# Mastering Chemistry

- Book 5
- Topic 12 Patterns in the Chemical World

# Content



Continued on next page

# Content



Continued on next page

# Content

- Key terms
- Summary
- Unit Exercise

# 41.1 Categories of elements in the modern Periodic Table (p.2)

- Elements in the modern Periodic Table are often divided into four categories:

  1 **Main group elements (主族元素)**

  2 **Transition metals (過渡元素)**

  3 **Lanthanides (鑭系元素)**

  4 **Actinides (錒系元素)**

# 41.1 Categories of elements in the modern Periodic Table (p.2)

| | Main group elements: Group I | Main group elements: Group II | Transition metals | | | | | | | | | | Main group elements: Group III | Group IV | Group V | Group VI | Group VII | Group 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period 1 | | | | | | | 1 H Hydrogen | | | | | | | | | | | 2 He Helium |
| Period 2 | 3 Li Lithium | 4 Be Beryllium | | | | | | | | | | | 5 B Boron | 6 C Carbon | 7 N Nitrogen | 8 O Oxygen | 9 F Fluorine | 10 Ne Neon |
| Period 3 | 11 Na Sodium | 12 Mg Magnesium | | | | | | | | | | | 13 Al Aluminium | 14 Si Silicon | 15 P Phosphorus | 16 S Sulphur | 17 Cl Chlorine | 18 Ar Argon |
| Period 4 | 19 K Potassium | 20 Ca Calcium | 21 Sc Scandium | 22 Ti Titanium | 23 V Vanadium | 24 Cr Chromium | 25 Mn Manganese | 26 Fe Iron | 27 Co Cobalt | 28 Ni Nickel | 29 Cu Copper | 30 Zn Zinc | 31 Ga Gallium | 32 Ge Germanium | 33 As Arsenic | 34 Se Selenium | 35 Br Bromine | 36 Kr Krypton |
| Period 5 | 37 Rb Rubidium | 38 Sr Strontium | 39 Y Yttrium | 40 Zr Zirconium | 41 Nb Niobium | 42 Mo Molybdenum | 43 Tc Technetium | 44 Ru Ruthenium | 45 Rh Rhodium | 46 Pd Palladium | 47 Ag Silver | 48 Cd Cadmium | 49 In Indium | 50 Sn Tin | 51 Sb Antimony | 52 Te Tellurium | 53 I Iodine | 54 Xe Xenon |
| Period 6 | 55 Cs Caesium | 56 Ba Barium | 57 La Lanthanum | 72 Hf Hafnium | 73 Ta Tantalum | 74 W Tungsten | 75 Re Rhenium | 76 Os Osmium | 77 Ir Iridium | 78 Pt Platinum | 79 Au Gold | 80 Hg Mercury | 81 Tl Thallium | 82 Pb Lead | 83 Bi Bismuth | 84 Po Polonium | 85 At Astatine | 86 Rn Radon |
| Period 7 | 87 Fr Francium | 88 Ra Radium | 89 Ac Actinium | 104 Rf Rutherfordium | 105 Db Dubnium | 106 Sg Seaborgium | 107 Bh Bohrium | 108 Hs Hassium | 109 Mt Meitnerium | 110 Ds Darmstadtium | 111 Rg Roentgenium | 112 Cn Copernicium | 113 Nh Nihonium | 114 Fl Flerovium | 115 Mc Moscovium | 116 Lv Livermorium | 117 Ts Tennessine | 118 Og Oganesson |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 58 Ce Cerium | 59 Pr Praseodymium | 60 Nd Neodymium | 61 Pm Promethium | 62 Sm Samarium | 63 Eu Europium | 64 Gd Gadolinium | 65 Tb Terbium | 66 Dy Dysprosium | 67 Ho Holmium | 68 Er Erbium | 69 Tm Thulium | 70 Yb Ytterbium | 71 Lu Lutetium |
| Actinides | 90 Th Thorium | 91 Pa Protactinium | 92 U Uranium | 93 Np Neptunium | 94 Pu Plutonium | 95 Am Americium | 96 Cm Curium | 97 Bk Berkelium | 98 Cf Californium | 99 Es Einsteinium | 100 Fm Fermium | 101 Md Mendelevium | 102 No Nobelium | 103 Lr Lawrencium |

key: atomic number / symbol / name

**The modern Periodic Table**

# 41.1 Categories of elements in the modern Periodic Table (p.2)

- ‘Transition metals’ is a group of rather unreactive metals. Most of them are useful metals.
- ‘Lanthanides’ is a series of metals that can be found naturally on the Earth. Only one metal in the series is radioactive.
- ‘Actinides’ is a series of radioactive metals. Only thorium and uranium exist naturally in the Earth’s crust in more than trace quantities.
- Patterns of physical properties of the elements across the second and the third periods can be seen across other periods too. This recurrence of the same pattern is called **periodicity (週期律)**.

# 41.1 Categories of elements in the modern Periodic Table (p.2)

- The most obvious periodicity in properties is the trend from metals through metalloids to non-metals.

| Group | I | II | III | IV | V | VI | VII | 0 |
|---|---|---|---|---|---|---|---|---|
| Period 2 | Li | Be | B | C | N | O | F | Ne |
| Period 3 | Na | Mg | Al | Si | P | S | Cl | Ar |

key: metal (Li, Be, Na, Mg, Al); metalloid (B, Si); non-metal (C, N, O, F, Ne, P, S, Cl, Ar)

# 41.1 Categories of elements in the modern Periodic Table (p.2)

- The following figure shows samples of Periods 2 and 3 elements.

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

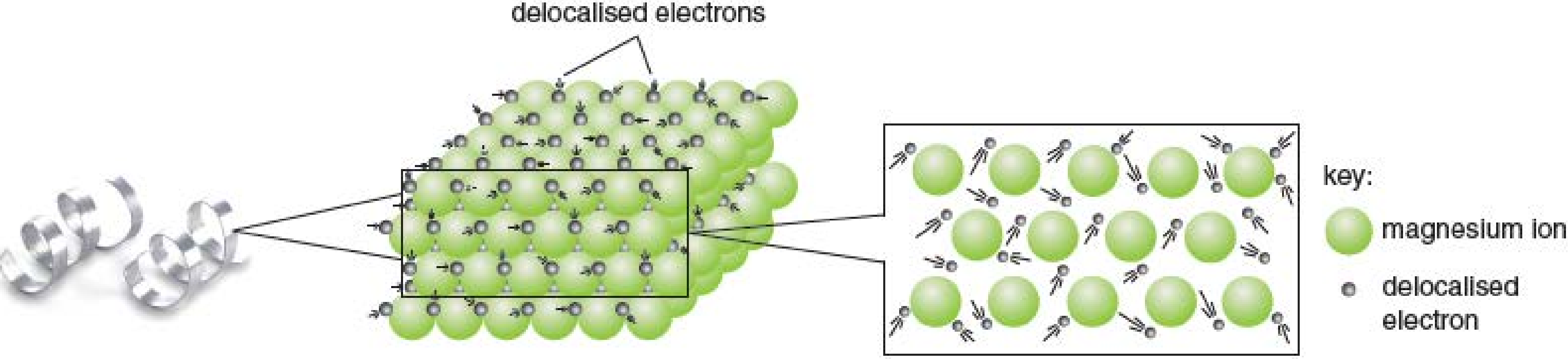
- Structures of the elements across the second and the third periods vary from giant metallic in the metals, through giant covalent in the metalloids to simple molecular in the non-metals.

| Period 2 | Li | Be | B | C (graphite) | N | O | F | Ne |
|---|---|---|---|---|---|---|---|---|
| **Structure** | giant metallic | | giant covalent | | simple molecular | | | |
| **Bonding and intermolecular forces** | positive metal ions surrounded by delocalised electrons | | atoms held together by covalent bonds | | atoms within a molecule joined together by covalent bonds; van der Waals' forces among molecules | | | van der Waals' forces among monatomic molecules |
| **Period 3** | Na | Mg | Al | Si | P | S | Cl | Ar |
| **Structure** | giant metallic | | | giant covalent | simple molecular | | | |
| **Bonding and intermolecular forces** | positive metal ions surrounded by delocalised electrons | | | atoms held together by covalent bonds | atoms within a molecule joined together by covalent bonds; van der Waals' forces among molecules | | | van der Waals' forces among monatomic molecules |

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

## Giant metallic structure

- Metals form giant structures in which a regular three-dimensional arrangement of positive metal ions is surrounded by a 'sea' of delocalised electrons.

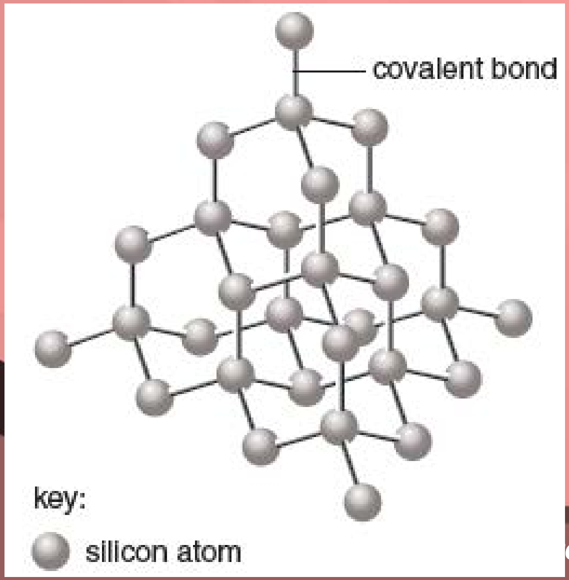



**A piece of magnesium consists of positive magnesium ions surrounded by a 'sea' of delocalised electrons**

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

## Giant covalent structure

- In a giant covalent structure, huge numbers of atoms are held together by a network of covalent bonds.
- The following figure shows the arrangement of atoms in silicon. It has a giant covalent structure similar to that of diamond. Each silicon atom is covalently bonded to four other silicon atoms in a tetrahedral arrangement.



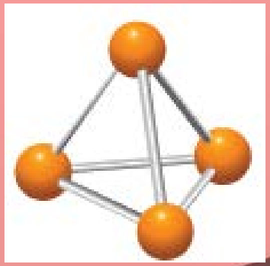

**Arrangement of atoms in silicon**

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

## Simple molecular structure

- Non-metals with simple molecular structures have strong covalent bonds joining their atoms within the molecules. However, only weak van der Waals' forces exist among the molecules.
- Phosphorus exists in several allotropic forms, one of which is white phosphorus. It consists of tetrahedral $P_4$ molecules, in which each phosphorus atom is bonded to three other phosphorus atoms by single bonds.

A sample of white phosphorus

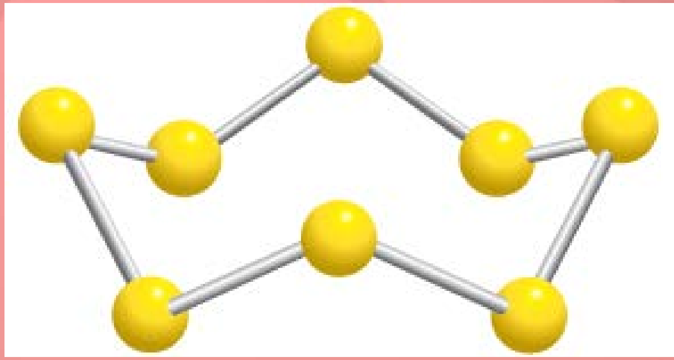


The tetrahedral structure of a $P_4$ molecule

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

- Sulphur also has various allotropes. **Rhombic sulphur (斜方晶硫)** is the most stable crystalline form below 96 °C. It is a yellow, brittle solid which consists of $S_8$.

**Rhombic sulphur is a yellow, brittle solid**



**$S_8$ molecule**

# 41.2 Periodic variations in structures and bonding of Periods 2 and 3 elements (p.3)

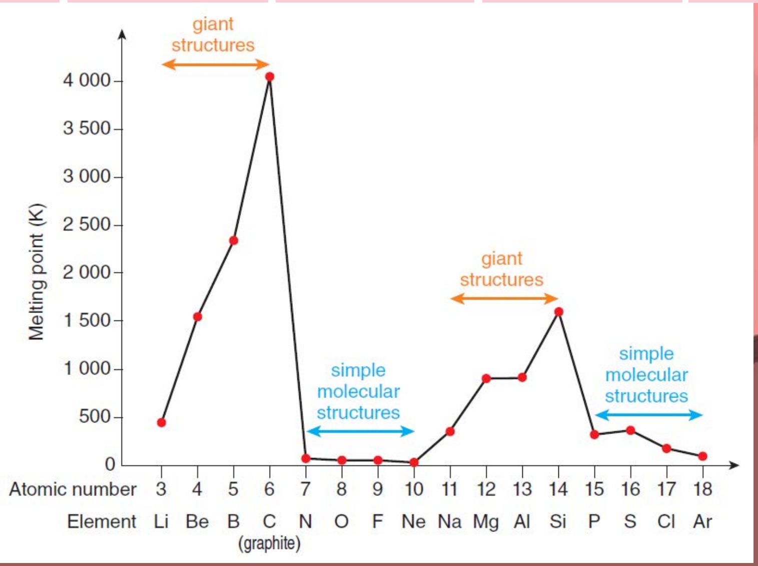
- **Monoclinic sulphur (單斜晶硫)** is another crystalline form of sulphur. It has the same type of $S_8$ molecules.

Needle-shaped crystals of monoclinic sulphur

# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

- The melting points of the elements in the second and third periods are shown in the table and figure below.

| Period 2 | Li | Be | B | C (graphite) | N | O | F | Ne |
|---|---|---|---|---|---|---|---|---|
| Melting point (K) | 453 | 1 553 | 2 349 | 4 003 | 63 | 54 | 53 | 24 |
| Period 3 | Na | Mg | Al | Si | P (white) | S (rhombic) | Cl | Ar |
| Melting point (K) | 371 | 923 | 933 | 1 687 | 317 | 388 | 172 | 84 |



# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

- Across Periods 2 and 3,
  - the melting points increase from Group I to Group IV;
  - there is a sharp decrease in melting points between Group IV and Group V;
  - the melting points are comparatively low from Group V to Group 0.
- The sharp decrease in melting points marks a change from giant structures to simple molecular structures of the elements.

| Giant metallic structure | | Giant covalent structure | | Simple molecular structure | | | |
|---|---|---|---|---|---|---|---|
| Li | Be | B | C | $N_2$ | $O_2$ | $F_2$ | Ne |
| Na | Mg | Al | Si | $P_4$ | $S_8$ | $Cl_2$ | Ar |

**Variation in structures of elements across Periods 2 and 3**

# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

- To melt an element with a giant metallic structure, a lot of heat is needed to overcome the attractive forces between the metal ions and the ‘sea’ of delocalised electrons. Hence the element has a high melting point.
- To melt an element with a giant covalent structure, lots of the covalent bonds between atoms have to be broken. These bonds are strong and need a lot of heat to break. Hence the element has a high melting point.
- An element with a simple molecular structure has only weak van der Waals’ forces among the molecules. To melt the element, very little heat is needed to overcome the forces and separate the molecules far apart. Hence the element has a low melting point.

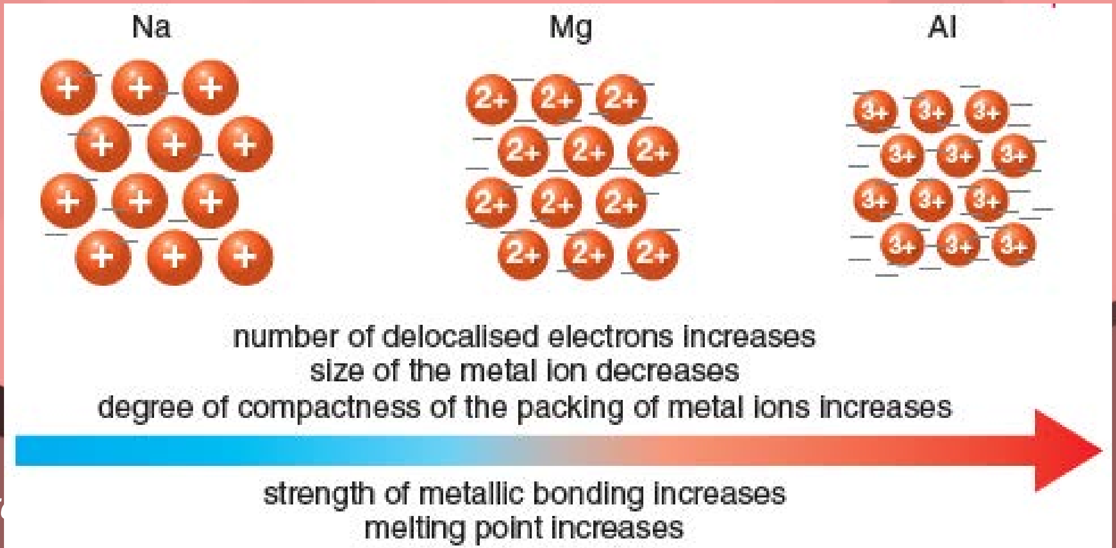
# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

**Comparing the melting points of sodium, magnesium and aluminium**

- The strength of metallic bond is affected by
  - the number of outermost shell electrons provided by each metal atom for bonding;
  - the size of the metal ion;
  - the degree of compactness of the packing of metal ions.
- Going from sodium to aluminium, the charge on each metal ion increases from +1 to +3 and the number of delocalised electrons available for bonding also increases. Hence the attraction between the metal ions and the delocalised electrons becomes greater.

# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

- The size of the metal ion decreases from sodium to aluminium. This again leads to a greater attraction between the smaller metal ions and the delocalised electrons as the electrons are closer to the positive nuclei of the metal ions.
- In addition, the degree of compactness of the packing of metal ions increases from sodium to aluminium. As a result, the strength of metallic bonding and melting points of the three metals increase from sodium to aluminium.



# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

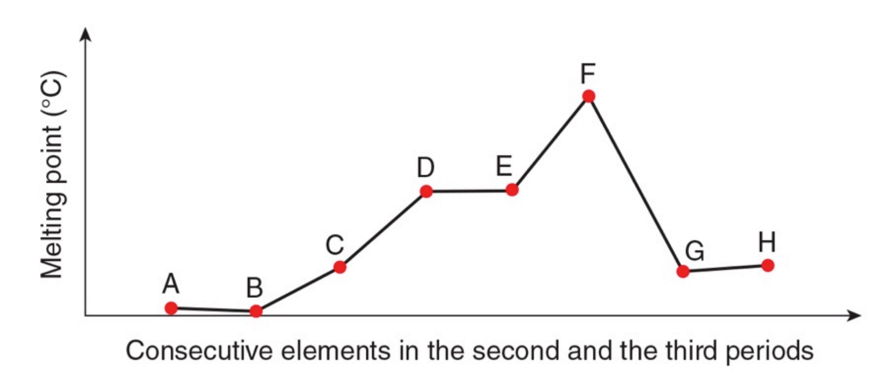
## Comparing the melting points of phosphorus, sulphur, chlorine and argon

- Phosphorus, sulphur and chlorine all form small covalent molecules, $P_4$, $S_8$ and $Cl_2$ respectively. To melt these elements, only the weak van der Waals' forces among the molecules are needed to overcome.
- The van der Waals' forces become weaker as the molecules become smaller. Hence the melting point decreases in the order: sulphur > phosphorus > chlorine.
- The melting point of argon is very low, as the van der Waals' forces among the monatomic molecules of argon are weak.

# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

## Practice 41.1

The graph shows the melting points of eight consecutive elements in the second and the third periods of the Periodic Table. The letters are NOT symbols for the elements.




a) Identify the element represented by F. Justify your answer.

F is silicon.
Silicon has a giant covalent structure.
Lots of strong covalent bonds between atoms have to be broken in melting.
A lot of heat is needed. Thus, silicon has a high melting point.

# 41.3 Periodic variation in melting points of Periods 2 and 3 elements (p.7)

Practice 41.1 (continued)

b) Explain the difference in melting points between the elements represented by C and D.

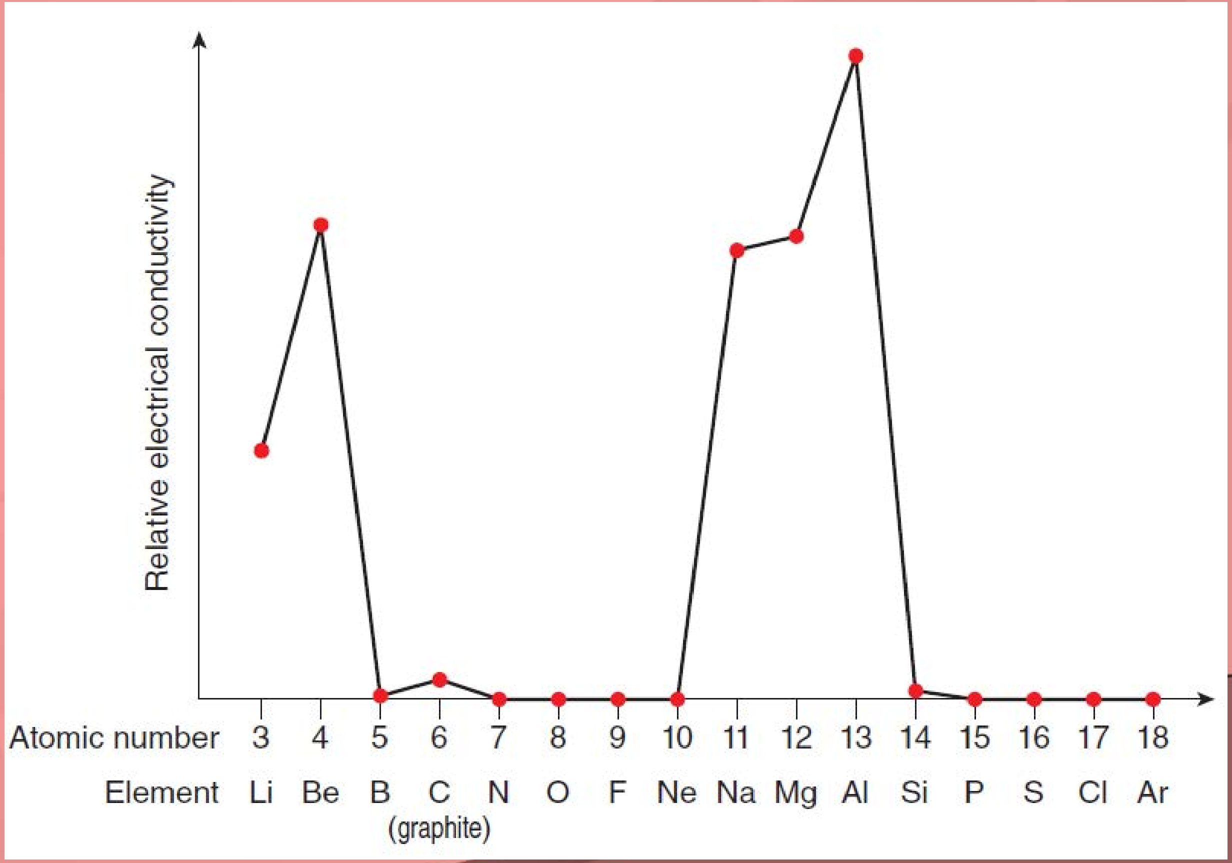
Both C (sodium) and D (magnesium) are metals.
Both have giant metallic structures.
The metallic bond in D is stronger than that in C as D has more delocalised electrons than C.
Thus, the melting point of D is higher than that of C.

c) Identify the element represented by B and explain why its melting point is so low.

B is neon.
Neon has a simple molecular structure.
The van der Waals' forces among monatomic molecules are weak.
Very little heat is needed to overcome the attractive forces among the molecules in melting.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

- The relative **electrical conductivities (導電性)** of the elements in the second and the third periods are shown in figure below.



# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

## Electrical conductivities of Period 2 elements

- In Period 2, the metals lithium and beryllium are good electrical conductors while the metalloid boron is a semi-conductor.
- Graphite conducts electricity due to the presence of delocalised electrons.
- The remaining non-metals are non-conductors.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

## Electrical conductivities of Period 3 elements

- In Period 3, the metals sodium, magnesium and aluminium are good electrical conductors while the metalloid silicon is a poor conductor. The remaining non-metals are non-conductors.

- Metals have giant metallic structures. They conduct electricity due to the delocalised electrons within the structures. When a potential difference is applied, the delocalised electrons drift through the metal towards the positive terminal.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

- The electrical conductivity increases from sodium to magnesium to aluminium. This can be explained by the number of electrons each atom donates into the 'sea' of delocalised electrons.
- Each sodium atom donates just one electron; each magnesium atom donates two electrons; each aluminium atom donates three electrons.
- There are more delocalised electrons available to drift through the structure when aluminium conducts an electric current. Hence aluminium is a better electrical conductor than sodium and magnesium.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

- The electrical conductivity of silicon is much lower than that of the metals at the start of the period.
- Silicon has a giant covalent structure. The four outermost shell electrons of each silicon atom are held in covalent bonds.
- At room temperature, very few electrons gain enough energy to become delocalised. At higher temperatures, more electrons gain enough energy and become delocalised, giving silicon limited conductivity. Silicon becomes a semi-conductor.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

- Non-metals have simple molecular structures. They do not conduct electricity at all because they do not contain mobile electrons.
- The figure below shows the variations in structures and electrical conductivities of the elements across the second and the third periods of the Periodic Table.

| Giant metallic structure | | Giant covalent structure | | Simple molecular structure | | | |
|---|---|---|---|---|---|---|---|
| Li | Be | B | C (graphite) | $N_2$ | $O_2$ | $F_2$ | Ne |
| Na | Mg | Al | Si | $P_4$ | $S_8$ | $Cl_2$ | Ar |

key: good conductor (Li, Be, C (graphite), Na, Mg, Al); semi-conductor (B, Si); non-conductor ($N_2$, $O_2$, $F_2$, Ne, $P_4$, $S_8$, $Cl_2$, Ar)

Note: In Period 3, Al belongs to the giant metallic structure and Si to the giant covalent structure.

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

## Practice 41.2

Some information about four elements in the third period of the Periodic Table is missing in the following table.

a) Complete the table above to show the bonding and structure of each element.

| Element | Sodium | Magnesium | Silicon | Phosphorus |
|---|---|---|---|---|
| Bonding | metallic | metallic | covalent | covalent |
| Structure | giant metallic | giant metallic | giant covalent | simple molecular |

# 41.4 Periodic variation in electrical conductivities of Periods 2 and 3 elements (p.14)

## Practice 41.2 (continued)

b) Arrange sodium, magnesium, silicon and phosphorus in decreasing order of electrical conductivity at room conditions, and explain your answer in terms of structure.

Electrical conductivity: magnesium > sodium > silicon = phosphorus (or silicon > phosphorus)
Both magnesium and sodium have giant metallic structures. They have high electrical conductivities due to the presence of delocalised electrons in the structures.
Each magnesium atom donates two electrons into the ‘sea’ of delocalised electrons while each sodium atom donates only one electron. Magnesium has more delocalised electrons than sodium. Thus, the electrical conductivity of magnesium is higher than that of sodium.
Silicon has a giant covalent structure.
At room temperature, very few electrons gain enough energy to become delocalised. Thus, silicon cannot conduct electricity. / At higher temperatures, more electrons gain enough energy and become delocalised, giving silicon limited conductivity. Silicon becomes a semi-conductor.
Phosphorus has a simple molecular structure. It cannot conduct electricity because it does not contain mobile electrons.

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

- Oxides of elements from sodium to sulphur can all be prepared by the direct reaction of the element with oxygen in air.

## Sodium

- Sodium burns brightly in air with a characteristic golden yellow flame. A white solid, sodium oxide, is formed.

$$4Na(s) + O_2(g) \longrightarrow 2Na_2O(s)$$

Sodium burns with a golden yellow flame

Sodium oxide is a white solid

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

- The sodium oxide formed may have a yellowish appearance due to the production of some sodium peroxide ($Na_2O_2$).

$$2Na(s) + O_2(g) \longrightarrow Na_2O_2(s)$$

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

## Magnesium

- A strip of magnesium ribbon burns brightly in air. The white powder produced is magnesium oxide.

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

Magnesium ribbon burns in oxygen from the air

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

## Aluminium

- Aluminium powder burns brightly in air to produce a white powder — aluminium oxide.

$$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$

- Aluminium powder reacts readily with oxygen but aluminium foil does not react with oxygen. This is because the aluminium foil has a protective aluminium oxide layer which prevents the reaction.

Powdered aluminium burns brightly in air

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

## Silicon

- Silicon forms silicon dioxide when it is heated strongly in oxygen.

$$Si(s) + O_2(g) \longrightarrow SiO_2(s)$$

- White phosphorus spontaneously ignites in air to produce a cloud of white phosphorus pentoxide.

$$P_4(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$$

If the supply of oxygen is limited, phosphorus trioxide ($P_4O_6$) is also formed.

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

## Sulphur

- Sulphur burns in air with a blue flame, forming misty fumes of a choking and pungent gas — sulphur dioxide.

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

- Sulphur dioxide can be converted to sulphur trioxide when it reacts with more oxygen in the presence of a catalyst under specific conditions.

$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$

**Sulphur burns with a blue flame**

# 41.5 Reactions of Period 3 elements with oxygen in air (p.17)

## Chlorine

- Despite having several oxides (e.g. $Cl_2O$, $ClO_2$, $Cl_2O_6$, $Cl_2O_7$), chlorine does not react directly with oxygen.

# 41.6 Properties of the oxides of Period 3 elements (p.19)

- The melting points of the oxides of Period 3 elements and their electrical conductivities when molten are listed in the table below.

| Element | Na | Mg | Al | Si | P | S | | Cl |
|---|---|---|---|---|---|---|---|---|
| Formula(e) of oxide(s) | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_2$ | $SO_3$ | $Cl_2O$ |
| State at 25 °C | solid | | | | | gas | liquid | gas |
| Melting point (°C) | 1 275 | 2 852 | 2 072 | 1 610 | 580 | –73 | 17 | –120 |
| Electrical conductivity when molten | good | | | none | | | | |

# 41.6 Properties of the oxides of Period 3 elements (p.19)

- These oxides can be grouped into three types:
  - ionic oxides with giant structures — oxides of sodium, magnesium and aluminium;
  - covalent oxide with a giant structure — oxide of silicon;
  - covalent oxides with simple molecular structures — oxides of phosphorus, sulphur and chlorine.

- The ionic oxides and covalent oxide with giant structures have higher melting points than the covalent oxides with simple molecular structures. Besides, the ionic oxides conduct electricity when molten.

# 41.7 Compositions of the oxides of Period 3 elements (p.20)

- The table below summarises the formulae of the oxides of Period 3 elements.

| Group | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Period 3 element | Na | Mg | Al | Si | P | S | Cl |
| Formula of oxide | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_3$ | $Cl_2O_7$ |
| Number of mole(s) of oxygen atoms combining with one mole of atoms | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 |

- From the table, there is a regular increase in the number of mole(s) of oxygen atoms combining with one mole of atoms of an element across the period.

# 41.8 Reactions of the oxides of Period 3 elements with water (p.20)

**Ionic oxides with giant structures**

- Sodium oxide dissolves and reacts with water to produce a colourless solution of sodium hydroxide which is alkaline.

$$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$$

- Magnesium oxide partly reacts with boiling water to give magnesium hydroxide. Magnesium hydroxide is very slightly soluble in boiling water and produces a solution that is slightly alkaline.

$$MgO(s) + H_2O(l) \longrightarrow Mg(OH)_2(s)$$

- Aluminium oxide is insoluble in water.

**Covalent oxide with a giant structure**

- Silicon dioxide is insoluble in water.

# 41.8 Reactions of the oxides of Period 3 elements with water (p.20)

## Covalent oxides with simple molecular structures

- The oxides of phosphorus, sulphur and chlorine are classified as acidic oxides because they dissolve in water to give acidic solutions.

- Phosphorus pentoxide reacts quite violently with little cold water to produce metaphosphoric acid ($HPO_3(aq)$).

$$P_4O_{10}(s) + 2H_2O(l) \longrightarrow 4HPO_3(aq)$$

- Phosphorus pentoxide also reacts violently with excess water to produce phosphoric acid ($H_3PO_4(aq)$).

$$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$$

# 41.8 Reactions of the oxides of Period 3 elements with water (p.20)

- Sulphur dioxide is fairly soluble in water. It reacts with water to produce sulphurous acid ($H_2SO_3(aq)$).

$$SO_2(g) + H_2O(l) \rightleftharpoons H_2SO_3(aq)$$

- Sulphur trioxide reacts violently with water to produce sulphuric acid ($H_2SO_4(aq)$).

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$$

- Dichlorine monoxide dissolves in water to produce hypochlorous acid (HOCl(aq)).

$$Cl_2O(g) + H_2O(l) \longrightarrow 2HOCl(aq)$$

# 41.8 Reactions of the oxides of Period 3 elements with water (p.20)

- The table below summarises the structures of the oxides of Period 3 elements and their reactions with water.

| Element | Na | Mg | Al | Si | P | S | | Cl |
|---|---|---|---|---|---|---|---|---|
| Formula(e) of oxide(s) | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_2$ | $SO_3$ | $Cl_2O$ |
| Structure | giant ionic | | | giant covalent | simple molecular | | | |
| Reaction with water | forms a hydroxide | | insoluble in water | | forms an acid | | | |
| Approximate pH of aqueous solution of oxide (actual value depends on concentration) | 13–14 | 8 | — | — | 1–2 | 2–3 | 0–1 | 4–5 |

**The overall pattern is that ionic oxides of metals form alkaline solutions in water and covalent oxides of non-metals form acidic solutions, whilst those in the middle do not react.**

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

## Basic oxides

- Sodium oxide is basic, so it reacts with an acid to produce a salt and water.
  Examples:
  $Na_2O(s) + 2HCl(aq) \longrightarrow 2NaCl(aq) + H_2O(l)$
  $Na_2O(s) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l)$
- Magnesium oxide is also basic. It reacts with an acid to produce a salt and water.
  Examples:
  $MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$
  $MgO(s) + 2HNO_3(aq) \longrightarrow Mg(NO_3)_2(aq) + H_2O(l)$

**Investigating the acid-base properties of the oxides of Period 3 elements** ***Ref.***

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

## Amphoteric oxide

- Aluminium oxide reacts with both acids and bases.

  Examples:

  - With acid

    $Al_2O_3(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$

    or

    $Al_2O_3(s) + 6H^+(aq) \longrightarrow 2Al^{3+}(aq) + 3H_2O(l)$

  - With hot concentrated sodium hydroxide solution

    $Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \longrightarrow 2NaAl(OH)_4(aq)$

    or

    $Al_2O_3(s) + 2OH^-(aq) + 3H_2O(l) \longrightarrow 2[Al(OH)_4]^-(aq)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

- When aluminium oxide reacts with an acid, it behaves like a base — it forms a salt plus water. In the above example, aluminium sulphate is formed when aluminium oxide reacts with sulphuric acid.
- When aluminium oxide reacts with an alkali, it behaves like an acid — it reacts to form a salt. In the above example, sodium tetrahydroxoaluminate is formed when aluminium oxide reacts with sodium hydroxide solution.
- Compounds that can act as both acids and bases, such as aluminium oxide, are called **amphoteric (兩性的)**.

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

## Acidic oxides

- Silicon dioxide is an acidic oxide, so it reacts with a base to form a silicate.
  For example, silicon dioxide reacts with hot concentrated sodium hydroxide solution, forming sodium silicate and water.
  $SiO_2(s) + 2NaOH(aq) \longrightarrow Na_2SiO_3(aq) + H_2O(l)$
  or
  $SiO_2(s) + 2OH^-(aq) \longrightarrow SiO_3^{2-}(aq) + H_2O(l)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

- Phosphorus pentoxide is an acidic oxide, so it reacts with a base to form a phosphate.
  For example, phosphorus pentoxide reacts with dilute sodium hydroxide solution, forming sodium phosphate and water.
  $P_4O_{10}(s) + 12NaOH(aq) \longrightarrow 4Na_3PO_4(aq) + 6H_2O(l)$
  or
  $P_4O_{10}(s) + 12OH^-(aq) \longrightarrow 4PO_4^{3-}(aq) + 6H_2O(l)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

- Sulphur dioxide is also an acidic oxide, so it reacts with a base to form a sulphite.
  For example, sulphur dioxide reacts with dilute sodium hydroxide solution, forming sodium sulphite and water.
  $SO_2(g) + 2NaOH(aq) \longrightarrow Na_2SO_3(aq) + H_2O(l)$
  or
  $SO_2(g) + 2OH^-(aq) \longrightarrow SO_3^{2-}(aq) + H_2O(l)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

- The table below shows a summary of the structures and acid-base properties of the oxides of Period 3 elements discussed above.

| Oxide | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_2$ |
|---|---|---|---|---|---|---|
| Structure | giant ionic | | | giant covalent | simple molecular | |
| Acid-base property | basic | | amphoteric | acidic | | |

**The overall pattern is that ionic oxides are basic and covalent oxides are acidic, whilst aluminium oxide is amphoteric.**

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

**Q** (Example 41.1)

Consider the following oxides:

$Na_2O$ $Al_2O_3$ $SiO_2$ $SO_2$

Outline chemical tests to show how these oxiders can be classified into acidic, basic and amphoteric.

**A** Add each oxide to HCl(aq) and measure the pH of the mixture. Only $Na_2O$ and $Al_2O_3$ react with HCl(aq) and the pH increases. These oxides demonstrate basic properties.

Add each oxide to NaOH(aq) and measure the pH of the mixture. Only $Al_2O_3$, $SiO_2$ and $SO_2$ react with NaOH(aq) and the pH decreases. These oxides demonstrate acidic properties.

$Al_2O_3$ react in both cases, so it is amphoteric.

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

Practice 41.3

1 This question is about the elements in Period 3 from sodium to phosphorus and their oxides.

a) Element X forms an oxide that has a low melting point. This oxide dissolves in water to form an acidic solution.

i) What type of structure does the oxide of X have?

Simple molecular structure

ii) Write the chemical equation for the reaction between this oxide of X and water.

$P_4O_{10}(s) + 2H_2O(l) \longrightarrow 4HPO_3(aq)$ /

$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

Practice 41.3 (continued)

1 b) Element Y reacts vigorously with water. An oxide of Y dissolves in water to form a solution with a pH of 14.

i) What type of structure does the oxide of Y have?

Giant ionic structure

ii) Write the chemical equation for the reaction between this oxide of Y and water.

$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

Practice 41.3 (continued)

1 c) Element Z forms an amphoteric oxide with a high melting point.

i) What type of structure does the oxide of Z have?

Giant ionic structure

ii) Write TWO chemical equations to show the amphoteric nature of the oxide of Z.

Reaction with acid

$Al_2O_3(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$

Reaction with alkali

$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \longrightarrow 2NaAl(OH)_4(aq)$

# 41.9 Acid-base properties of the oxides of Period 3 elements (p.22)

Practice 41.3 (continued)

2 State how the acid-base character of the oxide of an element can be used to identify whether the element is a metal or a non-metal.

Metals form oxides that are basic while non-metals form oxides that are acidic.

# Key terms (p.26)

| | | | |
|---|---|---|---|
| main group element | 主族元素 | electrical conductivity | 導電性 |
| transition metal | 過渡金屬 | ionic oxide | 離子氧化物 |
| lanthanide | 鑭系元素 | covalent oxide | 共價氧化物 |
| actinide | 錒系元素 | amphoteric | 兩性的 |
| periodicity | 週期律 | | |

# Summary (p.27)

1 The following table summarises the variations in the structures, bonding and physical properties of elements across Periods 2 and 3.

| Group | I | II | III | IV | V | VI | VII | 0 |
|---|---|---|---|---|---|---|---|---|
| Period 2 | Li | Be | B | C (graphite) | N | O | F | Ne |
| Type of element | metals | | metalloid | non-metals | | | | |
| Structure | giant metallic | | giant covalent | | simple molecular | | | |
| | | | | | $N_2$ | $O_2$ | $F_2$ | Ne |
| Bonding and intermolecular forces | positive metal ions surrounded by delocalised electrons | | atoms held together by covalent bonds | | atoms within a molecule joined together by covalent bonds; van der Waals' forces among molecules | | | van der Waals' forces among monatomic molecules |
| Melting point (°C) | 180 | 1 280 | 2 076 | 3 730 | –210 | –219 | –220 | –249 |
| Electrical conductivity | good conductors | | semi-conductor | conductor | non-conductors | | | |
| Period 3 | Na | Mg | Al | Si | P (white) | S (rhombic) | Cl | Ar |
| Type of element | metals | | | metalloid | non-metals | | | |
| Structure | giant metallic | | | giant covalent | simple molecular | | | |
| | | | | | $P_4$ | $S_8$ | $Cl_2$ | Ar |
| Bonding and intermolecular forces | positive metal ions surrounded by delocalised electrons | | | atoms held together by covalent bonds | atoms within a molecule joined together by covalent bonds; van der Waals' forces among molecules | | | van der Waals' forces among monatomic molecules |
| Melting point (°C) | 98 | 650 | 660 | 1 414 | 44 | 115 | –100 | –189 |
| Electrical conductivity | good conductors | | | semi-conductor | non-conductors | | | |

# Summary (p.27)

2 The main trends across a period of elements:
- a change from metals through metalloid to non-metals;
- a maximum in melting point is shown in the middle of the period;
- a change from conductors to non-conductors.

3 For the Period 3 metals, from sodium to aluminium,
- the number of outermost shell electrons provided by each metal atom for bonding increases;
- the size of the metal ion decreases;
- the degree of compactness of the packing of metal ions increases.

Thus, the strength of metallic bonding and melting points increase from sodium to aluminium.

# Summary (p.27)

5 The following table summarises some physical properties of oxides of Period 3 elements and the reactions of the oxides with water.

| Element | Na | Mg | Al | Si | P | S | | Cl |
|---|---|---|---|---|---|---|---|---|
| Formula(e) of oxide(s) | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_2$ | $SO_3$ | $Cl_2O$ |
| Structure | giant ionic | | | giant covalent | simple molecular | | | |
| State at 25 °C | solid | | | | | gas | liquid | gas |
| Melting point (°C) | 1 275 | 2 852 | 2 072 | 1 610 | 580 | –73 | 17 | –120 |
| Electrical conductivity when molten | good | | | none | | | | |
| Reaction with water | forms a hydroxide | | insoluble in water | | forms an acid | | | |
| Approximate pH of aqueous solution of oxide (actual value depends on concentration) | 13–14 | 8 | — | — | 1–2 | 2–3 | 0–1 | 4–5 |

The overall pattern is that ionic oxides of metals form alkaline solutions in water and covalent oxides of non-metals form acidic solutions, whilst those in the middle do not react.

# Summary (p.27)

6 For oxides of Period 3 elements, the ionic oxides are basic and covalent oxides are acidic, while aluminium oxide is amphoteric.

7 Aluminium oxide can react with both acids and bases.

e.g. $Al_2O_3(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$

$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \longrightarrow 2NaAl(OH)_4(aq)$

# Unit Exercise (p.29)

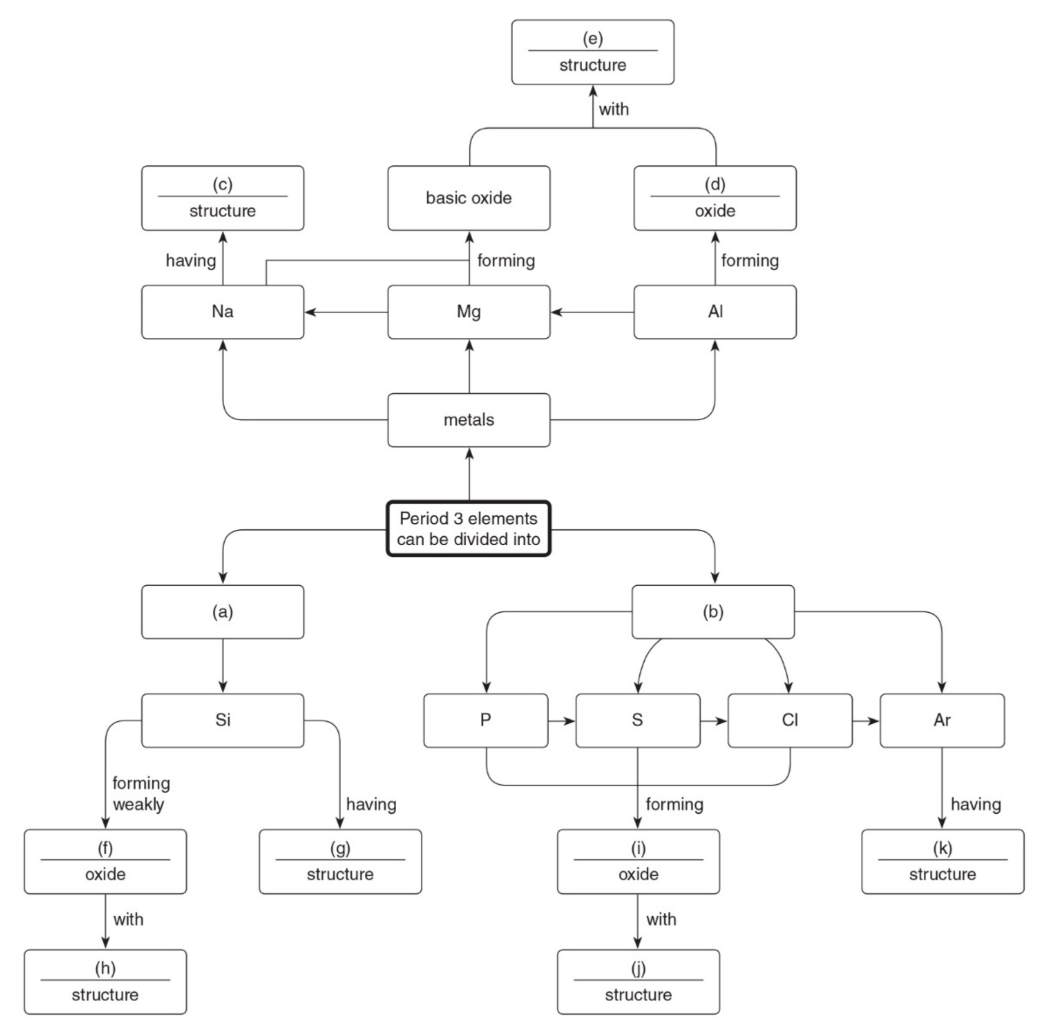
**Note: Questions are rated according to ascending level of difficulty (from 1 to 5):**

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
**‘ * ’ indicates 1 mark is given for effective communication.**

# Unit Exercise (p.29)

## PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.

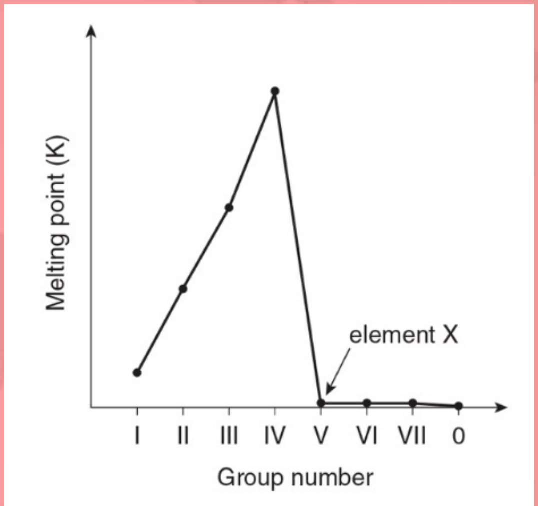



a) metalloid
b) non-metals
c) giant metallic
d) amphoteric
e) giant ionic
f) acidic
g) giant covalent
h) giant covalent
i) acidic
j) simple molecular
k) simple molecular

# Unit Exercise (p.29)

## PART II MULTIPLE CHOICE QUESTIONS

2 The diagram shows the melting points of successive elements across a period in the Periodic Table.



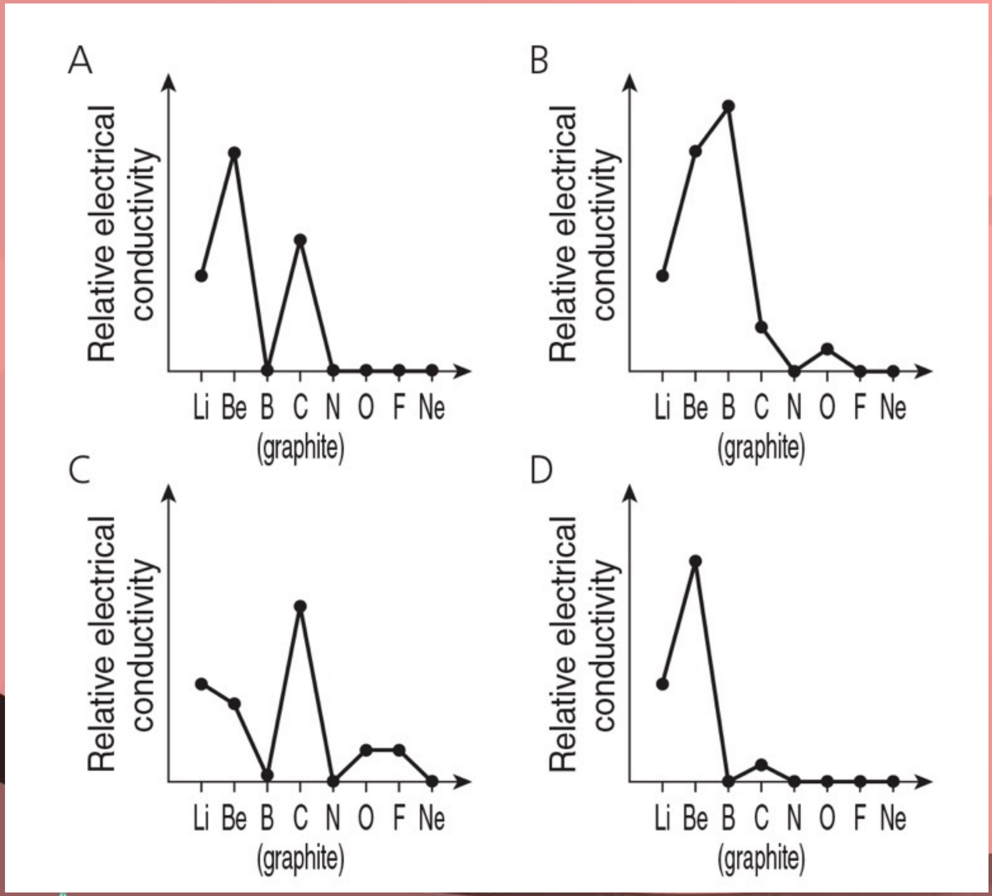

Which of the following is a correct reason for the low melting point of element X?

A It has weak ionic bonds.
B It has weak covalent bonds.
C It has weakly-held outermost shell electrons.
D It has weak forces among molecules.

Answer: D

# Unit Exercise (p.29)

3 Which of the following graphs (not drawn to scale) shows the variation of relative electrical conductivities of the elements in the second period of the Periodic Table?




Explanation:

In Period 2, the metals lithium and beryllium are good electrical conductors while the metalloid boron is a semi-conductor. Graphite conducts electricity due to the presence of delocalised electrons. The remaining non-metals are non-conductors.

Answer: D

# Unit Exercise (p.29)

4 Which of the following statements is correct?

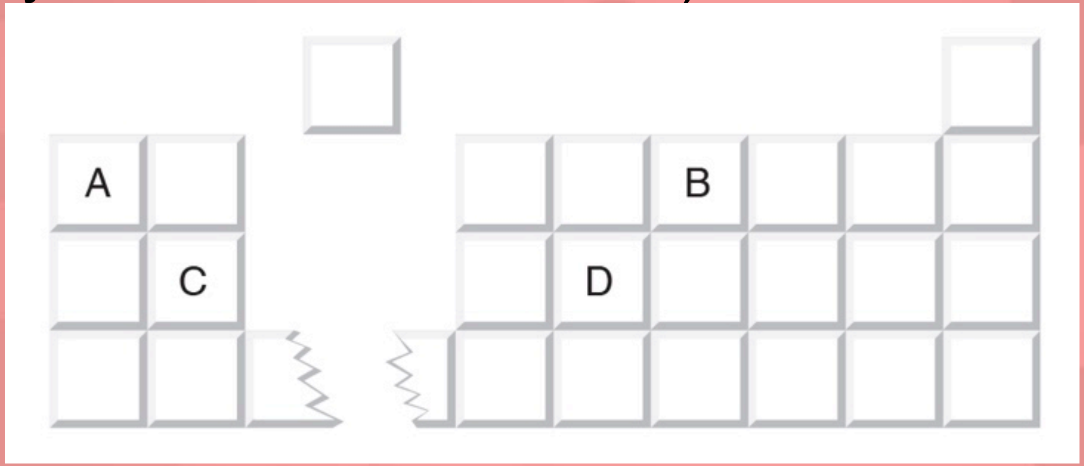
A The boiling point of argon is lower than that of neon.
B The boiling point of nitrogen is lower than that of oxygen.
C The melting point of silicon is lower than that of sodium.
D The melting point of aluminium is lower than that of magnesium.

*(HKDSE, Paper 1A, 2018, 28)*

Answer: B

# Unit Exercise (p.29)

5 The positions of four elements in the Periodic Table are shown by the letters A, B, C and D (the letters are NOT symbols of the elements).




Which letter shows the position of the element which has the HIGHEST melting point?

Answer: D

Explanation:

D is silicon. It has a giant covalent structure.

# Unit Exercise (p.29)

6 Which of the following statements concerning aluminium oxide is INCORRECT?

A It has a high melting point.
B It is an amphoteric oxide.
C It is soluble in sodium hydroxide solution.
D It produces a solution with a pH greater than 7 when mixed with water.

Explanation:
Aluminium oxide is insoluble in water.

Answer: D

# Unit Exercise (p.29)

7 Which of the following oxides produces a slightly alkaline solution when dissolved in water?

A $Al_2O_3$
B $MgO$
C $P_4O_{10}$
D $SiO_2$

Explanation:
MgO is a basic oxide.

Answer: B

# Unit Exercise (p.29)

8 Which of the following statements concerning silicon dioxide solid is correct?

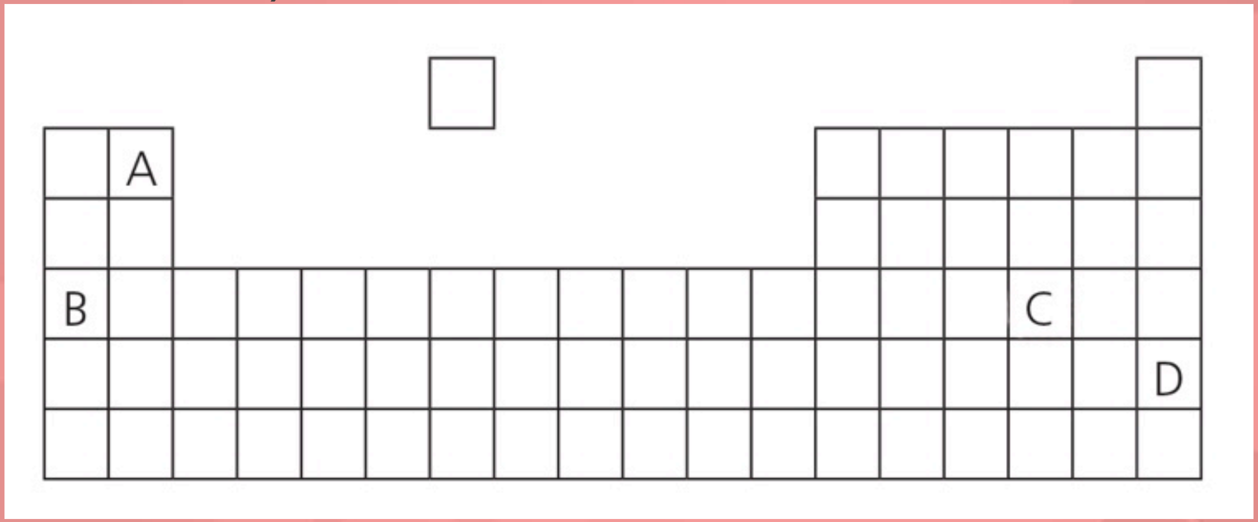
A There are single covalent bonds between silicon atoms and oxygen atoms.
B It is insoluble in sodium hydroxide solution.
C It has a simple molecular structure.
D It conducts electricity at room temperature.

*(HKDSE, Paper 1A, 2017, 30)*

Answer: A

# Unit Exercise (p.29)

9 The positions of four elements in the Periodic Table are shown by the letters A, B, C and D (the letters are NOT symbols of the elements).



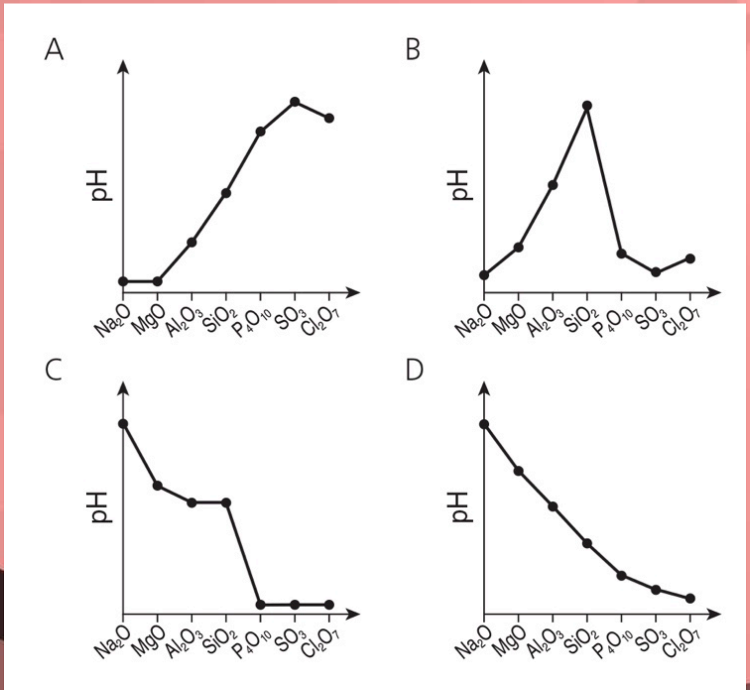

Answer: C

Which letter shows the position of the element which is likely to form an acidic oxide?

Explanation:
Non-metals form acidic oxides.

# Unit Exercise (p.29)

10 The oxides of the elements from sodium to chlorine (with elements in the highest oxidation states) are added separately to water.
Which of the following graphs (not drawn to scale) best represents the pH of the resulting mixture?




Explanation:
$Na_2O$ and MgO react with water to form alkaline solutions, i.e. pH > 7.
$Al_2O_3$ and $SiO_2$ are insoluble in water.
$P_4O_{10}$, $SO_3$ and $Cl_2O_7$ react with water to form acids, i.e. pH < 7.

Answer: C

# Unit Exercise (p.29)

11 Which of the following oxides has a molecular structure?

A $Al_2O_3$
B $Cl_2O$
C $MgO$
D $SiO_2$

Answer: B

# Unit Exercise (p.29)

12 Which of the following trends involving Na, Mg and Al is INCORRECT?

A Melting point of metal: Al > Mg > Na
B Electronegativity of metal: Al > Mg > Na
C Metal reactivity with water: Na > Mg > Al
D Base strength of metal oxide: $Al_2O_3$ > MgO > $Na_2O$

*(HKDSE, Paper 1A, 2016, 30)*

Answer: D

# Unit Exercise (p.29)

13 Which of the following oxides dissolves in water to form an acid where the central element has an oxidation state of +6?

A $Al_2O_3$
B $P_4O_{10}$
C $SiO_2$
D $SO_3$

Explanation:
$SO_3$ reacts with water to form sulphuric acid.

Answer: D

# Unit Exercise (p.29)

14 Which of the following statements concerning sodium oxide is / are correct?

(1) It is an amphoteric oxide.
(2) It conducts electricity when molten.
(3) It has a high melting point.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Answer: D

Explanation:
(1) Sodium oxide is a basic oxide.

# Unit Exercise (p.29)

15 Which of the following statements about sulphur dioxide are correct?

(1) It has a simple molecular structure.
(2) Its aqueous solution is a reducing agent.
(3) Its melting point is lower than that of sulphur trioxide.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Explanation:
(3) The size of $SO_2$ molecule is smaller than that of $SO_3$ molecule. Van der Waals' forces among $SO_2$ molecules are weaker than those among $SO_3$ molecules.

Answer: D

# Unit Exercise (p.29)

16 Which of the general trends are correct for the oxides of Period 3 elements (from $Na_2O$ to $Cl_2O$)?

(1) Bonding changes from ionic to covalent.
(2) Melting point increases.
(3) Electrical conductivity (in the molten state) increases.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Explanation:
(3) $Na_2O$, MgO and $Al_2O_3$ conduct electricity in the molten state while the oxides of other Period 3 elements do NOT.

Answer: A

# Unit Exercise (p.29)

## PART III STRUCTURED QUESTIONS

17 The table below refers to the elements of the third period sodium to chlorine and is incomplete.

| Element | Na | Mg | Al | Si | P | S | Cl | |
|---|---|---|---|---|---|---|---|---|
| Melting point | low | high | high | high | low | low | low | (2) |
| Electrical conductivity | high | high | high | moderate | none | none | none | (2) |

a) Complete the 'melting point' row by using only the words 'high' or 'low'.

b) Complete the 'electrical conductivity' row by using only the words 'high', 'moderate' or 'none'.

# Unit Exercise (p.29)

18 This question refers to the elements in Period 3 of the Periodic Table.

Na Mg Al Si P S Cl Ar

From this list of elements, identify ONE element that has the property described in each case. Give the symbol of the element.

a) An element that forms an oxide which is a reducing agent.

P / S (1)

b) An element which has a giant covalent structure.

Si (1)

c) An element which has the highest electrical conductivity.

Al (1)

d) An element which forms a basic oxide.

Na / Mg (1)

e) An element which forms a chloride with a low melting point and an oxide with a very high melting point.

Al / Si (1)

# Unit Exercise (p.29)

19 The elements lithium to neon make up the second period of the Periodic Table.

Li Be B C N O F Ne

a) Name an element from the second period that exists as a covalent network.

Boron or carbon / graphite / diamond (1)

b) Which element in the second period is the strongest reducing agent?

Lithium (1)

# Unit Exercise (p.29)

19 (continued)

*c) Arrange lithium, carbon (diamond), fluorine and neon in increasing order of melting point. Explain the order in terms of structure and bonding.

neon < fluorine < lithium < carbon (diamond) (1)

Both neon and fluorine have simple molecular structures. Only weak van der Waals' forces are needed to be overcome in melting. (1)

Neon exists as monatomic molecules while fluorine exists as diatomic molecules. A fluorine molecule has a larger size than a neon molecule. Thus, stronger van der Waals' forces exist among fluorine molecules.(1)

Thus, the melting point of fluorine is higher than that of neon.

Lithium has a giant metallic structure. (1)

The attractive forces between the lithium ions and the 'sea' of delocalised electrons are stronger than van der Waals' forces. Thus, the melting point of lithium is higher than that of neon and fluorine. (1)

Carbon (diamond) has the highest melting point as it has a giant covalent structure.(1)

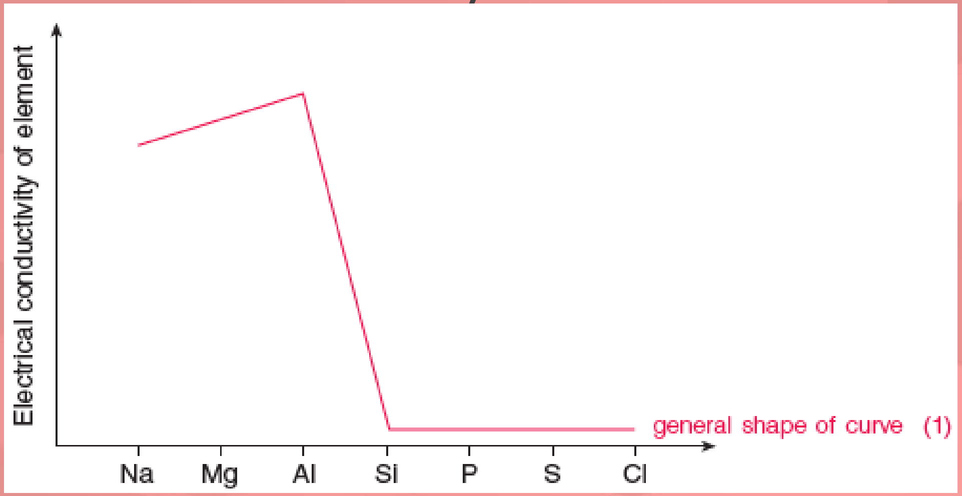
Lots of strong covalent bonds between atoms have to be broken in melting.

A lot of heat is needed. (1)

Communication mark (1)

# Unit Exercise (p.29)

20 Sketch the variation of electrical conductivities of Period 3 elements. Briefly account for the trend.




Sodium, magnesium and aluminium have giant metallic structures. They have high electrical conductivities due to the presence of delocalised electrons in the structures. (1)

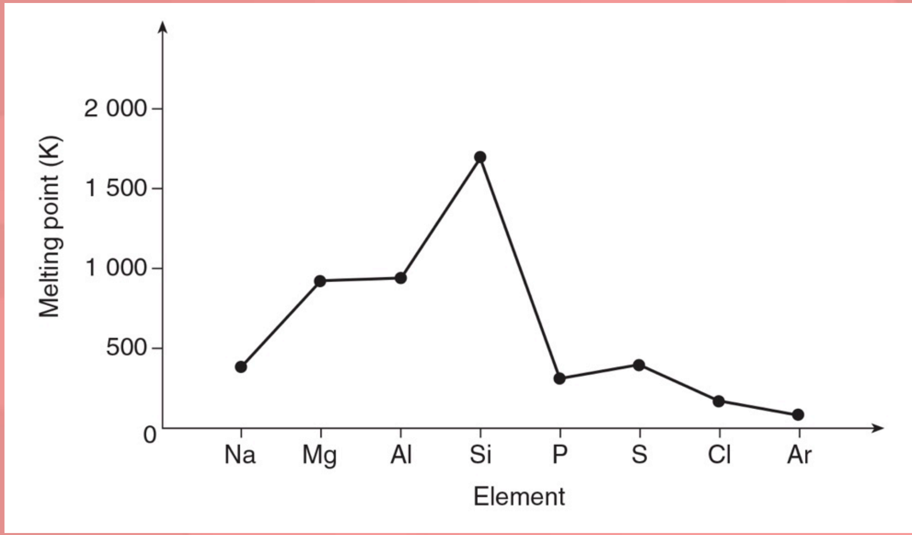
The number of delocalised electrons increases from sodium to aluminium. Thus, the electrical conductivity increases from sodium to aluminium. (1)

Silicon has a giant covalent structure.
At room temperature, very few electrons gain enough energy to become delocalised. Thus, silicon cannot conduct electricity. / At higher temperatures, more electrons gain enough energy and become delocalised, giving silicon limited conductivity. Silicon becomes a semi-conductor. (1)

Phosphorus, sulphur and chlorine have simple molecular structures. They cannot conduct electricity because they do not contain mobile electrons. (1)

# Unit Exercise (p.29)

21 The graph below shows the variation of melting points of Period 3 elements.




Explain why

a) silicon, a metalloid, has a very high melting point;

Silicon has a giant covalent structure. (1)

Lots of strong covalent bonds between atoms have to be broken in melting. A lot of heat is needed. (1)

# Unit Exercise (p.29)

21 (continued)

b) the melting points of the metals are in the order:
Al > Mg > Na;
Na, Mg and Al have giant metallic structures. (1)
The number of delocalised electrons increases from Na to Al. Thus, the order of strength of metallic bonding in the three metals is Al > Mg > Na. (1)

c) the melting point of sulphur is the highest among the non-metals.
P, S, Cl and Ar have simple molecular structures. Only weak van der Waals' forces are needed to be overcome in melting. (1)
The elements all form small covalent molecules, $P_4$, S8, $Cl_2$ and Ar respectively. $S_8$ molecules have the largest size. Thus, the van der Waals' forces among $S_8$ molecules are the strongest. (1)

# Unit Exercise (p.29)

22 The table below lists the melting points of elements in Periods 2 and 3 of the Periodic Table.

| Period 2 | Li | Be | B | C (graphite) | N | O | F | Ne |
|---|---|---|---|---|---|---|---|---|
| Melting point (K) | 453 | 1 553 | 2 349 | 4 003 | 63 | 54 | 53 | 24 |
| Period 3 | Na | Mg | Al | Si | P (white) | S (rhombic) | Cl | Ar |
| Melting point (K) | 371 | 923 | 933 | 1 687 | 317 | 388 | 172 | 84 |

a) What is the general pattern in melting temperatures across periods in the Periodic Table?

The melting points increase from Group I to Group IV. (1)
The melting points are comparatively low from Group V to Group 0. (1)

# Unit Exercise (p.29)

22 (continued)

b) How is this general trend related to the different types of elements?

Elements with giant metallic structures have high melting points. (1)
Elements with giant covalent structures have high melting points. (1)
Elements with simple molecular structures have low melting points. (1)

c) What is meant by the term 'periodicity'?

The recurrence of the same pattern across different periods is called periodicity. (1)

d) State ONE other physical property that can be described as periodic in relation to the Periodic Table.

Any one of the following:

- Boiling point (1)
- Electrical conductivity (1)
- Electronegativity (1)
- Atomic radius (1)

# Unit Exercise (p.29)

23 Lithium, beryllium, carbon (graphite) and nitrogen are elements of the second period of the Periodic Table. Arrange them in increasing order of melting point, and explain the order in terms of structure and bonding.

*(HKDSE, Paper 1B, 2013, 13)*

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

# Unit Exercise (p.29)

24 This question refers to the following oxides of Period 3 elements.

$Na_2O$ $SiO_2$ $SO_2$ $SO_3$

a) Explain why sulphur trioxide has a higher melting point than sulphur dioxide.

Both $SO_2$ and $SO_3$ have simple molecular structures. Only weak van der Waals' forces are needed to be overcome in melting. (1)
A $SO_3$ molecule has a larger size than a $SO_2$ molecule. Thus, stronger van der Waals' forces exist among $SO_3$ molecules. (1)

# Unit Exercise (p.29)

24 (continued)

b) Separate samples of $Na_2O$ and $SiO_2$ are melted. Each molten sample is then tested to see whether it conducts electricity.
Suggest what would be the result in each case. Explain your answers.

$Na_2O$ conducts
contains mobile ions. (1)
$SiO_2$ does not conduct
contains no mobile ions / electrons. (1)

c) Which of the above oxides is basic?

$Na_2O$ (1)

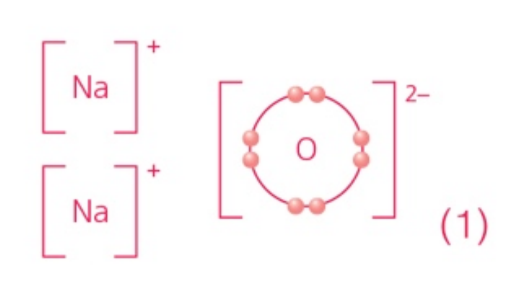
d) Suggest why $SiO_2$ is described as an acidic oxide even though it is insoluble in water.

$SiO_2$ reacts with bases / NaOH / CaO. (1)

# Unit Exercise (p.29)

25 This question is about oxides of some Period 3 elements.

a) Draw an electron diagram to show the bonding in sodium oxide, showing electrons in the *outermost shells* only.




b) A small mass of magnesium oxide is added to water. The mixture is stirred and an aqueous solution is formed.

i) Name the aqueous solution formed. Estimate its pH value.

Magnesium hydroxide (1)

pH 8 –13 (1)

# Unit Exercise (p.29)

25 (continued)

b) ii) Write the chemical equation for the reaction involved.

$MgO(s) + H_2O(l) \longrightarrow Mg(OH)_2(s)$ (1)

c) Dichlorine heptoxide ($Cl_2O_7$) has a simple molecular structure. Suggest ONE chemical property of $Cl_2O_7$.

Reacts with alkali / reacts with water to give an acid / strong oxidising agent (1)

# Unit Exercise (p.29)

26 White phosphorus ($P_4$) is a hazardous form of the element. It is stored under water.

a) Suggest why white phosphorus is stored under water.

To prevent it reacting with oxygen / air. (1)

b) Explain why phosphorus pentoxide ($P_4O_{10}$) has a higher melting point than sulphur trioxide ($SO_3$).

Both $P_4O_{10}$ and $SO_3$ have simple molecular structures. Only weak van der Waals' forces are needed to be overcome in melting. (1)

A $P_4O_{10}$ molecule has a larger size than a $SO_3$ molecule. Thus, stronger van der Waals' forces exist among $P_4O_{10}$ molecules. (1)

# Unit Exercise (p.29)

26 (Continued)

c) Write an equation for the reaction of $P_4O_{10}$ with water to form phosphoric acid.
Give the approximate pH of the final solution.

$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$ (1)

pH –1 to +2 (1)

d) A waste-water tank was contaminated by $P_4O_{10}$. The resulting phosphoric acid solution was neutralised using an excess of magnesium oxide. The mixture produced was then disposed of in a lake.

i) Write an equation for the reaction between phosphoric acid and magnesium oxide.

Any one of the following:

$3MgO + 2H_3PO_4 \longrightarrow Mg_3(PO_4)_2 + 3H_2O$ (1)

$MgO + 2H_3PO_4 \longrightarrow Mg(H_2PO_4)_2 + H_2O$ (1)

$MgO + H_3PO_4 \longrightarrow MgHPO_4 + H_2O$ (1)

# Unit Exercise (p.29)

26 (Continued)

d) ii) Explain why an excess of magnesium oxide can be used for this neutralisation.

MgO is slightly soluble / weakly alkaline. (1)

iii) Explain why the use of an excess of sodium hydroxide to neutralise the phosphoric acid solution might lead to environmental problems in the lake.

An excess of NaOH would make the lake alkaline / kill wildlife. (1)

*(AQA Advanced Level GCE, Unit 5, Jun. 2012, 1(a), (c)–(e))*

# Unit Exercise (p.29)

27 The chemical formulae of some oxides of Period 3 elements are listed below.

| Chemical formula | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_3$ |
|---|---|---|---|---|---|---|

a) Describe the trend in chemical formula shown in the above table.

Any one of the following:

- Increase in oxidation number of the Period 3 element (1)
- Increase in the number of moles of oxygen atoms combining with one mole of atoms of Period 3 element (1)

b) Identify ONE acidic oxide that does NOT react with water.

$SiO_2$ (1)

# Unit Exercise (p.29)

27 (Continued)

c) Silicon dioxide has a giant covalent structure. Suggest TWO physical properties of silicon dioxide.

Any two of the following:

- Does not conduct electricity when molten (1)
- Insoluble in water (1)
- High melting point / high boiling point (1)
- Very hard (1)

d) Write equations for TWO reactions which together show the amphoteric nature of aluminium oxide.

Reaction with acid

$Al_2O_3(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$ (1)

Reaction with alkali

$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \longrightarrow 2NaAl(OH)_4(aq)$ (1)

# Unit Exercise (p.29)

28 The table below gives the melting points of the oxides of Period 3 elements.

| Oxide | $Na_2O$ | $MgO$ | $Al_2O_3$ | $SiO_2$ | $P_4O_{10}$ | $SO_2$ | $Cl_2O_7$ | |
|---|---|---|---|---|---|---|---|---|
| Melting point (°C) | 1 132 | 2 830 | 2 054 | 1 710 | 580 | –73 | –92 | |
| Structure | GI | GI | GI | GC | SM | SM | SM | (2) |

a) Use the following notations to provide information about the structures of the oxides.
GI: giant ionic structure
GC: giant covalent structure
SM: simple molecular structure

# Unit Exercise (p.29)

28 (Continued)

b) Separate samples of $Na_2O$ and $SO_2$ are added to water. For each oxide, write a chemical equation for its reaction with water and suggest a numerical value for the pH of the resulting solution.

$Na_2O$

Equation $Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$ (1)

pH 10–14 (1)

$SO_2$

Equation $SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$ (1)

pH 2–5 (1)

c) By considering the trend of acid-base properties and that of bonding of these oxides, state the relationship between the two trends.

Ionic oxides are basic while covalent oxides are acidic. (1)

# Unit Exercise (p.29)

*29 X is an element in Group V of the Periodic Table. The oxide of X is a white powder which is insoluble in water. Describe how you would find out if it is a basic, an acidic or an amphoteric oxide.

Add the oxide to excess hot HCl(aq). If the solid oxide dissolves, measure the pH of the mixture. The pH increases. Then it is a basic oxide. (1)

Add the oxide to excess hot NaOH(aq). If the solid oxide dissolves, measure the pH of the mixture. The pH decreases. Then it is an acidic oxide. (1)

If the oxide reacts with both HCl(aq) and NaOH(aq), then it is an amphoteric oxide. (1)

Communication mark (1)

# Unit Exercise (p.29)

*30 Consider the following oxides:

magnesium oxide     aluminium oxide     sulphur dioxide

There are trends in properties of the oxides of Period 3 elements across the period. Using only the above three oxides, describe the trends in

- chemical formula;
- structure and bonding;
- action of water.

Include appropriate equation(s) in your answer.

# Unit Exercise (p.29)

30 (Continued)

Chemical formula

$MgO$ $Al_2O_3$ $SO_2$

Any one of the following:

- Increase in oxidation number of the element (1)
- Increase in the number of moles of oxygen atoms combining with one mole of atoms of the element (1)

Structure and bonding

$MgO$ and $Al_2O_3$ have giant ionic structures while $SO_2$ has a simple molecular structure. (1)

Action of water

$MgO$ reacts with water to form an alkaline solution. $Al_2O_3$ does not dissolve in water. $SO_2$ reacts with water to form an acid. (1)

$MgO(s) + H_2O(l) \longrightarrow Mg(OH)_2(s)$ (1)

$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$ (1)

Communication mark (1)