opposite ions in every direction, so much more heat is needed.

## 6 Long answers

**a.** ANSWER U · 4

Nitrogen is $1s^2\ 2s^2\ 2p^3$, with one electron in each of its three 2p orbitals, p<sub>x</sub>, p<sub>y</sub> and p<sub>z</sub>, which point at right angles to each other. When two N atoms approach along the x axis:

- the two p<sub>x</sub> orbitals overlap head-on: **one $\sigma$ bond**;
- the two p<sub>y</sub> orbitals, now parallel, overlap sideways above and below the axis: **one $\pi$ bond**;
- the two p<sub>z</sub> orbitals overlap sideways in front and behind: **a second $\pi$ bond**.

So N≡N is a triple bond, 1 $\sigma$ + 2 $\pi$, with six shared electrons. Each N keeps its 2s pair as a lone pair and has an octet. The triple bond is very strong (945 kJ/mol), so nitrogen is unreactive.

MARKING SCHEME

✓ Nitrogen has one electron in each of its three 2p orbitals, at right angles to each other.

✓ One pair of p orbitals, pointing at each other, overlaps head-on: one $\sigma$ bond.

✓ The other two pairs, parallel, overlap sideways: two $\pi$ bonds.

✓ So N≡N is 1 $\sigma$ + 2 $\pi$, with six shared electrons, and each N keeps an octet.



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**b.** ANSWER A · 4

**Avogadro's law:** equal volumes of all gases, at the same temperature and pressure, contain equal numbers of molecules.

Vapor density is the ratio of the mass of a volume of a gas to the mass of the same volume of hydrogen, at the same temperature and pressure:

$$\text{VD} = \frac{\text{mass of } V \text{ of the gas}}{\text{mass of } V \text{ of hydrogen}}$$

By Avogadro's law, the two volumes contain the same number of molecules, $n$:

$$\text{VD} = \frac{n \times \text{mass of one gas molecule}}{n \times \text{mass of one } H_2 \text{ molecule}} = \frac{\text{molecular mass of the gas}}{2}$$

since the molecular mass of hydrogen, $H_2$, is 2. So **molecular mass = 2 × vapor density**.

MARKING SCHEME

- ✓ Equal volumes of all gases at the same temperature and pressure contain equal numbers of molecules.
- ✓ VD = mass of a volume of the gas ÷ mass of the same volume of hydrogen.
- ✓ The two volumes hold the same number of molecules, so VD = molecular mass of the gas ÷ molecular mass of hydrogen.
- ✓ Hydrogen's molecular mass is 2, so molecular mass = 2 × vapor density.

## 7 Numerical problems

**a.** ANSWER A · 2

$n = 2.24 \div 22.4 = 0.1$ mol. Mass = $0.1 \times 16 =$ **1.6 g**. Molecules = $0.1 \times 6.022 \times 10^{23} =$ **$6.022 \times 10^{22}$**.

MARKING SCHEME

- ✓ n = 2.24 ÷ 22.4 = 0.1 mol.
- ✓ Mass = 1.6 g and molecules = $6.022 \times 10^{22}$.

**b.** ANSWER A · 3

$M = 2 + 32 + 64 = 98$ g/mol; $n = 4.9 \div 98 = 0.05$ mol; molecules = $0.05 \times 6.022 \times 10^{23} = 3.011 \times 10^{22}$. Hydrogen: $2 \times 3.011 \times 10^{22} =$ **$6.022 \times 10^{22}$ atoms**; sulphur: **$3.011 \times 10^{22}$ atoms**; oxygen: $4 \times 3.011 \times 10^{22} =$ **$1.204 \times 10^{23}$ atoms**.

MARKING SCHEME

- ✓ n = 4.9 ÷ 98 = 0.05 mol, so $3.011 \times 10^{22}$ molecules.
- ✓ Hydrogen $6.022 \times 10^{22}$ atoms.
- ✓ Sulphur $3.011 \times 10^{22}$ atoms and oxygen $1.204 \times 10^{23}$ atoms.

**c.** ANSWER A · 3

Molecular mass = $2 \times 8.5 =$ **17**. $n = 34 \div 17 = 2$ mol; volume = $2 \times 22.4 =$ **44.8 L**. It could be **ammonia**, $NH_3$ (14 + 3 = 17).

MARKING SCHEME

- ✓ Molecular mass = $2 \times 8.5 = 17$.
- ✓ n = 34 ÷ 17 = 2 mol, so the volume is 44.8 L.
- ✓ It could be ammonia, $NH_3$.



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## 8 Think

**ANSWER** HA · 3

In a gas the molecules are tiny compared with the empty space between them (at STP they fill less than a thousandth of the volume), so their size hardly affects the volume. At the same temperature every molecule has the same average kinetic energy and adds the same push to the pressure, so equal volumes at the same temperature and pressure hold **equal numbers** of molecules, whatever their size or mass (Avogadro's law). Mass does differ: each oxygen molecule (32) is 16 times heavier than a hydrogen molecule (2), so the liter of oxygen is **16 times heavier** (1.43 g against 0.09 g at STP), with the same number of molecules.

**MARKING SCHEME**

- ✓ Molecules are tiny compared with the space between them, so their size hardly affects the volume.
- ✓ Each molecule adds the same push at the same temperature, so equal volumes hold equal numbers (Avogadro's law).
- ✓ The liter of oxygen is 16 times heavier (32 ÷ 2), with the same number of molecules.

## 9 Activity: Weigh a mole

(not marked)

**WHAT STUDENTS SHOULD FIND**

Water 18 g, salt 58.5 g, urea 60 g and calcium carbonate 100 g. Each holds $6.022 \times 10^{23}$ formula units, though the heaps look very different in size: the same count, but different masses for each particle.

## See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Himalayan Pink Salt** (exhibit): Rock salt is sodium chloride: each sodium atom has given an electron to a chlorine atom, and the NaNand ClOions hold tight.

| Marks by level | Knowledge | Understanding | Application | Higher ability | Total |
|---|---|---|---|---|---|
| **Marks** | 11 | 11 | 19 | 3 | **44** |



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