**1.** This question is about the chemistry of compounds containing phosphorus.

Phosphorus forms several acids including $H_3PO_4$ and $H_3PO_3$.

$H_3PO_4$ is a tribasic acid. The equilibria for the dissociations are shown below.

**1** $H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$
**2** $H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$
**3** $HPO_4^{2-} \rightleftharpoons H^+ + PO_4^{3-}$

i. During the equilibria, $H_2PO_4^-$ behaves both as an acid and as a base.

Explain this statement, using the equilibria **1**, **2** and **3**, as required.

**[2]**

ii. In a $H_3PO_3$ molecule, the O atoms are covalently bonded to the P atom. The H atoms are bonded to the O atoms.

Draw the structure of a $H_3PO_3$ molecule, showing all the bonds.

On your diagram, add the values for the O−P−O and P−O−H bond angles.

**[3]**

iii. The systematic name of $H_3PO_4$ is phosphoric(V) acid.

What is the systematic name of $H_3PO_3$?

**[1]**

**2.** Short-chain carboxylic acids, such as methanoic acid, HCOOH, are soluble in water.

Explain, with a labelled diagram, how HCOOH interacts with water when it dissolves.

**[2]**

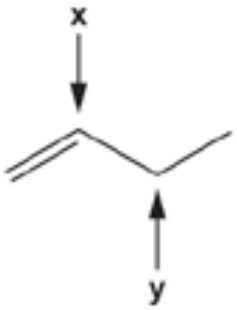
**3.** Hydrogen reacts much more readily with alkenes than with alkanes.

Why is this?

**A** Alkenes are polar molecules whereas alkanes are not.
**B** All atoms in an alkane have a full outer shell of electrons.
**C** The bond enthalpy of C–C σ bonds is **higher** than that of **π** bonds.
**D** The bond enthalpy of C–C σ bonds is **lower** than that of **π** bonds.

Your answer ☐ **[1]**

**4.** The structure of but-1-ene is shown below.




Which row has the correct **shape** around carbon atoms labelled **x** and **y**?

| | x | y |
|---|---|---|
| **A** | Tetrahedral | Pyramidal |
| **B** | Trigonal planar | Tetrahedral |
| **C** | Trigonal planar | Pyramidal |
| **D** | Pyramidal | Tetrahedral |

Your answer ☐ **[1]**

**5.** All organic compounds have covalent bonds.

What is the electrostatic attraction in a covalent bond between?

**A** A shared pair of electrons and the nuclei of the bonded atoms
**B** Cations and delocalised electrons
**C** Oppositely charged ions
**D** Two molecules

Your answer ☐ **[1]**

**6.** This question is about covalent compounds of nitrogen.

Hydrogen cyanide, HCN, is bonded by a single bond between the H and C atoms and a triple bond between the C and N atoms.

Draw a 'dot-and-cross' diagram for a molecule of HCN.

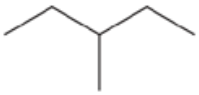
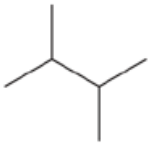
Use different symbols for electrons from H, C and N.

Show outer electrons only.

**[2]**

**7(a).** This question is about hydrocarbons.

The skeletal formulae and boiling points of three isomers of $C_6H_{14}$ are shown in the table below.

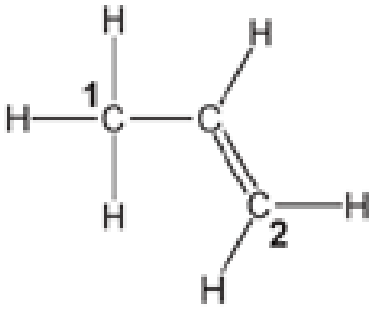
| Isomer | Molecular formula | Skeletal formula | Boiling point/°C |
|---|---|---|---|
| **A** | $C_6H_{14}$ |  | 69 |
| **B** | $C_6H_{14}$ |  | 63 |
| **C** | $C_6H_{14}$ |  | 58 |

State and explain the trend in the boiling points shown in the table.

Refer to the isomers **A**, **B** and **C** in your answer.

**[4]**

**(b).** Propene, $C_3H_6$, has different bond angles and shapes around the carbon atoms. The displayed formula of a propene molecule is shown below.




Predict the bond angles and the names of the shapes around the C atoms **1** and **2** above, and explain why the bond angles and shapes are different.

| Carbon atom | Bond angle | Name of shape |
|---|---|---|
| **1** | | |
| **2** | | |

Explanation:

**[5]**

**8.** Which reaction produces a product with linear molecules?

**A** $2B + 3F_2 \rightarrow$
**B** $C + O_2 \rightarrow$
**C** $2H_2 + O_2 \rightarrow$
**D** $N_2 + 3H_2 \rightarrow$

Your answer ☐ **[1]**

**9.** This question is about two oxides of sulfur: sulfur dioxide, $SO_2$, and sulfur trioxide, $SO_3$.

$SO_2$ and $SO_3$ both have molecules with sulfur in the centre and bond angles of approximately 120°.

i. Explain why the bond angles in $SO_3$ are 120°.

**[1]**

ii. Explain why both $SO_2$ and $SO_3$ have polar bonds, but only $SO_2$ has polar molecules.

**[2]**

**10.** The table shows the melting points of some of the elements in Period 3 of the periodic table.

| **Element** | **Al** | **Si** | **$P_4$** | **$S_8$** |
|---|---|---|---|---|
| **Melting point / °C** | 660 | 1410 | 44 | 119 |

Explain the melting points in terms of bonding and structure.

[6]

**11.** Water has the anomalous properties below.

- Water has relatively high melting and boiling points.
- Ice is less dense than water.

Which statement explains these anomalous properties?

**A** The covalent bonding within water molecules.
**B** The hydrogen bonding between water molecules.
**C** The induced dipole-dipole interactions (London forces) between water molecules.
**D** The ionic bonding between water molecules.

Your answer ☐ **[1]**

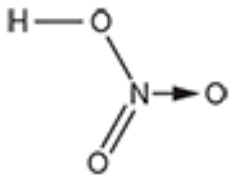
**12.** Which statement explains the trend in boiling points down the halogens group?

**A** The bond enthalpy of the covalent bonds increases.
**B** The halogens become less electronegative.
**C** The induced dipole-dipole interactions (London forces) become stronger.
**D** The reactivity of the halogens decreases.

Your answer ☐ **[1]**

**13(a).** This question is about nitric acid, hydrochloric acid and sulfuric acid.

Nitric acid has 2 single covalent bonds, 1 double covalent bond and 1 dative covalent bond as shown below.




**Nitric acid**

Predict the H–O–N and O–N–O bond angles in nitric acid.

Explain your reasoning.

[4]

**(b).** Dilute nitric acid reacts with aluminium oxide to form a solution of aluminium nitrate.

i. Write an equation for this reaction.

---

**[2]**

ii. The solution contains nitrate ions, $NO_3^-$.

Draw a 'dot-and-cross' diagram for the $NO_3^-$ ion.

Use a different symbol for the extra electron.

**[2]**

**14(a).** This question is about the first 36 elements in the periodic table:

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H | | | | | | | | | | | | | | | | | He |
| Li | Be | | | | | | | | | | | B | C | N | O | F | Ne |
| Na | Mg | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |

From these 36 elements **only**, write the symbol for the element(s) that fit each description.

The **three** elements that, when in a molecule, can form hydrogen bonds with other suitable molecules.

..... **[1]**

**(b).** An element that is a solid at RTP with a simple molecular lattice structure.

..... **[1]**

**(c).** The p-block element in Period 3 that forms a compound with fluorine with octahedral molecules.

..... **[1]**

**15.** Which substance(s) has/have induced dipole–dipole interactions (London forces) in the solid state?

**1** $C_2H_6$
**2** $H_2O$
**3** Si

**A** 1, 2 and 3
**B** Only 1 and 2
**C** Only 2 and 3
**D** Only 1

Your answer ☐ **[1]**

**16.** Which compound has polar molecules?

**A** HCN
**B** $BCl_3$
**C** $CO_2$
**D** $C_2F_4$

Your answer ☐ **[1]**

**17(a).** This question is about $NF_3$ and $BF_3$ molecules.

$NF_3$ and $BF_3$ contain covalent bonds.

i. What is meant by a **covalent bond**?

---

**[1]**

ii. Draw 'dot-and-cross' diagrams for $NF_3$ and $BF_3$.

Show outer electrons only.


**[2]**

**(b).** Molecules of $NF_3$ and $BF_3$ have different shapes and bond angles.

i. Predict the different shapes of, and bond angles in, $NF_3$ and $BF_3$ molecules.

| | Bond angle | Name of shape |
|---|---|---|
| **$NF_3$** | | |
| **$BF_3$** | | |

**[2]**

ii. Explain why $NF_3$ and $BF_3$ molecules have different shapes and bond angles.

**[2]**

**18.** This question is about hydrocarbons.

The boiling points of 2 hydrocarbons are shown below.

| Hydrocarbon | Boiling point / °C |
|---|---|
| butane | 0 |
| pentane | 36 |

Explain the difference in the boiling points of butane and pentane.

**[2]**

**19.** Which statement explains the trend in boiling points down the halogens group?

**A** Covalent bonds become stronger.
**B** Induced dipole–dipole interactions (London forces) become stronger.
**C** Ionic bonds become stronger.
**D** Permanent dipole–dipole interactions become stronger.

Your answer ☐ **[1]**

**20.** This question is about hydrocarbons.

The boiling points of some hydrocarbons containing 6 carbon atoms are shown below.

| Hydrocarbon | Boiling point / ºC |
|---|---|
| 2,2-dimethylbutane | 50 |
| 2-methylpentane | 60 |
| hexane | 69 |

State and explain the trend in boiling points shown by these hydrocarbons.

**[4]**

**21.** Which ion(s) contain(s) bond angles of approximately 120º?

**1** $CH_3COO^-$
**2** $C_6H_5O^-$
**3** $(CH_3)_3C^+$
**A** 1, 2 and 3
**B** Only 1 and 2
**C** Only 2 and 3
**D** Only 1

Your answer ☐ **[1]**

**22.** The table below shows melting points and electrical conductivities of some elements in Period 3 and compounds they form.

| **Substance** | **Magnesium sulfide, MgS** | **Aluminium, Al** | **Silicon, Si** | **Phosphorus trichloride, $PCl_3$** |
|---|---|---|---|---|
| **Melting point / °C** | 2000 | 660 | 1414 | –94 |
| **Electrical conductivity** | | Good | Poor | |
| **Type of lattice structure** | Giant<br>..... | .....<br>..... | .....<br>..... | .....<br>..... |

i. Complete the table above to show the type of lattice structure of each substance.

**[4]**

ii. Explain the following:

- MgS has a higher melting point than $PCl_3$.
- Al has a greater electrical conductivity than Si.

Melting points _____

_____

_____

_____

Conductivities _____

_____

_____

**[4]**

**23.** This question is about titanium (atomic number 22) and its compounds.

An ore of titanium contains impure $TiO_2$.

Titanium is manufactured from $TiO_2$ in a two-stage process.

**Stage 1** $TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO$ **Reaction 1.1**

**Stage 2** $TiCl_4 + 4Na \rightarrow Ti + 4NaCl$ **Reaction 1.2**

i. The common name for $TiO_2$ is titanium dioxide.

What is the systematic name of $TiO_2$?

---

**[1]**

ii. In **Reaction 1.2**, the percentage yield of titanium from $TiCl_4$ is 72.0%.

Calculate the minimum mass, in kg, of sodium that is needed to produce 1.00 kg of titanium.

Give your answer to **3** significant figures.

mass of sodium = ..... kg **[4]**

iii. **Reaction 1.2** produces a mixture of titanium and sodium chloride.

Suggest how titanium could be separated from this mixture at room temperature.

Explain your answer.

---

**[2]**

**24.** This question is about different types of bonding.

Ionic compounds have ionic bonding and exist in a giant ionic lattice structure.

i. What is meant by **ionic bonding**?

_____

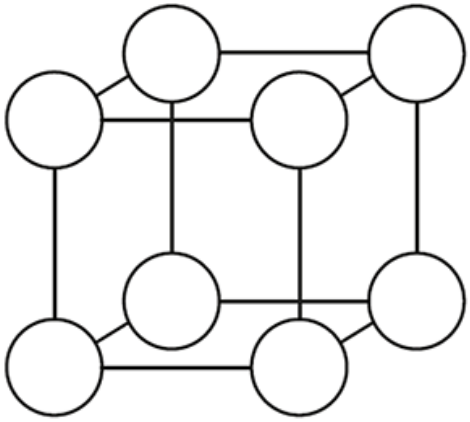
_____

_____ **[1]**

ii. Magnesium reacts with sulfur to form a compound which has a giant ionic lattice structure.

The diagram shows ions as circles in part of the lattice.

Complete the diagram by showing the symbols of the ions, including charges.



**[2]**

**25.** What is the meaning of the term electronegativity?

**A** The ability of an atom to attract the electrons in a covalent bond.
**B** The ability of an atom to gain an electron.
**C** The electrostatic attraction between a negative ion and a positive ion.
**D** The size of the charge on a negative ion.

Your answer ☐ **[1]**

**26.** What is the correct explanation for the trend in the boiling points of chlorine, bromine, and iodine down the group?

**A** Bond enthalpy increases.
**B** Chemical reactivity decreases.
**C** Electronegativity decreases.
**D** London forces increase.

Your answer ☐ **[1]**

**27.** The three reactions below each form one product only.
Which reaction(s) form(s) a product with non-polar molecules?

1 $2CO + O_2 \rightarrow$
2 $Si + 2Cl_2 \rightarrow$
3 $S + 3F_2 \rightarrow$

**A** 1, 2 and 3
**B** Only 1 and 2
**C** Only 2 and 3
**D** Only 1

Your answer ☐ **[1]**

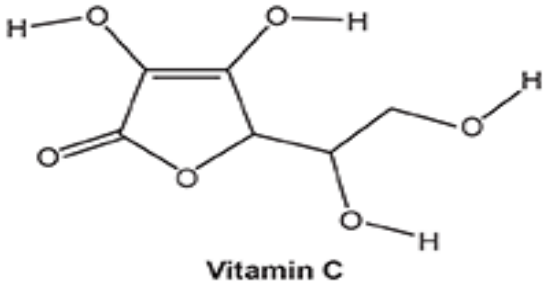
**28.** $CO_2$ and $H_2O$ molecules have different shapes.

State the bond angles in $CO_2$ and $H_2O$ molecules and explain, in terms of electron pair repulsion, why the bond angles are different.

**[4]**

**29(a).** A student carries out an investigation on vitamin C, $C_6H_8O_6$.

The structure of vitamin C is shown below. Vitamin C is an optical isomer.



Vitamin C

What is the total number of optical isomers with the structure of vitamin C?

total number of optical isomers = ..... **[1]**

**(b).** Vitamin C is extremely soluble in water. This means that vitamin C is removed rapidly from the body. 'Vitamin C ester' is available in tablet form as a less soluble source of vitamin C which stays in the body for longer.

i. Suggest why vitamin C is extremely soluble in water.

**[1]**

ii. A 'vitamin C ester' tablet contains an ester with the molecular formula $C_{22}H_{38}O_7$.

This ester can be prepared by reacting vitamin C with a long chain carboxylic acid, $C_x H_y COOH$, in the presence of an acid catalyst.

Vitamin C and the long chain carboxylic acid react in a 1:1 molar ratio.

Determine *x* and *y* in the formula of this carboxylic acid.

*x* = ..... *y* = ..... **[2]**

**30(a).** Ammonia, $NH_3$, and ammonium nitrate, $NH_4NO_3$, are compounds of nitrogen.

i. The boiling point of $NH_3$ is -33 °C.

The boiling point of $NH_4NO_3$ is 210 °C.

Explain why there is a large difference in boiling points.

**[2]**

ii. Two students discuss the oxidation numbers in ammonium nitrate, $NH_4NO_3$.

One student claims that the two nitrogen atoms have the same oxidation number. The other student disagrees and claims that the nitrogen atoms have different oxidation numbers.

Explain with reasons which student is correct.

**[1]**

**(b).** Glycine, $H_2NCH_2COOH$, is an α-amino acid.

i. Glycine reacts with NaOH to form the salt $H_2NCH_2COONa$.

Glycine reacts with HCl to form the salt $HOOCCH_2NH_3Cl$.

The salts have different H-N-H bond angles.

State the different H-N-H bond angles and explain why they are different.

$H_2NCH_2COONa$ H-N-H bond angle = ..... °

$HOOCCH_2NH_3Cl$ H-N-H bond angle = ..... °

explanation

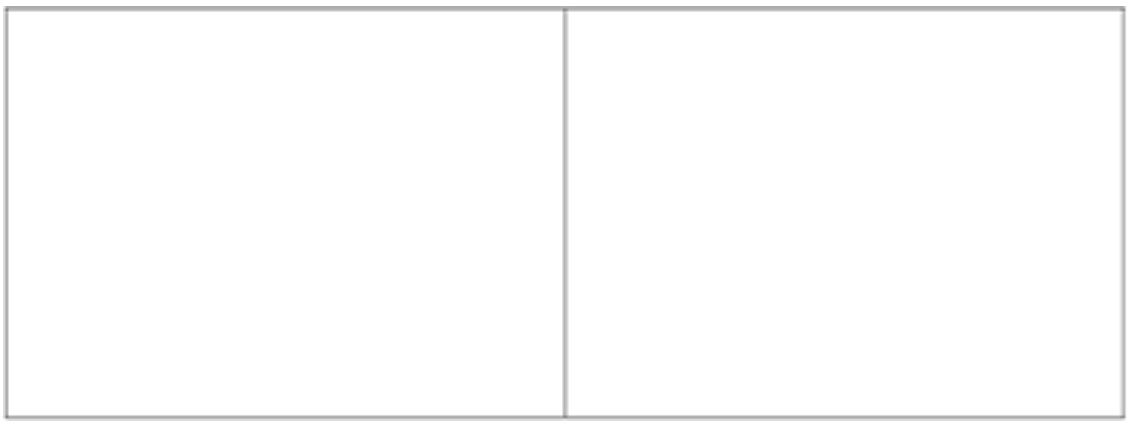
**[3]**

ii. Glycine reacts with aqueous copper(II) ethanoate to form copper(II) glycinate, $Cu(H_2NCH_2COO)_2$, and ethanoic acid. Copper(II) glycinate is a complex which exists as two square planar isomers.

Write an equation for this reaction and draw the structures of the two square planar isomers of the complex $Cu(H_2NCH_2COO)_2$.

equation

structures



**[3]**

**END OF QUESTION PAPER**