1. Hydrogen forms compounds with most non-metallic elements and with some metals.

(a) Calculate the empirical formula of the compound used in the manufacture of artificial rubber which has the following composition by mass.

Hydrogen 11.1% Carbon 88.9%

(3)

(b) The boiling temperatures of hydrogen chloride and hydrogen iodide are:

Hydrogen chloride –85ºC

Hydrogen iodide –35ºC

Explain why hydrogen iodide has a higher boiling temperature than hydrogen chloride.

.....

.....

.....

(2)

(c) Draw and explain the shapes of:

(i) the PH_3 molecule;

....

.....

(2)

(ii) the AlH_4^- ion.

.....

.....

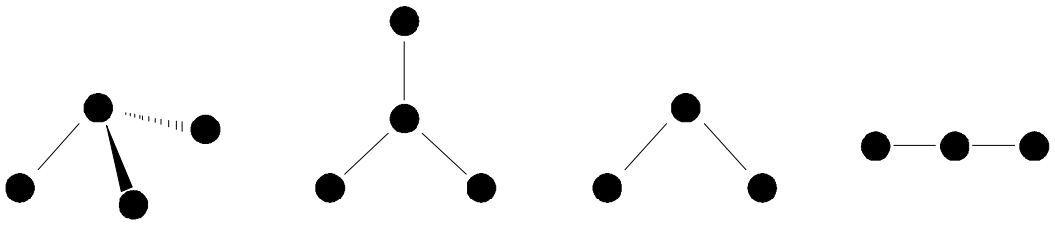
(2)

(d) Calculate the number of **molecules** in 8.0 cm^3 of gaseous phosphine, PH_3, at room temperature and pressure.

(The molar volume of a gas at room temperature and pressure should be taken as 2.4×10^4 cm^3 mol^{-1}. The Avogadro constant is 6.0×10^{23} mol^{-1}.)

(2)
(Total 11 marks)

2. Consider the following shapes



A **B** **C** **D**

Indicate by a letter (**A, B, C** or **D**) the shape of the following ions or molecules:

(i) H_2O .....

(ii) NH_3 .....

(iii) CO_2 .....

(iv) CO_3^{2-} .....

(Total 4 marks)

3. (a) Complete the table below.

Element	Chlorine	Bromine	Iodine
State at room temperature			solid
Colour			grey
What would be seen on adding to an aqueous solution of potassium iodide			

(6)

(b) Solid iodine has a simple covalent molecular structure.

(i) Define the term **covalent bond**.

.....

.....

(2)

(ii) Explain how the covalent structure iodine leads to it having a low melting temperature (114 °C).

.....

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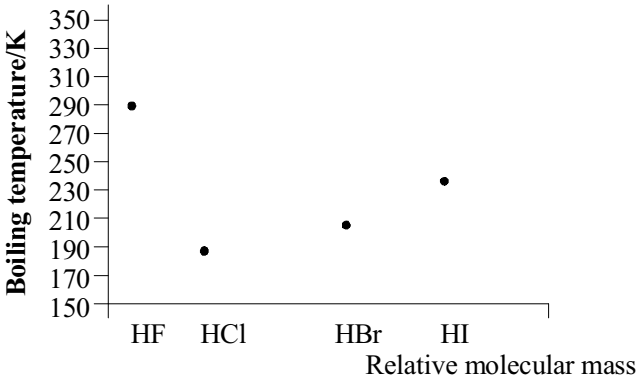
....

(3)

(c) The diagram below shows a plot of boiling temperature against relative molecular mass for four halides, HF, HCl, HBr, and HI.



(i) Explain the increase in the boiling temperature from hydrogen chloride, HCl, to hydrogen iodide, HI.

.....

....

.....

(2)

(ii) Explain why the boiling temperature if hydrogen fluoride, HF, is higher than the boiling temperature of hydrogen chloride, HCl.

.....

....

.....

(2)
(Total 15 marks)

4. Methane, CH_4, chloromethane, CH_3Cl, and methanol, CH_3OH, have molecules with similar shapes but they have different boiling temperatures.

Compound	Boiling temperature /°C
Methane	–162
Chloromethane	–24
Methanol	+65

(a) Draw a dot and cross diagram to show the bonding in chloromethane. You need only draw the outer electrons of the atoms.

(2)

(b) Draw a diagram to show the shape of the chloromethane molecule and explain why it has this shape.

.....

.....

(2)

(c) Explain why the boiling temperature of chloromethane is higher than that of methane.

.....

.....

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.....

.....

(4)

(d) Explain why the boiling temperature of methanol is higher than that of chloromethane.

.....

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.....

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(3)

(Total 11 marks)

5. (a) When the Group 2 element calcium is added to water, calcium hydroxide and hydrogen are produced.

Write an equation for the reaction.

....

(1)

(b) State the trend in solubility of the hydroxides of the Group 2 elements as the atomic mass of the metal increases.

....

(1)

(c) (i) Define the term **first ionisation energy**, and write an equation to represent the change occurring when the first ionisation energy of calcium is measured.

.....

....

.....

.....

(4)

(ii) State and explain the trend in the first ionisation energy of the Group 2 elements.

....

.....

....

.....

(3)
(Total 9 marks)

6. Deduce and draw the shapes of the following molecules or ions. Suggest a value for the bond angle in each case. Give a brief explanation of why each has the shape you give.

(a) **SF_6**

.....

.....

(3)

(b) **PH_3**

.....

.....

(3)

(c) **PF_4^+**

.....

.....

(3)

(Total 9 marks)

7. (a) Boron forms the chloride BCl_3. Draw a dot-and-cross diagram for BCl_3.

(1)

(b) (i) Draw the shape of the BCl_3 molecule.

(1)

(ii) Explain why BCl_3 has this shape.

.....

.....

.....

(2)

(c) (i) The B—Cl bond is polar due to the different electronegativity of the atoms.
Explain what is meant by the term **electronegativity**.

.....

.....

(2)

(ii) The B—Cl bond is polar. Explain why BCl_3 is **not** a polar molecule.

.....

.....

.....

(2)
(Total 8 marks)

8. (a) (i) State how a flame test would distinguish between samples of calcium nitrate, $Ca(NO_3)_2$ and barium nitrate, $Ba(NO_3)_2$.

.....

.....

(2)

(ii) Explain the origin of the flame colour.

.....

.....

.....

.....

.....

(3)

(b) Write the equation for the action of heat on barium nitrate.

.....

(2)

(c) (i) What is meant by the term **polarising power** as applied to cations?

.....

.....

.....

(2)

(ii) Give **two** factors which affect the polarising power of cations.

....

.....

(2)

(iii) Use this information to explain why it is easier to decompose magnesium nitrate than barium nitrate by heating.

.....

....

.....

....

.....

(3)
(Total 14 marks)

9. (a) Draw the shape of each of the following molecules and mark on the diagram a value for the bond angle in each case.

(i) CH_4

(2)

(ii) NH_3

(2)

(iii) $BeCl_2$

(2)

(b) Name the strongest type of intermolecular force present in separate samples of each of the following substances:

(i) CH_4

.....

(1)

(ii) HF

..... .

(1)

(c) State and explain which of the substances CH_4 and HF has the higher boiling temperature.

.....

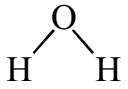
.....

.....

(2)

(Total 10 marks)

10. (i) On the following diagram of a water molecule draw partial charges on each atom to show the bond polarities:



(1)

(ii) Explain why a water molecule has the partial charges you have drawn.

.....

.....

.....

.....

(2)

(iii) Explain whether or not a water molecule is polar overall.

.....

.....

(1)

(Total 4 marks)

11. (a) State the number of protons, neutrons and electrons in a $^{7}_{3}Li^{+}$ ion.

protons: …… neutrons: …… electrons: ……

(3)

(b) The mass spectrum of lithium shows two peaks. Their mass/charge ratios and

percentage abundance are shown below.

Mass/charge	% Abundance
6.02	7.39
7.02	92.61

Calculate the relative atomic mass of lithium, giving your answer to three significant figures.

(2)

(c) Describe a test that you would do to distinguish between solid lithium chloride and solid sodium chloride. Clearly state what you would do and what you would see with both substances.

……

……

……

……

(3)
(Total 8.marks)

12. Nitrogen and phosphorus are in the same group of the Periodic Table. Phosphorus and hydrogen form the compound phosphine, PH_3, and nitrogen and hydrogen form ammonia, NH_3.

(a) (i) State the number of bond pairs and lone pairs of electrons in a molecule of phosphine.

Bond pairs of electrons: ..... Lone pairs of electrons: .....

(2)

(ii) Use your answer to (i) to draw the shape of the molecule and indicate on your diagram the approximate HPH bond angle that you would expect.

(2)

(b) The boiling temperature of ammonia is –33 °C and that of phosphine –88°C.

(i) List all the intermolecular forces that exist between molecules of ammonia.

……..……..……..

……..……..……..

……..……..……..

……..……..……..

(2)

(ii) Explain why the boiling temperature of phosphine is lower than that for ammonia.

……..……..……..

……..……..……..

……..……..……..

……..……..……..

(2)

(c) Ammonia forms a dative covalent bond with H^+ ions to form the ammonium ion, NH_4^+.

(i) Explain what is meant by the term **dative covalent bond**.

……..……..……..

……..……..……..

(2)

(ii) What part of the ammonia molecule enables it to form such a bond?

……..

(1)

(iii) State and explain the shape of the ammonium ion, NH_4^+.

……..

(3)

(Total 14 marks)

13. This question is about nitrogen trifluoride, NF_3, and nitrogen trichloride, NCl_3, which are covalent compounds. Van der Waals attractions and permanent dipole–dipole attractions exist between molecules of both compounds in the liquid state.

(a) (i) Describe how van der Waals attractions are caused.

.....

.....

.....

.....

(1)

(ii) In which of the two compounds would you expect there to be greater van der Waals attractions? Justify your answer.

.....

.....

(1)

(iii) In which of the two compounds would you expect there to be the greater permanent dipole–dipole attractions? Justify your answer.

.....

.....

(1)

(iv) The boiling point of nitrogen trichloride is much higher than that of nitrogen trifluoride. How might this be explained in terms of the two types of intermolecular attractions?

.....

....

(1)

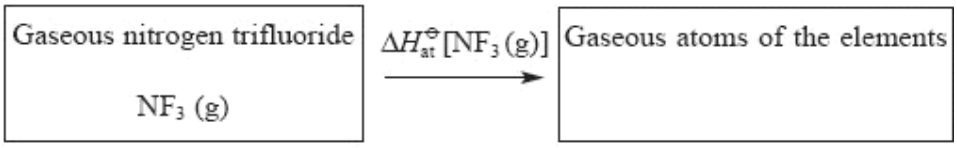
(b) The standard enthalpy change for the formation of gaseous nitrogen trifluoride is -125 kJ mol^{-1}.

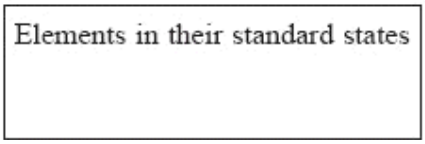
$$\tfrac{1}{2}\,N_2\,(g) + 1\tfrac{1}{2}\,F_2\,(g) \rightarrow NF_3\,(g) \quad \Delta H^{\ominus}_f = -125 \text{ kJ mol}^{-1}$$

The standard molar enthalpy changes of atomisation of nitrogen, N_2, and of fluorine, F_2, are given below.

	ΔH_{at}/kJ mol^{-1}
$\tfrac{1}{2}\,N_2\,(g) \rightarrow N\,(g)$	+ 473
$\tfrac{1}{2}\,F_2\,(g) \rightarrow F\,(g)$	+ 79

This information can be represented on a Hess cycle in the following way, and then used to calculate bond energies.





(i) Insert formulae, showing the correct quantities of each element, into the appropriate boxes.

(1)

(ii) Insert arrows between the boxes and write the correct numerical data alongside the appropriate arrows.

(2)

(iii) Use the cycle to calculate the N — F bond energy in nitrogen trifluoride.

(2)
(Total 9 marks)

14. (a) State and explain the trend in the boiling temperatures of the noble gases.

.....

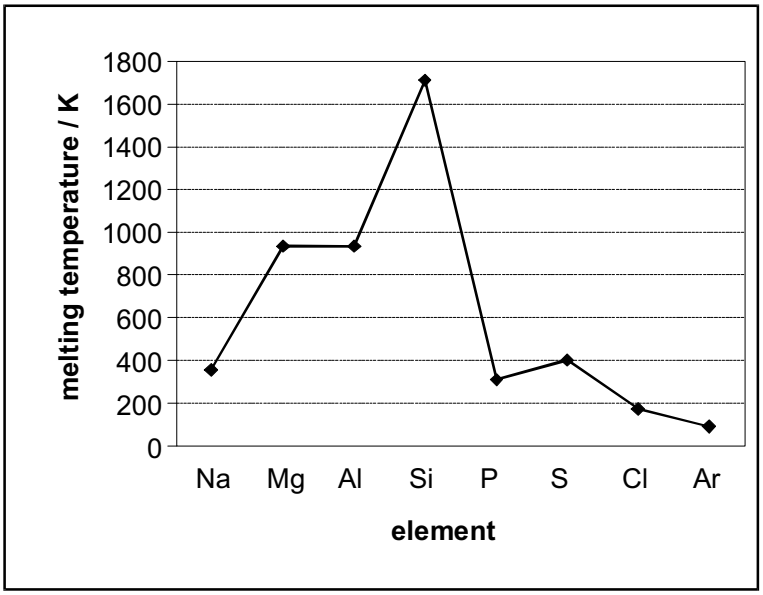
.....

.....

.....

(3)

(b) The graph below shows the melting temperatures of the elements of Period 3 of the Periodic Table, sodium to argon, plotted against atomic number.



(i) Identify one of the elements above that is composed of simple molecules at room temperature.

.....

(1)

(ii) Silicon has a giant atomic structure. Explain how this structure results in the high melting temperature shown on the graph.

.....

.....

....

.....

(2)

(iii) Explain why the melting temperature of magnesium is higher than that of sodium.

.....

....

.....

....

.....

(3)
(Total 9 marks)

15. (a) State the shape of a water molecule and explain why it has this shape.

Shape .....

Explanation .....

....

....

....

(3)

(b) Predict the shape of the H_3O^+ ion and draw a diagram to illustrate its shape.

Shape ....

Diagram

(2)

(c) (i) Use water as an example to explain what is meant by the term **hydrogen bond**.

.....

.....

.....

.....

.....

.....

(3)

(ii) State the difference in density between solid ice and liquid water and describe how the presence of hydrogen bonds accounts for this.

.....

.....

.....

.....

.....

.....

(3)
(Total 11 marks)

16. (a) A few crystals of potassium bromide were dissolved in water in a test tube. A few drops of aqueous chlorine solution were then added and a colour change was observed.

(i) What colour are potassium bromide crystals?

.....

(1)

(ii) What colour was the solution after the chlorine solution had been added?

.....

(1)

(iii) Write a balanced **ionic** equation for the reaction of bromide ions with chlorine solution.
Do not include spectator ions in your equation.

.....

(1)

(iv) What would you expect to **see** if the contents of the test tube were shaken with a small quantity of a hydrocarbon solvent and then allowed to settle?

.....

.....

(2)

(b) (i) Hydrogen bromide can be made by bubbling hydrogen sulphide gas into liquid bromine.
The equation for the reaction is:

$$2H_2S(g) + 3Br_2(l) \rightarrow 4HBr(g) + S_2Br_2(l)$$

Two elements show changes in oxidation number during this reaction.
Identify these elements, stating their original and final oxidation numbers.

First element.....

Initial oxidation number..... Final oxidation number .....

Second element .....

Initial oxidation number..... Final oxidation number .....

(3)

(ii) The equation shows that 2 moles of hydrogen sulphide molecules react with 3 moles of bromine molecules. Show how your answers to (i) agree with this ratio.

(1)

(c) The boiling points of three hydrogen halides are given in the following table:

Compound	Boiling point /K
HF	293
HBr	206
HI	238

(i) Explain why hydrogen iodide has a higher boiling point than hydrogen bromide.

.....

....

(2)

(ii) Explain why hydrogen fluoride has a higher boiling point than either hydrogen bromide or hydrogen iodide.

.....

.....

(1)

(iii) Predict the boiling point, in K, of hydrogen chloride.
Justify your prediction.

Predicted boiling point.....

Justification .....

.....

.....

....

(2)

(Total 14 marks)

17. (a) Complete the electronic configurations of the following noble gases.

(i) Neon: $1s^2$ .....

(1)

(ii) Krypton: $1s^2$ .....

(1)

(b) Explain whether krypton or neon has the higher boiling temperature.

.....

.....

.....

.....

(2)

(c) A mass spectrometer can be used to analyse a sample of a certain element.

Explain how each of the following is achieved in a mass spectrometer.

(i) Ionisation: ....

....

....

(2)

(ii) Acceleration: .....

....

(1)

(iii) Deflection: ..... .

....

(1)

(Total 8 marks)

18. (a) Deduce the oxidation number of iodine in the following species.

(i) I_2O_7 ....

(1)

(ii) IO_4^-

..... .

(1)

(b) Iodine, I_2, can be reduced to iodide ions, I^-, by tin(II) ions, Sn^{2+}, which are themselves oxidised to tin(IV) ions, Sn^{4+}.

(i) Construct the oxidation and reduction half-equations for the above system.

....

.....

(2)

(ii) Use the above half-equations to construct the overall ionic equation for the reaction.

....

....

....

(1)

(Total 5 marks)

19. (a) Define the term **oxidising agent** in terms of electron transfer, and suggest which element in Group 7 is the strongest oxidising agent.

....

....

....

(2)

(b) Chlorine can react with hydroxide ions to produce chloride ions, chlorate(l) ions and water.

(i) Write the ionic equation for this reaction. There is no need to include state symbols.

....

(2)

(ii) What type of reaction is taking place in (b)(i)?

....

(1)

(c) (i) Write an equation for the reaction between concentrated sulphuric acid and solid sodium chloride.

....

(1)

(ii) State ONE observation that you would make.

..... .

....

(1)

(d) Draw the shapes of the following molecules, and mark on the diagram the value of the bond angles in each case.

(i) BCl_3

(2)

(ii) PCl_5

(3)
(Total 12 marks)

20. (a) State the meaning of the following terms:

(i) electrophile;

.....

.....

(1)

(ii) free radical;

.....

.....

(1)

(iii) nucleophile.

.....

.....

(1)

(b) Classify the following reactions:

(i) chloroethane with aqueous sodium hydroxide;

....

....

(2)

(ii) ethane with chlorine;

....

....

(2)

(iii) ethene with hydrogen bromide.

....

....

(2)

(Total 9 marks)

21. (a) Draw a 'dot-and-cross' diagram for a magnesium **ion**.

Show ALL the electrons present and give the charge on this ion.

(2)

(b) Why do salts containing magnesium ions give no colour in a flame test?

....

....

(1)

(Total 3 marks)

22. This question is about the compounds of Group 6 elements with hydrogen.

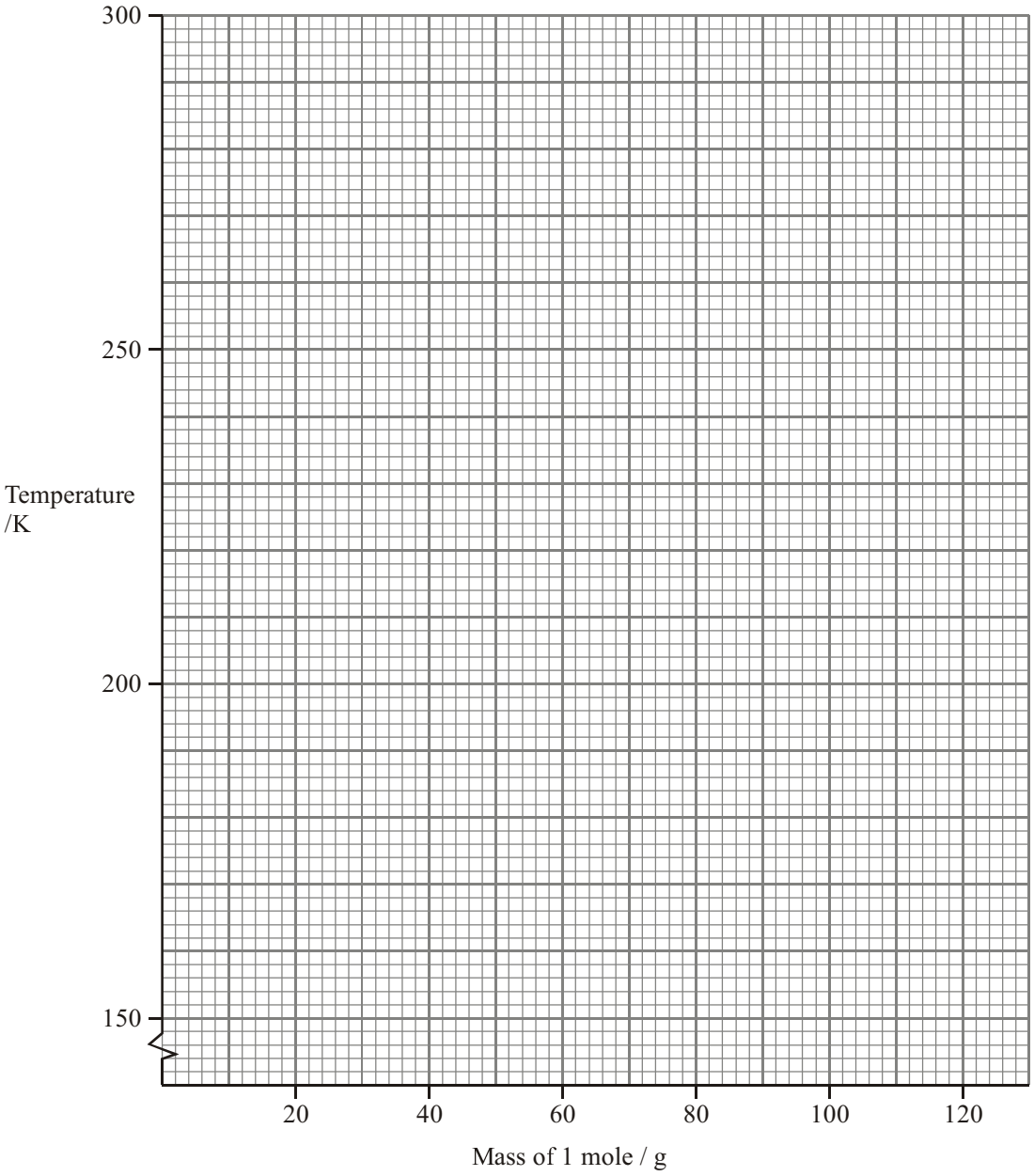
The table below shows some of the boiling points and molar masses of these hydrides.

Hydride	Boiling point /K	Mass of 1 mole /g
Water, H_2O	—	18
Hydrogen sulphide, H_2S	212	34
Hydrogen selenide, H_2Se	232	—
Hydrogen telluride, H_2Te	271	130

(a) What is the mass of one mole of hydrogen selenide, H_2Se?
Use the Periodic Table as a source of data.

(1)

(b) (i) Plot a graph of the boiling points of the three hydrides H_2S, H_2Se, and H_2Te against their molar masses.



(2)

(ii) Why do the boiling points of these hydrides increase as the molar mass increases?

.....

.....

.....

.....

(2)

(c) (i) Use your graph to predict the boiling point of water if it were to follow the pattern of the other three hydrides.

.....

(1)

(ii) What causes the boiling point of water to be 373 K, rather than your answer in (i)?

.....

....

(1)

(iii) Explain why this arises in water and not in the other hydrides.

..... .

.....

.....

(1)

(iv) Give the names of TWO other hydrides which, like water, have boiling points higher than you would expect.

.....

....

(2)

(d) Give TWO properties of water, other than high melting and boiling points, which are brought about by the strong intermolecular forces between water molecules.

.....

.....

(2)
(Total 12 marks)

23. Phosphorus(III) chloride, PCl_3, can be formed by the reaction of phosphorus and chlorine.

$$2P(s) + 3Cl_2(g) \rightarrow 2PCl_3(s)$$

(a) (i) Calculate the maximum mass of phosphorus(III) chloride, PCl_3, which could be obtained from 93.0 g of phosphorus.

(3)

(ii) Calculate the minimum volume of chlorine required to react completely with 93.0 g of phosphorus.
[One mole of gas occupies a volume of 24.0 dm^3 under the conditions of the experiment].

(2)

(iii) Identify the oxidising agent in the above reaction and explain your answer.

.....

.....

(2)

(b) (i) Draw a dot and cross diagram for a molecule of PCl_3.

(2)

(ii) Draw the predicted shape of a PCl_3 molecule and mark on the diagram a value for the bond angle.

(2)

(c) Suggest the name for the shape of the PCl_4^+ ion.

....

(1)

(Total 12 marks)

24. (a) State the type of bonding in the following substances and draw diagrams to illustrate their 3-dimensional structures.

Diamond

Bonding .....

Diagram

(3)

(b) Explain why sodium chloride conducts electricity when molten but not when solid.

.....

.....

.....

.....

(2)
(Total 5 marks)

25. The industrial processes involved in the production of poly(chloroethene) are summarised in the flow chart:

ethane → ethene → 1,2-dichloroethane → chloroethene → poly(chloroethene)

(a) (i) Ethane is converted to ethene by dehydrogenation.

Write a balanced equation, including state symbols, for this equilibrium reaction.

(1)

(ii) Explain why conditions of high pressure are less favourable for ethene production

.....

.....

.....

.....

(2)

(b) Draw a labelled diagram of an ethene molecule, showing the electron density distribution in the σ and π bonds between the carbon atoms.

(2)

(c) Give a chemical test which would distinguish between ethane and ethene.

State the result of your test with ethene.

Test ....

Result ....

(2)

(d) 1,2-dichloroethane is formed from ethene by reaction with chlorine.

State the type and mechanism of this reaction.

Type ....

Mechanism ....

(2)

(Total 9 marks)

26. Phosphine, PH_3, is a hydride of the Group 5 element, phosphorus.

(a) (i) Draw a 'dot-and-cross' diagram of a phosphine molecule. You should include only outer shell electrons.

(1)

(ii) Draw the shape you would expect for the phosphine molecule, suggesting a value for the HPH bond angle.

HPH bond angle .....

(2)

(iii) Explain the shape of the phosphine molecule you have given in your answer in (ii).

Justify your value for the HPH bond angle.

.....

....

.....

....

(2)

(b) (i) Write a balanced equation, including state symbols, for the atomisation of phosphine gas.

.....

(1)

(ii) Use your answer to (i) and the data below to calculate the standard enthalpy change of atomisation of phosphine at 298 K. Include a sign and units in your answer.

$\Delta H^{\ominus}_{f}[PH_3(g)] = +\ 5.4$ kJ mol^{-1}

$\Delta H^{\ominus}_{at}[\frac{1}{2}H_2(g)] = +218.0$ kJ mol^{-1}

$\Delta H^{\ominus}_{at}[P(s)] = +314.6$ kJ mol^{-1}

(3)

(iii) Calculate a value for the bond energy of the bond between phosphorus and hydrogen, using your answer to (ii).

(1)
(Total 10 marks)

27. This question is about phosphine, PH_3, and ammonia, NH_3.

(a) Which compound has the stronger van der Waals forces?

Justify your answer.

....

....

(1)

(b) (i) The boiling points of ammonia and phosphine are:

Ammonia	240 K
Phosphine	185 K

Name the intermolecular force responsible for the higher boiling point of ammonia.

.....

(1)

(ii) Use **displayed** formulae to show this intermolecular bond between two ammonia molecules.

Clearly mark and label the bond angle **between** the molecules.

(2)
(Total 4 marks)

28. You may find the following table useful in answering the question below.

Element	Electronegativity
Hydrogen	2.1
Oxygen	3.5

Draw a diagram to show a hydrogen bond between two water molecules and explain why it forms.

Diagram

Explanation .....

....

....

....

(Total 4 marks)

29. (a) Draw diagrams to show how the following bonds are formed from atomic orbitals.

σ bond

π bond

(2)

(b) (i) State the shape of a methane, CH_4, molecule, and explain why it has this shape.

Shape: .....

Explanation: .....

.....

(3)

(ii) State the shape of a carbon dioxide, CO_2, molecule, and explain why it has this shape.

Shape: ....

Explanation: .....

....

(2)

(Total 7 marks)

30. The table below shows some data for four organic compounds.

	Butane	Propan-1-ol	Propan-2-ol	Propanone
Structural formula	$CH_3CH_2CH_2CH_3$	$CH_3CH_2CH_2OH$	$CH_3CH(OH)CH_3$	CH_3COCH_3
Number of electrons per molecule	34	34	34	32
Boiling point/°C	–0.5	97.2	82.4	?

(a) The molecules of each compound contain a similar number of electrons.
What type of intermolecular forces are likely to be similar in strength?

.....

(1)

(b) Explain why propan-1-ol boils at a **higher** temperature than

(i) butane

.....

.....

(1)

(ii) propan-2-ol.

.....

.....

.....

.....

(2)

(Total 4 marks)

31. (a) Complete the electronic configuration for calcium, Ca.

$1s^2$ ....

(1)

(b) (i) Define the term **first ionisation energy**.

.....

....

.....

....

.....

(3)

(ii) Explain why the first ionisation energy of calcium is lower than that of magnesium.

.....

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.....

.....

.....

.....

.....

(3)

(c) A sample of magnesium contains three isotopes of mass numbers 24, 25 and 26.

(i) In terms of sub-atomic particles, state ONE similarity and ONE difference between these isotopes.

Similarity ....

.....

Difference ....

.....

(2)

(ii) The following data were obtained from the mass spectrum of this sample of magnesium.

Peak at *m/e*	%
24.0	78.6
25.0	10.1
26.0	11.3

Calculate the relative atomic mass of this sample of magnesium. Give your answer to 3 significant figures.

(2)
(Total 11 marks)

32. Sodium and chlorine react together in a redox reaction to form sodium chloride, NaCl.

(i) Write the half equation for

the oxidation of sodium, Na

....

the reduction of chlorine, Cl_2.

....

(2)

(ii) Write the equation for the reaction of sodium with chlorine.

....

....

(1)

(Total 3 marks)

33. Silicon reacts with chlorine to produce silicon tetrachloride, as shown in the following equation

$$Si(s) + 2Cl_2(g) \rightarrow SiCl_4(l)$$

(a) (i) Calculate the mass of silicon tetrachloride obtained from 10.0 g of silicon.

(3)

(ii) Calculate the minimum volume of chlorine that would be required to react completely with 10.0 g of silicon.

[1 mol of gas occupies 24.0 dm^3 under the conditions of the experiment]

(2)

(b) Draw a silicon tetrachloride molecule, $SiCl_4$, showing its three-dimensional shape. Name the shape and state the bond angle. Explain why the molecule has this shape.

Diagram

Name of shape .....

Bond angle .....

Explanation of shape

....

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(5)

(c) (i) Why are silicon-chlorine bonds polar?

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(1)

(ii) Explain why the silicon tetrachloride molecule has no permanent dipole.

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(2)

(Total 13 marks)

34. (a) The table below gives the boiling points of three organic compounds.

Compound	Boiling point /K
chloroethane	285
1-chloropropane	320
2-chloropropane	309

(i) Explain why 1-chloropropane has a higher boiling point than chloroethane.

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(2)

(ii) Explain why 1-chloropropane has a higher boiling point than its isomer, 2-chloropropane.

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(1)

(b) Both chloroethane and iodoethane react with aqueous potassium hydroxide solution to form ethanol. The hydroxide ions act as nucleophiles.

(i) What is a **nucleophile**?

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(1)

(ii) Explain why iodoethane reacts faster than chloroethane with aqueous potassium hydroxide, under the same conditions.

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(1)

(c) (i) Under what conditions does chloroethane react with potassium hydroxide to form ethene rather than ethanol?

.....

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(1)

(ii) Name the **type** of reaction in which ethene is formed from chloroethane.

.....

(1)

(Total 7 marks)

35. (a) Draw the ammonia molecule, NH_3, making its three-dimensional shape clear. Mark in the bond angle on your diagram. Explain why ammonia has this shape and this bond angle.

Diagram

Explanation

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(4)

(b) Explain whether ammonia is a polar molecule or not.

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(2)

(c) Explain, in terms of the intermolecular forces in both compounds, why ammonia has a higher boiling temperature than phosphine, PH_3.

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(3)

(d) (i) Explain, in terms of electrons, how ammonia can react with hydrogen ions to form ammonium ions, NH_4^+.

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(2)

(ii) State the number of protons and the number of electrons present in an ammonium ion.

number of protons .....

number of electrons.....

(2)

(Total 13 marks)

36. Read the passage on **Halothane – the first designer anaesthetic** straight through, and then more carefully. Answer the following questions.

HALOTHANE – THE FIRST DESIGNER ANAESTHETIC

Various methods have been used since antiquity to lessen operative pain, including hypnosis, the use of narcotics prepared from marijuana, stupefying with alcohol or even knocking the patient unconscious with a blow to the jaw.

In 1818, Michael Faraday noted the ability of ether vapour to induce a profound lethargic state. Earlier, Humphry Davy had reported the results of his research on nitrogen(I) oxide, and claimed that it appeared capable of destroying physical pain, and might probably be used with advantage during surgical operations. But neither the application of ether nor of nitrogen(I) oxide was followed up at this time.

Three Americans are generally credited with the introduction of inhalation anaesthesia. In 1842, Dr Crawford Long used ether to render a patient unconscious while he removed a cyst from his neck. In 1844, dentist Horace Wells had one of his own teeth painlessly extracted while under nitrogen(I) oxide anaesthesia and in 1846, William Morton successfully used ether to anaesthetise a patient at his dental practice. The era of truly painless operations had begun. In 1847, James Simpson used chloroform ($CHCl_3$) as an anaesthetic for the first time, and for the remainder of the century chloroform, nitrogen(I) oxide and ether reigned supreme as anaesthetic agents.

The use of anaesthetics was not, however, without risk. When they were given in sufficiently large amounts to cause muscle relaxation, the doses were not far removed from those which caused breathing paralysis, and ether caused gastric irritation and post-operative vomiting. Chloroform in large, repeated doses, sometimes caused irreversible liver damage. In the early part of the last century, nitrogen(I) oxide was mainly used for quick operations such as tooth extraction, where its analgesic (pain-killing) action also came in useful. However, for any but the most trivial of operations, ether was the anaesthetic of first choice. That said, a significant number of operations ended in explosions – the flammable ether/air mixture would have been ignited by sparks from switches and other electrical apparatus, and sometimes static discharge from clothing. The search was on for an agent lacking all the undesirable chemical and physiological properties associated with ether and chloroform.

In 1928, Thomas Midgley came up with the first of the chlorofluoro compounds (CFCs), dichlorodifluoromethane, which he advocated for use as a heat transfer agent in refrigerators. Several research chemists coincidentally realized that CFCs, being non-flammable, non-toxic and volatile might well prove to be promising anaesthetics too. In the mid-1940s, pharmacologist Benjamin Robbins carried out extensive experiments on 46 potential CFC anaesthetics and concluded that:

- the majority of the CFCs produced anaesthesia;
- within a group of related compounds, potency increased with increasing boiling point;
- the introduction of a bromine atom increased the safety of an anaesthetic and its potency.

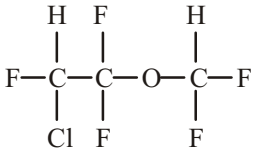
Subsequently, a research chemist, Charles Suckling, working in the ICI's laboratories at Widnes, was guided by three factors to help him choose potential anaesthetics. First was the inertness of fluorine in the C—F bond, especially in the CF_3 and CF_2 groups. The C—F group also conferred stability to adjacent C—Hal bonds. Thus compounds of the type CF_3CHalX_2 (X = H or Hal) should have high chemical stability and thus low toxicity. Second, the CFCs that had a C—H bond were safer than the totally halogenated alkanes. Chemists reasoned that the greater polar nature of the former species enabled them to interact electrostatically with 'brain molecules' and thus show anaesthetic effects at lower doses compared with the latter group. Finally, potential anaesthetics should be able to produce narcosis ("deep sleep") at the lowest concentrations possible.

Only one compound, halothane, $CF_3CHBrCl$, satisfied all these requirements.

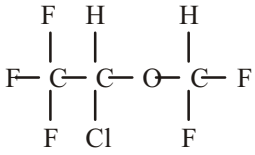
The early 1950s, and the arrival of halothane on the clinical scene, marked the start of an exciting new era in anaesthesia. Whereas ether had several problems associated with its use, halothane was a potent inhalation agent with a smooth, pleasant induction for the patient. Although having no analgesic properties, when used in conjunction with intravenous painkillers and muscle relaxant drugs, halothane provided ideal conditions for a multitude of surgical operations, and rapidly became the agent of choice. But was it too good to be true?

Despite its huge popularity and success in the 1960s, warning bells were beginning to ring about the role of halothane in post-operative liver dysfunction, especially after repeated exposure. In the face of increasing concern, it became evident that the concept of a 'safe period' between administrations should be questioned.

During the 1980s, the use and popularity of halothane began to wane, while the use of even safer and cheaper fluorinated agents, such as enflurane and isoflurane, increased. By the early 1990s halothane's use had all but ceased, isoflurane having taken its place.



enflurane



isoflurane

[777 words]

Adapted from "Halothane - the first designer anaesthetic" by T. Dronsfield, M. Hill and J. Pring, Education in Chemistry, September 2002

(a) What is the formula of nitrogen(I) oxide?

....

(1)

(b) Explain the link between the search for good refrigerants and good anaesthetics.

....

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(1)

(c) Explain why it was desirable to choose CFCs with CF_2 and CF_3 groups as potential anaesthetics.

....

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(1)

(d) (i) Suggest why the molecule CF_3CH_2Cl is more polar than CF_3CCl_3.

....

.....

.....

(1)

(ii) According to the text, which of these two molecules is likely to be the safer to use as an anaesthetic? Justify your answer.

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.....

(1)

(e) Give the systematic name for halothane.

....

(1)

(f) Estimate the value of the COC bond angle in **enflurane**.

....

(1)

(Total 7 marks)

37. (a) Methane and poly(ethene) are both hydrocarbons.

(i) State the type of bond between carbon and hydrogen atoms in the molecules of both compounds.

.....

(1)

(ii) State the type of **intermolecular** force present in **both** compounds.

.....

(1)

(iii) Explain why poly(ethene) melts at a higher temperature than methane.

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(3)

(b) Explain, in terms of its bonding, why magnesium has a high melting temperature.

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.....

(2)
(Total 7 marks)

38. (a) Sodium iodide reacts with chlorine to produce sodium chloride and iodine.

(i) State the oxidation numbers of the iodine and chlorine species in the spaces provided.

$$2NaI + Cl_2 \rightarrow 2NaCl + I_2$$

....

(2)

(ii) Use these oxidation numbers to explain why this reaction is a redox reaction.

.....

.....

(2)

(iii) Calculate the maximum mass of iodine that could be produced from 30.0 g of sodium iodide.

(3)

(iv) Calculate the volume of chlorine gas required to produce this amount of iodine.

[1 mol of gas occupies 24 dm^3 under the conditions of the experiment]

(1)

(b) (i) Give the colour of iodine and its physical state at room temperature and pressure.

Colour .....

Physical state .....

(2)

(ii) Write an equation, including state symbols, to represent the process occurring when the first ionisation energy of iodine atoms is measured.

.....

(2)
(Total 12 marks)

39. (a) (i) Explain why a water molecule does **not** have a linear shape.

.....

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(2)

(ii) State the HOH bond angle in water and explain why it has this value.

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(2)

(b) (i) Draw the boron trichloride molecule, BCl_3, making its shape clear. Mark in the bond angle on your diagram.

(2)

(ii) Explain why a B–Cl bond is polar.

.....

.....

(1)

(iii) Explain why a BCl_3 molecule is non-polar.

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(1)

(iv) Name the strongest intermolecular force between boron trichloride molecules.

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(1)

(c) A compound of phosphorus and chlorine has the composition by mass shown below.

Element	% by mass
P	14.9
Cl	85.1

Calculate the empirical formula of this compound.

(2)
(Total 11 marks)

40. (a) Write an equation for the reaction of calcium with oxygen to form calcium oxide, CaO.

....

(1)

(b) Draw a 'dot and cross' diagram of calcium oxide, CaO, showing **all** the electrons. Indicate the charges clearly on your diagram.

(2)

(c) (i) Name the compound formed when calcium oxide reacts with water.

.....

(1)

(ii) Which pH or pH range would include the pH of a saturated solution of the product of this reaction?

pH	0–4	5–6	7	8–9	10–14

.....

(1)
(Total 5 marks)

41. This question is about the chemistry of sodium and magnesium.

(a) Sodium and chlorine react together as shown in the equation.

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Is sodium oxidised or reduced in this reaction? Explain your answer.

.....

.....

.....

(1)

(b) (i) Sodium chloride and magnesium chloride can be distinguished by carrying out a flame test. State the observation you would make for each.

Sodium chloride .....

Magnesium chloride.....

(2)

(ii) Explain the changes which occur when electrons in sodium produce a flame colour.

.....

.....

.....

.....

(2)

(iii) Suggest ONE use for the coloured light produced by sodium.

.....

(1)

(c) Write the electron configuration of a magnesium **ion**, Mg^{2+}, using s, p notation.

.....

(1)

(d) The table below gives some ionisation energies for sodium and magnesium.

	First ionisation energy / kJ mol^{-1}	Second ionisation energy / kJ mol^{-1}
Sodium	496	4563
Magnesium	738	

(i) Write the chemical equation, with state symbols, which corresponds to the **first** ionisation energy of magnesium.

(2)

(ii) Explain why the first ionisation energy of magnesium is greater than the first ionisation energy of sodium.

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(2)

(iii) Predict a value for the **second** ionisation energy of magnesium. Explain your choice.

Value .....kJ mol $^{-1}$

Explanation .....

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(3)

(e) Which atom has the larger radius, sodium or magnesium? Explain your answer.

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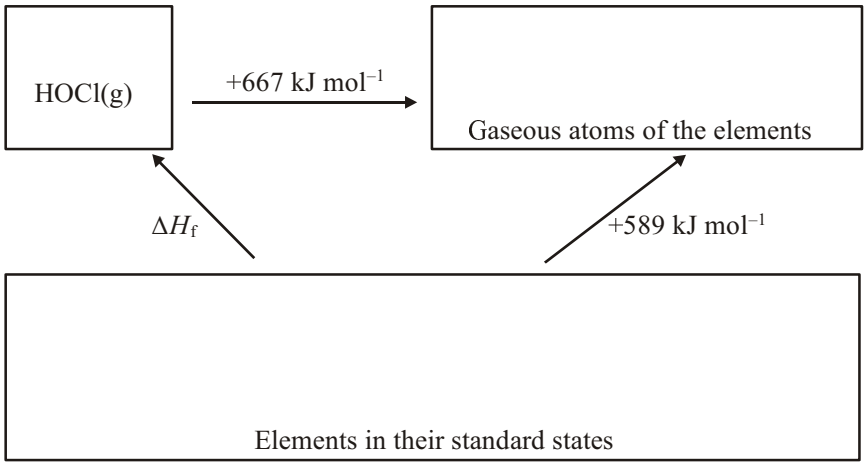
(1)

(Total 15 marks)

42. The Hess cycle below can be used to estimate the enthalpy change of formation, ΔH_f, of the unstable gaseous compound with the formula HOCl(g).



(a) (i) Insert formulae, with state symbols, into the appropriate boxes, to show the correct quantities of each element.

(1)

(ii) Use the cycle to calculate a value for the enthalpy change of formation, ΔH_f [HOCl(g)].

(1)

(iii) Assuming that the H—O bond energy is +464 kJ mol^{-1}, calculate a value for the O—Cl bond energy.

(1)

(b) (i) Draw a 'dot and cross' diagram for the HOCl molecule showing outer electrons only.

(2)

(ii) Predict the HOCl bond angle. Justify your answer.

Angle .....

Justification .....

....

.....

....

.....

(2)

(c) HOCl(g) can be made from chlorine(I) oxide by the reversible reaction

$$Cl_2O(g) + H_2O(g) \rightleftharpoons 2HOCl(g)$$

What effect, if any, would an increase in pressure have on the proportion of HOCl(g) at equilibrium? Justify your answer.

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(2)

(Total 9 marks)

43. Two reactions of a chloroalkane, **X**, are shown below.

Propanol-2-ol $\xleftarrow{\textbf{Reaction 1}}$ Chloroalkane **X** $\xleftarrow{\textbf{Reaction 2}}$ $CH_2{=}CHCH_3$ propene

(a) The chloroalkane **X** can be used to make propan-2-ol in **Reaction 1**.

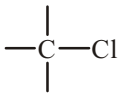
(i) Name and draw the **displayed** formula of the chloroalkane **X**.

Name .....

Displayed formula

(2)

(ii) **Reaction 1** is an example of nucleophilic substitution. The nucleophile is the hydroxide ion. Use the diagram below to show how it is able to attack the chloroalkane **X**.



(2)

(b) (i) What type of reaction is **Reaction 2**?

.....

(1)

(ii) Give the reagent and conditions needed for this reaction.

Reagent .....

Conditions .....

....

(2)

(c) Propan-2-ol has a higher boiling point than both the chloroalkane **X** and propene.

(i) Name the strongest intermolecular force between propan-2-ol molecules.

.....

(1)

(ii) Draw a diagram to show this force between two propan-2-ol molecules. Clearly mark and label the bond angle between the molecules.

(2)

(d) Propene, $CH_2=CHCH_3$, can be polymerised forming poly(propene).

(i) Draw a section of the poly(propene) polymer chain formed from two monomer units.

(2)

(ii) Explain, in terms of intermolecular forces, why poly(propene) is a solid at room temperature.

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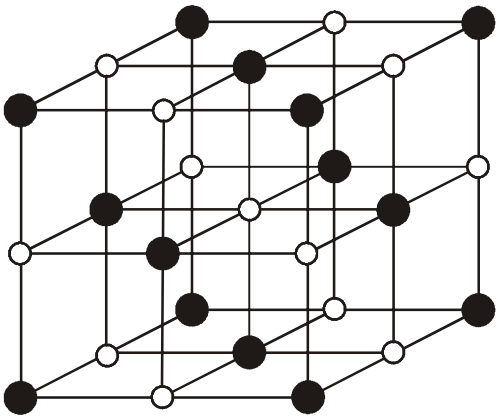
(2)
(Total 14 marks)

44. (a) (i) A diagram of the structure of solid sodium chloride is shown below.

Label the diagram to identify the particles present in solid sodium chloride.



(1)

(ii) Explain why sodium chloride has a high melting temperature.

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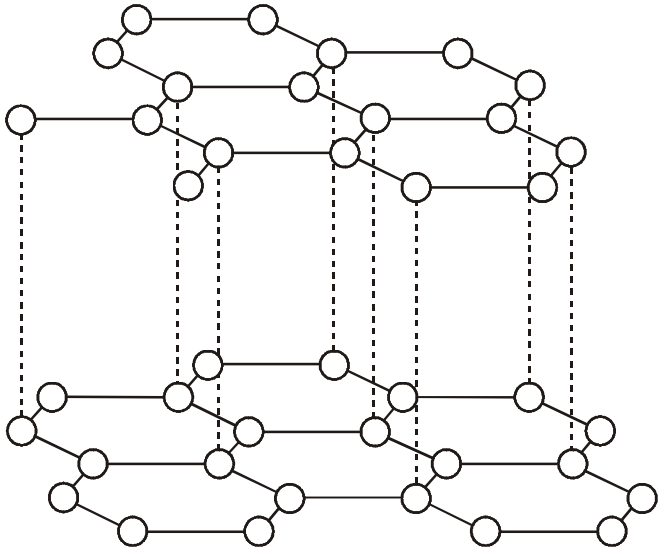
(2)

(b) A diagram of the structure of solid graphite is shown below.

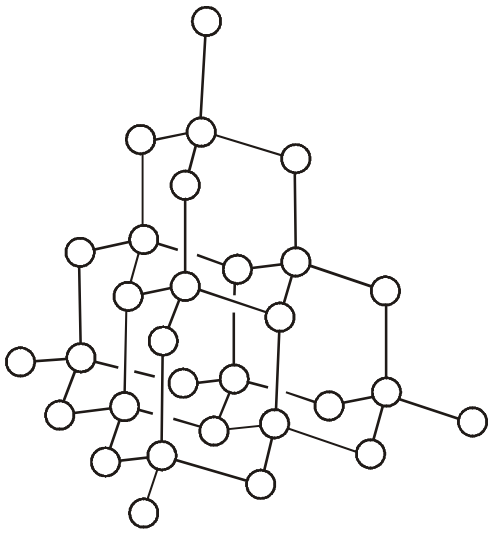
On the diagram name and label the types of bonding that exist in solid graphite.



(2)

(c) A diagram of the structure of solid diamond is shown below.

On the diagram name and label the type of bond that exists in solid diamond.



(1)

(d) The densities of diamond and graphite are

	Density / g cm^{-3}
Diamond	3.53
Graphite	2.25

Suggest, using information from (b) and (c), why diamond is more dense than graphite.

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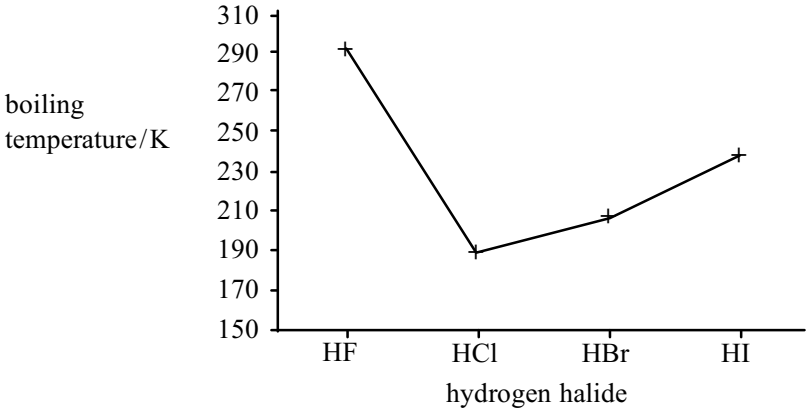
(2)
(Total 8 marks)

45. The graph shows the boiling temperatures of the hydrogen halides, hydrogen fluoride, HF, to hydrogen iodide, HI.



(a) Complete the table to identify the **strongest** intermolecular forces present in the **liquid** form of each hydrogen halide.

Hydrogen halide	**Strongest** intermolecular force
HF	
HCl	
HBr	
HI	

(2)

(b) Explain why HF has a higher boiling temperature than the other hydrogen halides and why there is an increase from HCl to HI.

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(3)
(Total 5 marks)

46. A methanol molecule has 18 electrons **in total**.

(i) Give the name and formula of a hydrocarbon with the same number of electrons.

Name .....

Formula

(1)

(ii) Which intermolecular force depends to a large extent on the number of electrons present?

.....

(1)

(iii) Would you expect methanol or your hydrocarbon in (i) to have the higher boiling point? Justify your answer.

.....

.....

.....

(1)

(iv) Draw a diagram to show the strongest intermolecular force between TWO molecules of the compound with the higher boiling point.
Indicate and give the value of the bond angle between these two molecules.

.....

(2)
(Total 5 marks)

47. Beryllium chloride, $BeCl_2$, is covalent.

(i) Use ideas of **ion polarisation** or **electronegativity** to suggest why beryllium chloride, a compound of a metal and a non-metal, is covalent rather than ionic.

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(2)

(ii) Draw a 'dot and cross' diagram to show the bonding in a beryllium chloride **molecule**, $BeCl_2$. In your diagram show all the outer shell electrons in the atoms of beryllium and chlorine.

(1)
(Total 3 marks)

48. In hydrogen fluoride, HF, and water, H2O, the major intermolecular force is the **hydrogen bond**.

(a) Draw a diagram to show the formation of hydrogen bonds between water molecules in ice. Show at least three water molecules in your diagram and any relevant polarity in the molecules.

(3)

(b) Suggest why water has a higher boiling temperature than hydrogen fluoride.

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(2)

(c) When hydrogen fluoride reacts with water it forms hydrogen ions. A lone pair of electrons on the water molecule joins with the hydrogen ion, H^+, to produce the ion H_3O^+.

(i) Draw a diagram to show clearly the shape of the H_3O^+ ion.

(1)

(ii) Suggest an approximate value for the bond angle H—O—H in H_3O^+.

.....

(1)

(iii) The oxygen atom in water has two lone pairs of electrons. Suggest why the ion H_4O^{2+} is not generally formed in acid solutions that contain the H^+ ion.

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(1)

(Total 8 marks)

49. (a) Cooking fuels and petrol for car engines need to be gases or liquids which vaporise easily. This will be the case if the intermolecular forces are weak.

Two common fuels are methane, CH_4, and 2,2,4-trimethylpentane, C_8H_{18}.

	Electronegativity
carbon	2.1
hydrogen	2.5

(i) Explain the meaning of the term **electronegativity**.

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(2)

(ii) The C—H bond in methane has some polarity but overall the molecule is non-polar.

Explain why methane is a non-polar molecule.

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(2)

(iii) Identify the strongest **intermolecular** force that exists between 2,2,4-trimethylpentane molecules in the liquid state.

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(1)

(b) In a car engine 2,2,4-trimethylpentane burns in air to produce carbon dioxide and water.

The equation is

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

Molar mass of C_8H_{18} = 114 g mol^{-1}

(i) Calculate the volume of oxygen needed to burn 700 g of 2,2,4-trimethylpentane.
[Assume the molar volume of a gas = 24.0 dm^3 mol^{-1}]

(3)

(ii) Calculate the mass of carbon dioxide produced in the reaction in (i).

(2)
(Total 10 marks)

50. Silicon, phosphorus and sulphur form chlorides with molecular formulae $SiCl_4$, PCl_3, SCl_2.

Draw the shapes you would expect for these molecules, suggesting a value for the bond angle in each case.

$SiCl_4$

ClSiCl bond angle .....

PCl_3

ClPCl bond angle .....

SCl_2

ClSCl bond angle .....

(Total 3 marks)

51. The data below shows the decomposition temperatures of the carbonates of two Group 2 elements.

Compound	Decomposition temperature / °C
$MgCO_3$	400
$BaCO_3$	1360

Use the idea of polarisation of ions to explain why $MgCO_3$ decomposes more readily than $BaCO_3$.

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(Total 3 marks)

52. Phosphorus reacts with a limited amount of chlorine to produce phosphorus trichloride, PCl_3.

(i) Draw a dot and cross diagram to show the arrangement of the electrons in phosphorus trichloride, PCl_3. You need only show the outer shell electrons.

(2)

(ii) Draw the phosphorus trichloride molecule, making its three-dimensional shape clear.

(1)

(iii) Explain

- the shape of the phosphorus trichloride molecule.
- why the Cl—P—Cl bond angle is different from the H—C—H bond angle in methane, CH_4.

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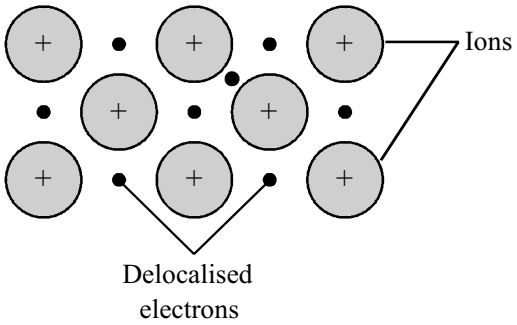
(3)
(Total 6 marks)

53. (a) The diagram shows the type of bonding present in the elements lithium and sodium in the solid state.



(i) What name is given to this type of bonding?

.....

(1)

(ii) Suggest why the melting point of lithium is greater than that of sodium.

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(2)

(b) Lithium can react with chlorine to produce lithium chloride. When a sample of lithium chloride is heated in a Bunsen flame, a red colour is seen.

(i) Draw a 'dot and cross' diagram of lithium chloride showing **all** the electrons. Indicate the charges clearly on your diagram.

(2)

(ii) Describe the changes that occur within the lithium ion to produce the flame colour.

.....

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....

.....

(2)

(iii) Name ONE other metallic element whose compounds produce a red coloured flame.

.....

(1)

(Total 8 marks)

54. This question is about three organic compounds with the following physical properties:

Compound	Formula	Boiling Point /K	$\Delta H^{\ominus}_{vap}$ / kJ mol^{-1}
Butane	$CH_3CH_2CH_2CH_3$	273	6.9
Propan-1-ol	$CH_3CH_2CH_2OH$	371	14.8
Propanone	CH_3COCH_3	330	9.0

(a) (i) Name the intermolecular force present in all three compounds.

.....

(1)

(ii) Explain why this intermolecular force is likely to have a similar strength in butane and propan-1-ol.

.....

.....

(1)

(b) (i) Draw a 'dot and cross' diagram for the propan-1-ol molecule, showing outer electrons only.

(1)

(ii) Name the strong additional intermolecular force between propan-1-ol molecules **not** present in the other two compounds.

....

(1)

(iii) Using displayed formulae, draw a diagram to show this intermolecular force between two propan-1-ol molecules.

State the values of the following bond angles:

COH .....

The bond angle between the molecules .....

(3)

(c) (i) Name the intermolecular force between propanone molecules that is **not** present in butane.

....

(1)

(ii) Explain why you would expect propanone to mix with propan-1-ol.

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(2)
(Total 10 marks)

55. Which of the following best describes the molecular shape of carbon dioxide, CO2?

A linear

B trigonal planar

C triangular

D v-shaped

(Total 1 mark)

56. Which of the following species is polar?

A NH_3

B BF_3

C SO_3

D CO_3

(Total 1 mark)

57. Polar liquids are affected by electric fields. For which of the following liquids would a jet of the liquid be affected by an electric field?

A hexane

B cyclohexane

C cyclohexene

D cyclohexanol

(Total 1 mark)

58. What are the intermolecular forces in methanal, HCHO?

A London forces only

B hydrogen bonds and London forces

C permanent dipole – permanent dipole only

D permanent dipole – permanent dipole and London forces

(Total 1 mark)

59. Which of the following substances is likely to be insoluble in water?

A methanol, CH_3OH

B ethanol, CH_3CH_2OH

C fluoromethane, CH_3F

D hydrogen fluoride, HF

(Total 1 mark)

60. The following liquids have a similar number of electrons per molecule. Suggest which is likely to have the highest boiling point?

A $CH_3CH_2CH_2CH_2CH_3$

B $(CH_3)_3COH$

C $CH_3CH_2CH(OH)CH_3$

D $CH_3CH_2CH_2CH_2OH$

(Total 1 mark)

61. The Group 2 metals, considered in order of increasing atomic number, show a **decrease** in

A first ionisation energy

B nuclear charge

C chemical reactivity

D ionic radius

(Total 1 mark)