ATOMIC STRUCTURE

Q1. (a) State the relative charge and relative mass of a proton, of a neutron and of an electron. In terms of particles, explain the relationship between two isotopes of the same element. Explain why these isotopes have identical chemical properties. (7)

(b) Define the term relative atomic mass. An element exists as a mixture of three isotopes. Explain, in detail, how the relative atomic mass of this element can be calculated from data obtained from the mass spectrum of the element. (7)

(Total 14 marks)
PERIODICITY

Q2. (a) Explain why certain elements in the Periodic Table are classified as p-block elements. Illustrate your answer with an example of a p-block element and give its electronic configuration. (3)

(b) Explain the meaning of the term periodicity as applied to the properties of rows of elements in the Periodic Table. Describe and explain the trends in atomic radius, in electronegativity and in conductivity for the elements sodium to argon. (13)

(Total 16 marks)
AMOUNT OF SUBSTANCE

Q3. (a) Calcium phosphate reacts with aqueous nitric acid to produce phosphoric acid and calcium nitrate as shown in the equation.

\[ \text{Ca}_3(\text{PO}_4)_2 + 6\text{HNO}_3 \rightarrow 2\text{H}_3\text{PO}_4 + 3\text{Ca(NO}_3)_2 \]

(i) A 7.26 g sample of calcium phosphate reacted completely when added to an excess of aqueous nitric acid to form 38.0 cm$^3$ of solution.

Calculate the concentration, in mol dm$^{-3}$, of phosphoric acid in this solution. Give your answer to 3 significant figures.

(5)

(ii) Calculate the percentage atom economy for the formation of calcium nitrate in this reaction. Give your answer to 1 decimal place.

(2)

(b) Write an equation to show the reaction between calcium hydroxide and phosphoric acid to produce calcium phosphate and water.

(1)

(c) Calcium dihydrogenphosphate can be represented by the formula Ca(H$_2$PO$_4$)$_x$ where $x$ is an integer.

A 9.76 g sample of calcium dihydrogenphosphate contains 0.17 g of hydrogen, 2.59 g of phosphorus and 5.33 g of oxygen.

Calculate the empirical formula and hence the value of $x$. Show your working.

(4)

(Total 12 marks)
AMOUNT OF SUBSTANCE

Q4. The chloride of an element \( Z \) reacts with water according to the following equation.

\[
\text{ZCl}_4(l) + 2\text{H}_2\text{O}(l) \rightarrow \text{ZO}_2(s) + 4\text{HCl}(aq)
\]

A 1.304 g sample of \( \text{ZCl}_4 \) was added to water. The solid \( \text{ZO}_2 \) was removed by filtration and the resulting solution was made up to 250 cm\(^3\) in a volumetric flask. A 25.0 cm\(^3\) portion of this solution was titrated against a 0.112 mol dm\(^{-3}\) solution of sodium hydroxide, of which 21.7 cm\(^3\) were required to reach the end point.

Use this information to calculate the number of moles of \( \text{HCl} \) produced and hence the number of moles of \( \text{ZCl}_4 \) present in the sample. Calculate the relative molecular mass, \( M_r \), of \( \text{ZCl}_4 \).

From your answer deduce the relative atomic mass, \( A_r \), of element \( Z \) and hence its identity.

(Total 9 marks)
GROUP 2

Q5.  
(i) For the elements Mg–Ba, state how the solubilities of the hydroxides and the solubilities of the sulphates change down Group II.

(ii) Describe a test to show the presence of sulphate ions in an aqueous solution. Give the results of this test when performed on separate aqueous solutions of magnesium chloride and magnesium sulphate. Write equations for any reactions occurring.

(iii) State the trend in the reactivity of the Group II elements Mg–Ba with water.
Write an equation for the reaction of barium with water.  

(Total 11 marks)
GROUP 2

Q6. State the trends in solubility of the hydroxides and of the sulphates of the Group II elements Mg–Ba.

Describe a chemical test you could perform to distinguish between separate aqueous solutions of sodium sulphate and sodium nitrate. State the observation you would make with each solution. Write an equation for any reaction which occurs.

(Total 6 marks)
GROUP 2

Q7. The following two-stage method was used to analyse a mixture containing the solids magnesium, magnesium oxide and sodium chloride.

Stage 1
A weighed sample of the mixture was treated with an excess of dilute hydrochloric acid. The sodium chloride dissolved in the acid. The magnesium oxide reacted to form a solution of magnesium chloride. The magnesium also reacted to form hydrogen gas and a solution of magnesium chloride. The hydrogen produced was collected.

(a) Write equations for the two reactions involving hydrochloric acid.

(b) State how you would collect the hydrogen. State the measurements that you would make in order to calculate the number of moles of hydrogen produced. Explain how your results could be used to determine the number of moles of magnesium metal in the sample.

Stage 2
Sodium hydroxide solution was added to the solution formed in Stage 1 until no further precipitation of magnesium hydroxide occurred. This precipitate was filtered off, collected, dried and heated strongly until it had decomposed completely into magnesium oxide. The oxide was weighed.

(c) Write equations for the formation of magnesium hydroxide and for its decomposition into magnesium oxide.

(d) When a 2.65 g sample of the mixture of the three solids was analysed as described above, the following results were obtained.

<table>
<thead>
<tr>
<th>Hydrogen obtained in Stage 1</th>
<th>0.0528 mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of magnesium oxide obtained in Stage 2</td>
<td>6.41 g</td>
</tr>
</tbody>
</table>

Use these results to calculate the number of moles of original magnesium oxide in 100 g of the mixture.

(Total 15 marks)
GROUP 7

Q8.(a) Describe and explain the trend in the boiling points of the elements down Group VII from fluorine to iodine.

(b) Describe what you would observe when aqueous silver nitrate, followed by dilute aqueous ammonia, is added to separate aqueous solutions of sodium chloride and sodium bromide.

(c) State the trend in the oxidising abilities of the elements down Group VII from chlorine to iodine. Explain how this trend can be shown by displacement reactions between halogens and halide ions in aqueous solutions. Illustrate your answer with appropriate observations and equations.

(Total 15 marks)
GROUP 7

Q9. (a) Explain, by referring to electrons, the meaning of the terms reduction and reducing agent.

(b) Iodide ions can reduce sulphuric acid to three different products.
   (i) Name the three reduction products and give the oxidation state of sulphur in each of these products.
   (ii) Describe how observations of the reaction between solid potassium iodide and concentrated sulphuric acid can be used to indicate the presence of any two of these reduction products.
   (iii) Write half-equations to show how two of these products are formed by reduction of sulphuric acid.

(c) Write an equation for the reaction that occurs when chlorine is added to cold water. State whether or not the water is oxidised and explain your answer.

(Total 15 marks)
GROUP 7

Q10. Concentrated sulfuric acid reacts with solid potassium iodide as shown in the equation.

\[ 8\text{KI} + 9\text{H}_2\text{SO}_4 \rightarrow 4\text{I}_2 + 8\text{KHSO}_4 + \text{H}_2\text{S} + 4\text{H}_2\text{O} \]

Give two observations that you would make when this reaction occurs.

In terms of electrons, state what happens to the iodide ions in this reaction.

State the change in oxidation state of sulfur that occurs during this formation of \( \text{H}_2\text{S} \) and deduce the half-equation for the conversion of \( \text{H}_2\text{SO}_4 \) into \( \text{H}_2\text{S} \)

(Total 5 marks)
BONDING

Q11. Diamond and graphite are both forms of carbon. Diamond is able to scratch almost all other substances, whereas graphite may be used as a lubricant. Diamond and graphite both have high melting points.

Explain each of these properties of diamond and graphite in terms of structure and bonding. Give one other difference in the properties of diamond and graphite.

(Total 9 marks)

BONDING

Q12. (a) Describe the bonding in, and the structure of, sodium chloride and ice. In each case draw a diagram showing how each structure can be represented. Explain, by reference to the types of bonding present, why the melting point of these two compounds is very different.

(12)

(b) Explain how the concept of bonding and non-bonding electron pairs can be used to predict the shape of, and bond angles in, a molecule of sulfur tetrafluoride, SF₄. Illustrate your answer with a diagram of the structure.

(8)

(Total 20 marks)
BONDING

Q13.  (a) Name the strongest type of intermolecular force between hydrogen fluoride molecules and draw a diagram to illustrate how two molecules of HF are attracted to each other.
In your diagram show all lone pairs of electrons and any partial charges. Explain the origin of these charges.
Suggest why this strong intermolecular force is not present between HI molecules.

(b) Crystals of sodium chloride and of diamond both have giant structures. Their melting points are 1074 K and 3827 K, respectively. State the type of structure present in each case and explain why the melting point of diamond is so high.

(Total 11 marks)

BONDING

Q14. Iodine and diamond are both crystalline solids at room temperature. Identify one similarity in the bonding, and one difference in the structures, of these two solids. Explain why these two solids have very different melting points.

(Total 6 marks)
BONDING

Q15. (a) Predict the shapes of the SF$_6$ molecule and the \( \text{AlCl}_4^- \) ion. Draw diagrams of these species to show their three-dimensional shapes. Name the shapes and suggest values for the bond angles. Explain your reasoning.

(b) Perfume is a mixture of fragrant compounds dissolved in a volatile solvent.
When applied to the skin the solvent evaporates, causing the skin to cool for a short time. After a while, the fragrance may be detected some distance away. Explain these observations.

(Total 12 marks)

Q16. A student studying GCSE science is puzzled by data which indicate that a sodium atom is larger than a chlorine atom and that a sodium ion is smaller than a chloride ion. How should an A-level Chemistry student explain this apparently conflicting information.

(Total 6 marks)
ENERGETICS

Q17.  (a) Define the term *standard enthalpy of formation.*

(b) State Hess’s Law and use it, together with the data given in the table below, to calculate the standard enthalpy change for the following reaction.

\[ \text{MgO(s) + 2HCl(g) \rightarrow MgCl}_2(s) + \text{H}_2\text{O(l)} \]

\[
\begin{array}{|c|c|c|c|}
\hline
& \text{MgO} & \text{HCl(g)} & \text{MgCl}_2 & \text{H}_2\text{O} \\
\hline
\Delta H^\Theta /\text{kJ mol}^{-1} & -602 & -92 & -642 & -286 \\
\hline
\end{array}
\]

(c) In an experiment, an excess of solid magnesium oxide was added to 50 cm\(^3\) of 3.0 mol dm\(^{-3}\) hydrochloric acid. The initial temperature of the solution was 21 °C. After reaction, the temperature had risen to 53 °C. (The specific heat capacity of water is 4.2 J K\(^{-1}\) g\(^{-1}\))

Use this information to calculate the enthalpy change for the reaction of one mole of magnesium oxide with hydrochloric acid. For your calculation you should assume that all the heat from the reaction is used to raise the temperature of 50 g of water.

(Total 15 marks)
ENERGETICS

Q18. Methanol, CH₂OH, is a convenient liquid fuel.

(a) An experiment was conducted to determine the enthalpy of combustion of liquid methanol. The energy obtained from burning 2.12 g of methanol was used to heat 150 g of water. The temperature of the water rose from 298 K to 362 K. (The specific heat capacity of water is 4.18 J K⁻¹ g⁻¹)

(i) Define the term standard enthalpy of combustion.

(ii) Use the data above to calculate a value for the enthalpy of combustion of one mole of liquid methanol.

(b) Methanol can be synthesised from methane and steam by a process that occurs in two stages.

\[ \text{Stage 1 } \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons 3\text{H}_2(g) + \text{CO}(g) \quad \Delta H^\circ = +206 \text{ kJ mol}^{-1} \]

\[ \text{Stage 2 } \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \quad \Delta H^\circ = -91 \text{ kJ mol}^{-1} \]

(i) Explain why, in Stage 1, a higher yield of hydrogen and carbon monoxide is not obtained if the pressure is increased.

(ii) Stage 2 is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for Stage 2.

(c) The standard enthalpies of combustion of carbon monoxide and of hydrogen are −283 kJ mol⁻¹ and −286 kJ mol⁻¹, respectively. Use these data and the enthalpy change for Stage 2 to calculate a value for the standard enthalpy of combustion of gaseous methanol.

(Total 15 marks)
ENERGETICS AND EQUILIBRIA

Q19. A method of synthesising ammonia directly from nitrogen and hydrogen was developed by Fritz Haber. On an industrial scale, this synthesis requires a high temperature, a high pressure and a catalyst and is very expensive to operate.

(a) Use the data given below to calculate a value for the enthalpy of formation of ammonia

<table>
<thead>
<tr>
<th>Bond</th>
<th>$\text{N} \equiv \text{N}$</th>
<th>$\text{H} - \text{H}$</th>
<th>$\text{N} - \text{H}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean bond enthalpy/kJ mol$^{-1}$</td>
<td>945</td>
<td>436</td>
<td>391</td>
</tr>
</tbody>
</table>

(b) A manager in charge of ammonia production wished to increase the daily production of ammonia and reduce the production costs. How would a chemist explain the factors that would influence the commercial efficiency of this production process?

(Total 11 marks)
ENERGETICS AND EQUILIBRIA

Q20. Hydrogen is produced by the reaction between steam and methane when the following dynamic equilibrium is established.

\[
\text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + 3\text{H}_2(g) \quad \Delta H = +206 \text{ kJ mol}^{-1}
\]

(a) Use Le Chatelier’s principle to predict the separate effects of an increase in temperature and of an increase in pressure on the yield of hydrogen obtained in the above reaction. In each case, explain your answer.

(6)

(b) State how, and explain why, the use of a catalyst might or might not change the equilibrium yield of hydrogen, and also the amount of hydrogen produced, in a given time.

(4)

(Total 10 marks)
M1. (a) Proton: mass 1, charge +1 (1)
Neutron: mass 1, charge 0 (1)
Electron mass 1/1840, charge -1 (1)
   Allow mass = 0, or negligible, or 1/1800 to 1/2000

Isotopes have the same number of protons (1)
   OR atomic number

different number of neutrons (1)

Isotopes have the same electronic configuration (1)
   OR same number of electrons

Chemical properties depend on electrons (1)

(b) mass of 1 atom of $^{12}$C $\times$ 12 (1)

$$\text{mass of 1 mol of atoms}$$
   OR $\text{mass of 1 atom of } ^{12}C \times 12 \text{ or in words}$

Spectrum gives (relative) abundance (1)
   OR % or amount

And m/z (1)
Multiply m/z by relative abundance for each isotope (1)
   Allow instead of m/z mass no, A. or actual value from example

Sum these values (1)
Divide by the sum of the relative abundances (1)
   only award this mark if previous 2 given
   Max 2 if e.g. has only 2 isotopes
M2. (a) Elements in the p block have their outer electron(s) in 
p orbital(s) or levels or sub-shells (1) 
example of element (1) 
correct electronic configuration (1)

(b) Pattern in the change in the properties of a row of elements (1) 
OR Trend in the properties of elements across a period 
Repeated in the next row (1) 
OR element underneath (or in same group) has similar properties 

atomic radius 
decreases across the row (1) 
CE if trend is wrong 
number of protons increases (1) (or nuclear charge increases) 
more attraction for electrons in the same shell (1)

electronegativity 
increases across the row (1) 
number of protons increases (1) (or nuclear charge) 
atomic radius decreases (1) (or shielding remains the same or electrons 
in the same shell) more attraction for bonding or shared electrons (1)

conductivity 
decreases row (1) 
OR significant drop from Al to Si 
Na–Al metals (1) 
OR metallic bonding or description of metallic bonding 
Two of Si - Ar non metals (1) 
OR molecular or covalent 
EITHER electrons free to move (or delocalised) in metals 
OR electrons unable to move in non-metals (1)
M3.(a)  

(i) M1 - M, calcium phosphate = 310(.3)  
   If M wrong, lose M1 and M5.  

\[
M2 - \text{Moles calcium phosphate} = \frac{7.26}{M1} = 0.0234 
\]

0.0234 moles can score M1 and M2.  
\[
\text{If M incorrect, can score M2 for M1.} 
\]

Allow M2 and / or M3 to 2 significant figures here but will lose M5 if answer not 1.23.  

(ii) M3 - Moles phosphoric acid = 2 \times 0.0234 = 0.0468  
   Allow student’s M2 \times 2. If not multiplied by 2 then lose M3 and M5.  

M4 - Vol phosphoric acid = 0.038(0) dm\(^3\)  
   If not 0.038(0) dm\(^3\) then lose M4 and M5.  

\[
\text{Conc phosphoric acid} = \frac{0.0468}{0.038(0)} 
\]

M5 = 1.23 (mol dm\(^{-3}\))  
   This answer only – unless arithmetic or transcription error that has been penalised by 1 mark.  
   Allow no units but incorrect units loses M5.  

\[
\begin{align*}
\text{(ii)} & \quad 688.3 \times 100 & \text{OR} & \quad 688 \times 100 \\
& \quad = 71.5\% 
\end{align*}
\]

1 mark for both M, correctly placed.

(b) 3\(\text{Ca(OH)}_2\) + 2\(\text{H}_3\text{PO}_4\) \(\rightarrow\) \(\text{Ca}_3(\text{PO}_4)_2\) + 6\(\text{H}_2\text{O}\)  
   Allow multiples.
If $x = 2$ with no working, allow M4 only.

\[
\text{Ca} = 1.67 \text{ g (M1).}
\]

Mark for dividing by correct A in Ca and P (M2).

If M1 incorrect can only score M2.

Correct ratio (M3).

\[
\text{CaH}_4\text{P}_2\text{O}_8 \quad \text{OR} \quad \text{Ca(H}_2\text{PO}_4)_2 \quad \text{OR} \quad x = 2
\]

Value of $x$ or correct formula (M4).

Alternative

\[
\text{Ca} \quad \text{H}_3\text{PO}_4
\]

\[
\begin{array}{c}
\text{Ca} = 1.67 \text{ g (M1).} \\
1.67 \quad 8.09 \\
40.1 \quad 97.0
\end{array}
\]

Mark for dividing by correct A \( M \) in Ca and \( \text{H}_3\text{PO}_4 \) (M2).

If M1 incorrect can only score M2.

\[
= 0.042 \quad 0.083 \\
1 \quad 2
\]

Correct ratio (M3).

\[
\text{CaH}_4\text{P}_2\text{O}_8 \quad \text{OR} \quad \text{Ca(H}_2\text{PO}_4)_2 \quad \text{OR} \quad x = 2
\]

Value of $x$ or correct formula (M4).
M4. moles NaOH used = vol / 1000 × conc (1) = 21.7 (if uses 25 here only scores

\[
\text{moles HCl in 25 cm}^3 = 0.00243 (1) \text{ (or 1 mol HCl reacts with 1 mol NaOH)}
\]

\[
\text{moles of HCl in 250 cm}^3 = 0.0243 (1)
\]

\[
\text{moles ZCl}_4 = 0.0243 / 4 = 0.006075 (1) \text{ (or 0.006076 or 0.006 mark)}
\]

\[
M = \text{mass / no. Moles (1) (method mark also 1.304 / 0.006075)} = 214.7 (1) \text{ (or 0.006 gives 217) (allow 214 to 215)}
\]

\[
A = 214.7 - 142 = 72.7 (1) \text{ (217 gives 75, 142 is 35.5)}
\]

Therefore element is Germanium (1) (allow conseq correct from A)

If not / 4 C.E. from there on but can score 2 independent marks for (mass / moles / method and identity of element)

(for candidates who use \( m.v. = m.v. \) and calculate [HCl] = 0.0972 allow 1st 3 marks

if 25 and 21.7 wrong way round only award 1/3)
M5. (i) Hydroxide solubility increases *(need trend)*

Sulphate solubility decreases *(need trend)*
*(If both Mg/Ba salts correctly compared - but no trend - allow 1 max)*

Add acid name/correct formula HCl

(ii) *(accept HNO₃/CH₃COOH) [NOT hydrogen chloride]*
*If acid added is H₂SO₄ = CE – allow only M2*

Add Ba⁺⁺ salt name/correct formula BaCl₂
*(accept Ba(NO₃)₂ / Ba(CH₃COO)₂)*
*[If reagent added is BaSO₄ / Ba/Ba(OH)₂ = CE – allow only M1]*

MgCl₂ No change / no ppt / no reaction

MgSO₄ White ppt / solid / suspension *[NOT chalky, milky]*
*Both observations tied to Ba⁺⁺ ions being added*

MgSO₄ + BaCl₂ → BaSO₄ + MgCl₂
*Accept ionic equation*

(Reagent mark (M2) can be awarded from full equation)

[Treat incorrect equation for MgCl₂ as contradiction of correct equation]*
*(Ignore carbonate equations) (Ignore state symbols)*

(iii) Reactivity increases (down group) *[NOT solubility increases]*

**Ba + 2H₂O → Ba(OH)₂ + H₂**

[11]
M6. **Hydroxide:** solubility increases

**Sulphate:** solubility decreases  
[BOTH inc/dec allow 1/2]

[Allow correct solubilities of top (Mg) and bottom (Ba) cpds]

Add:  
$\text{BaCl}_2($aq) / $\text{Ba(NO}_3)_2($aq) / $\text{Ba(OH)}_2($aq)

[Not solid added]

[Not $\text{Ba}^+ / \text{Ba} + \text{HCl} / \text{Pb(NO}_3)_2($aq)]

[If $\text{BaSO}_4 / \text{H}_2\text{SO}_4$, used, M3 to M6 = CE = 0]

[Allow any sensible nitrate test as an alternative to the sulphate test]

[Note: If M3 not awarded but test would work, allow correct observations and equations]

$\text{Na}_2\text{SO}_4$  
white precipitate / solid / suspension
[not cloudy/milky]

$\text{NaNO}_3$  
no change

$\text{BaCl}_2 + \text{Na}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + 2\text{NaCl}$

Accept ionic equation

[6]
M7. (a) \( \text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2 \)  

\( \text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O} \)

*Allow ionic equations*

(b) Hydrogen collection  
Using a gas syringe or measuring cylinder/ graduated vessel over water

*Allow if shown in a diagram*

Measurements  
(i) \( P \)  
(ii) \( T \)  
(iii) \( V \)

Use ideal gas equation to calculate mol hydrogen or mass/\( M_r \)  
\( \text{Mol H}_2 = \text{mol Mg} \) (Mark consequentially to equation)

(c) \( \text{MgCl}_2 + 2\text{NaOH} \rightarrow \text{Mg(OH)}_2 + 2\text{NaCl} \) Species

Balanced  

*Allow an ionic equation*

\( \text{Mg(OH)}_2 \rightarrow \text{MgO} + \text{H}_2\text{O} \)

(d) *Allow 2 significant figures in these calculations and ignore additional figures*

EITHER  

\( \text{Mol MgO obtained stage 2} = \frac{\text{mass MgO}}{M_r \text{MgO}} \)

\[ = \frac{6.41}{40.(3)} = 0.159 \]  

*Allow 0.16  
Allow method mark if formula of magnesium oxide or \( M_r \) incorrect*

Moles of Mg = moles of \( \text{H}_2 \) hence  

\( \text{Mol original MgO} = \text{mol MgO from stage 2} - \text{mol H}_2 \)

\[ = 0.159 - 0.0528 = 0.106 \]  

*Allow 0.11  
Mark consequentially to moles of magnesium oxide determined above*
OR

Mass MgO formed from Mg = 0.0528 \times M_{\text{MgO}} \text{ (or 40.3)} \quad (1)

= 2.13 g

Allow 2.1 \quad (1)

Allow method mark if formula of magnesium oxide or Mr incorrect

Mass original MgO = total mass MgO - mass formed from Mg \quad (1)

= 6.41 – 2.13 = 4.28 g \quad Allow 4.3 \quad (1)

Mark consequentially mass of magnesium oxide determined above

NB

As there is an error in part (d), the mass of sample should have been 6.25 NOT 2.65, award full marks to any candidate who has crossed out their correct first answer.
M8. (a) increases from fluorine to iodine (1)

sizes of molecules increase (1)
(or molecules have more electrons or mass of molecules increases)

QoL mark

Magnitude of intermolecular forces or vdW forces increase (1) (or more vdW forces)

More energy required to separate molecules (or particles) (1)
(or more energy to break intermolecular forces)
or intermolecular forces difficult to break

4

(b) with NaCl white ppt (1)
soluble in ammonia (1)

note, if ppt clearly refers to wrong substance
e.g. NaCl then C.E = 0

with NaBr cream (or off white or beige) ppt (1)
partially soluble (or insoluble) in ammonia (1)

ignore references to conc ammonia
if obviously added silver nitrate mixed with ammonia allow:
NaCl: no change (2)
NaBr: cream ppt (2)

4

(c) oxidising ability decreases from chlorine to iodine (or down the Group) (1)

\[
\text{Cl}_2 + 2\text{Br}^- \rightarrow 2\text{Cl}^- + \text{Br}_2 \quad (1)
\]

allow use of NaBr, HBr etc

Br$_2$ red brown (or yellow or orange) liquid (or solution but not solid) (1)

\[
\text{Cl}_2 + 2\text{I}^- \rightarrow 2\text{Cl}^- + \text{I}_2 \quad (1)
\]

allow use of NaBr etc, penalise HI once only

I$_2$ brown solution / black solid (1)
do not allow any reference to purple

Br$_2$ + 2I$^-$ → 2Br$^-$ + I$_2$ (1)

Yellow/orange/red-brown/brown solution goes brown/darker
brown solution/black solid (1)
M9. (a) Reduction involves gain of electrons (1)

A reducing agent loses (donates) electrons (1)

(b) (i) Sulphur dioxide (1)

oxidation state +4 (1)

Sulphur (1)

oxidation state 0 (1)

Hydrogen sulphide (1)

oxidation state – 2 (1)

(ii) Sulphur dioxide is a choking gas or has a pungent odour (1)

Sulphur is a yellow solid (1)

Hydrogen sulphide has a smell of bad eggs (1)

Any 2 marks

(iii) \( \text{SO}_4^{2-} + 4\text{H}^+ + 2e^- \rightarrow \text{SO}_2 + 2\text{H}_2\text{O} \) (1)

\( \text{SO}_4^{2-} + 8\text{H}^+ + 6e^- \rightarrow \text{S} + 4\text{H}_2\text{O} \) (1)

\( \text{SO}_4^{2-} + 10\text{H}^+ + 8e^- \rightarrow \text{H}_2\text{S} + 4\text{H}_2\text{O} \) (1)

Any 2 marks

(Allow equations with \( \text{H}_2\text{SO}_4 \))

(c) \( \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{Cl}^- + \text{HOCI} \)

or \( \text{Cl}_2 + \text{H}_2\text{O} \rightarrow 2\text{H}^+ + \text{Cl}^- + \text{OCl}^- \)

or \( \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HCl} + \text{HOCl} \) (1)

Water is not oxidised (1)

The oxidation states of O (–2) and H (+1) remain unchanged (1)
M10.M1 and M2 (either order)

Any two from

- purple vapour / gas
- (white solid goes to) black or black / grey or black / purple solid
- bad egg smell or words to this effect
  
  \[ \text{Ignore misty white fumes} \]
  \[ \text{Ignore yellow solid} \]
  \[ \text{Ignore purple solid} \]
  \[ \text{Ignore “goes (dark) brown”} \]

M3

Or multiples for possible equation in M3

The iodide ion(s) / they lose (an) electron(s)

OR

\[ 2I^- \rightarrow I_2 + 2e^- \]

M4

Accept “changes by – 8”

Oxidation state of S changes from \(+6\) to \(-2\) or changes by \(8\)

M5

\[ H_2SO_4 + 8H^+ + 8e^- \rightarrow H_2S + 4H_2O \]

OR

\[ SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O \]
M11. Structure and hardness

M1
Q of L both macromolecular/giant atomic/giant covalent/giant molecular;

M2
C atoms in diamond joined to 4 other C atoms / diagram with min 5 C atoms i.e. shows tetrahedral shape / coordination number = 4;

M3
C atoms in graphite joined to 3 other C atoms diagram with clear extended hexagonal plane/pattern i.e. shows trigonal planar shape / coordination number = 3;

M4
diamond hard / crystal strong;
(not diamond stronger than graphite)

M5
because of 3-D structure / rigid structure / not layered;

M6
graphite (soft) as layer can slide over each other;

M7
Q of L as only (weak) van der Waals' forces between layers;

Melting point (for either allotrope)

M8
covalent bonds must be broken / overcome;

M9
which are strong / many / hard to break;
(M9 tied to M8)

Other difference

M10
diamond is non-conductor of electricity, graphite is conductor OR appropriate difference in appearance;
M12.  
(a) NaCl is ionic  
cubic lattice  
ions placed correctly  
electrostatic attraction between ions  
Covalent bonds between atoms in water  
Hydrogen bonding between water molecules  
Tetrahedral representation showing two covalent and two hydrogen bonds  
2 hydrogen bonds per molecule  
Attraction between ions in sodium chloride is very strong  
Covalent bonds in ice are very strong  
Hydrogen bonds between water molecules in ice are much weaker  
Consequently, less energy is required to break the hydrogen bonds in ice to form separate water molecules than to break the ionic bonds in sodium chloride and make separate ions

(b) The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates’ QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question

**Descriptor**
an answer will be expected to meet most of the criteria in the level descriptor

<table>
<thead>
<tr>
<th>Mark Range</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>- claims supported by an appropriate range of evidence</td>
<td></td>
</tr>
<tr>
<td>- good use of information or ideas about chemistry, going beyond those given in the question</td>
<td></td>
</tr>
<tr>
<td>- argument well structured with minimal repetition or irrelevant points</td>
<td></td>
</tr>
<tr>
<td>- accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling</td>
<td></td>
</tr>
</tbody>
</table>
| 2 | - claims partially supported by evidence  
|   | - good use of information or ideas about chemistry given in the question but limited beyond this  
|   | - the argument shows some attempt at structure  
|   | - the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling |
| 0-1 | - valid points but not clearly linked to an argument structure  
|    | - limited use of information or ideas about chemistry  
|    | - unstructured  
|    | - errors in spelling, punctuation and grammar or lack of fluency |

4 bonding electron pairs
and one lone pair
repel as far apart as possible QWC
lone pair - bond pair repulsion > bp—bp QWC
pushes S-F bonds closer together
shape is trigonal bipyramidal with lone pair either axial or equatorial QWC
angles <90
and < 120

[20]
M13. (a) **Hydrogen bonding** *(full name)*

Diagram shows at least one \( ^+H \) and at least one \( ^-F \)
*(If full charges shown, \( M2 = 0 \)*)

3 lone pairs shown on at least one fluorine atom
H-bond indicated, between H and a lone pair on F

\[ \text{\( \delta^+ \) \( \delta^- \) \( \text{H-F} \) \( \cdots \) \( \text{H-F} \) \( \delta^- \) \( \delta^+ \)} \]

*(If atoms not identified, zero for diag)*
*(‘Fi’ for fluorine - mark to Max 2)*
*(Max 1 if only one HF molecule shown, or HCl shown)*

Dipole results from electronegativity *difference* or values quoted
*(‘difference’ may be inferred)*
*(Allow explanation – e.g. F attracts bonding electrons more strongly than H)*

**QoL** Fluorine more/very electronegative or iodine less electronegative or electronegativity difference too small in HI
Comparison required, may be implied.

HI dipole weaker or bonding e- more equally shared - *wtte*

(b) **NaCl is ionic** *(lattice)*
*(Treat atoms/molecules as a contradiction)*
*(Accept ‘cubic lattice’)*

Diamond is macromolecular/giant covalent/giant atomic/giant molecular
*(NOT molecular or tetrahedral)*
*(Ionic/van der Waals’ = CE = 0)*

(Many) covalent/C-C bonds need to be broken / overcome
*(NOT just ‘weakened’ etc.)*
*(‘Covalent’ may be inferred from diagram)*
*(Treat diagram of graphite (without one of diamond) as a contradiction – lose M2 but allow M3/M4)*

Which takes much energy or covalent bonds are strong
*(References to van Der Waals’ bonds breaking lose M3/M4)*

[11]
M14. QoL Bonding Both covalent
*(linked statement)*

Structure Iodine = molecular $I_2$ *(stated or in diagram)*
*treat incorrect diagram as contradiction*

Diamond = giant molecular/macromolecular/giant covalent / giant atomic *(stated only)*
*Reference to van der Waals’/dipole-dipole = contradiction*

QoL Iodine Weak van der Waals’ forces / induced dipole-induced dipole

Diamond Covalent bonds would need to be *broken*

Many / strong covalent bonds *OR* much energy needed
*Tied to M5 or near miss*
*If ionic/metallic structure suggested then CE for that substance*
*If hydrogen bonding suggested, for I, lose M2 & M4; for diamond lose M3, M5 & M6*
M15. 

(a) SF₆ shown as octahedral / square based bipyramid (1)

Bond angle: 90° or 180° and 90° (1)
Shape = octahedral (1)

*If lone pair shown then C.E. = 0 / 4*

![Diagram of SF₆ molecule with lone pairs]

Wrong symbols - no diagram mark

Equal repulsion between 6 bonding or shared electron pairs QoL (1)

AlCl₃ shape shown as tetrahedral (1)

Bond angle = 109° to 109.5° (1)
Shape = tetrahedral (1)

*If lone pair shown then C.E. = 0/4*

![Diagram of AlCl₃ molecule with lone pair]

(Equal repulsion between) 4 bonding pairs or shared electron pairs (1)

QoL may be awarded here also
Mark all points independently

(b) Solvent has low bp or weak intermolecular forces or evaporates quickly (1)

(Solvent) needs energy to evaporate (to overcome intermolecular forces) or valid reference to latent heat of vaporisation (or evaporation is endothermic) (1)

OR higher energy or faster molecules more likely to escape so mean energy (and hence temperature) falls

Energy taken from the skin (and so it cools) (1)

Fragrance or perfume (molecules) slowly spreads (through the room) (1)

By random movement or diffusion (of the perfume / fragrance) (1)
M16. A chlorine atom has more protons in its nucleus than has a sodium atom

Both have three shells of electrons

Electrons more strongly attracted by chlorine nucleus so size smaller than Na

An electron shell is lost when a sodium ion is formed from a sodium atom

Inner electrons more strongly attracted so ion smaller than atom

An electron is added to the outer shell when a chloride ion is formed

Greater repulsion between shells so size of chloride ion greater than Cl atom
M17. (a) (i) enthalpy (or heat or heat energy) change when
1 mol of a substance (1) (QL mark) is formed from its elements (1)
all substances in their standard states (1) (or normal states at 298K,
100 kPa or std condits)
not STP, NTP

(b) enthalpy change (or enthalpy of reaction) is independent of route (1)

\[ \Delta H = \Sigma \Delta H_{\text{f}} \text{prods} - \Sigma \Delta H_{\text{f}} \text{reactants} (or \ cycle) (1) \]
minimum correct cycle is:

\[
\begin{align*}
\text{MgO} + 2\text{HCl} & \rightarrow \text{MgCl}_2 + \text{H}_2\text{O} \\
\text{Mg} & + \text{Cl}_2 + \frac{1}{2}\text{O}_2 \\
\Delta H &= -642 - 286 - (-602 + 2 \times -92) (1) \\
&= -142 \text{ (kJ mol}^{-1}\text{)} (1)
\end{align*}
\]
penalise this mark for wrong units
+142 scores 1 mark out of the last three

(c) \[ \Delta H = mcT (1) \quad (or \ mc\Delta T) \]
\[ = 50 \times 4.2 \times 32 = 6720 \text{ J} = 6.72 \text{ kJ} (1) \]
mark is for 6720 \text{ J} or 6.72 \text{ kJ}

\[ \text{moles HCl} = \frac{\text{vol}}{1000} \times \text{conc} = \frac{50}{1000} \times 3 (1) \]
\[ = 0.15 (1) \]
if error here mark on conseq.

Therefore moles of MgO reacted = moles HCl/2 (1)
(mark is for/2, CE if not/2)
\[ = 0.15/2 = 0.075 \]

Therefore \[ \Delta H = 6.72/0.075 (1) \]
\[ = -90 \text{ kJ (mol}^{-1}\text{)} \]
kJ must be given, allow 89 to 91
value (1)
sign (1); this mark can be given despite CE for /2

Note various combinations of answers to part (c) score as follows:

-89 to -91 \text{ kJ (8) (or -89000 to 91000J)}
no units (7)

+89 to +91 \text{ kJ (7) (or +89000 to 91000J)}
no units (6)

-44 to -46 kJ (5) (or -44000 to -46000 J)
  no units (4) if units after 6.72 or 6720 (5)

+44 to +46 kJ (4) (or +44000 to +46000)
  if no units and
  if no units after 6.72 or 6720 (3)
  otherwise check, could be (4)
M18. (a) (i) **enthalpy change** when 1 mol of a substance (or compound) (QL mark) is (completely) burned in oxygen (or reacted in *excess* oxygen) at 298 K and 100 kPa (or under standard conditions) 1 1

(ii) heat produced = mass of water × Sp heat capacity $x\Delta T$ (or $mc\Delta T$) 1

$= 150 \times 4.18 \times 64$ (note if mass = 2.12 lose first 2 marks then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2 must have correct units) 1

moles methanol = mass/M$_r$ = 2.12/32 (1)

= 0.0663 1

$\Delta H = -\frac{40.1}{0.0663} = -605$ kJ (mol$^{-1}$) 1

*(allow –602 to –608 or answer in J) (note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks)*

(b) (i) equilibrium shifts to left at high pressure 1

because position of equilibrium moves to favour fewer moles (of gas) 1

(ii) at high *temperature* reaction yield is low (or at low $T$ yield is high) 1

at low *temperature* reaction is slow (or at high $T$ reaction is fast) 1

therefore use a balance (or compromise) between rate and yield 1

(c) $\Delta H = \Sigma \Delta H_r^\circ$(reactants) – $\Sigma \Delta H_r^\circ$(products) (or correct cycle) 1

$\Delta H_r^\circ$(CH$_3$OH) = $\Delta H_r^\circ$(CO) + 2 × $\Delta H_r^\circ$(H$_2$) – $\Delta H$ 1
\[= (-283) + (2 \times -286) - (-91) \text{ (mark for previous equation or this)}\]

\[= -764 \text{ (kJ mol}^{-1}\text{) (units not essential but lose mark if units wrong)}\]

\[(\text{note } +764 \text{ scores } 1/3)\]
M19. (a) Equation \( \frac{1}{2}N_2 + \frac{3}{2}H_2 \rightarrow NH_3 \)

\[ \Delta H_f = [(945 \times 0.5) + (426 \times 1.5)] - (391 \times 3) \]

\[ = -46.5 \text{ kJ mol}^{-1} \]

(b) The higher the temperature the faster the reaction QWC

but, since the reaction is exothermic

the equilibrium yield is lower QWC
The higher the pressure the greater the equilibrium yield QWC because there is a reduction in the number of moles of gas in the reaction

but higher pressure is expensive to produce or plant is more expensive to build QWC

A better catalyst would lessen the time to reach equilibrium

and allow more ammonia to be produced in a given time QWC

[11]
(a) **Increase in temperature:**

Yield is increased *(Allow if for H₂ (g) or products)* *(1)*

Reaction endothermic *(1)*

Equilibrium moves to the right OR forward, OR Equilibrium moves to oppose change OR to absorb heat *(1)*

*If “Yield statement” incorrect allow max one if reaction stated to be endothermic*

---

**Increase in pressure:**

Yield is decreased *(Allow if for H₂ (g) or products)* *(1)*

Increase in moles of gas or 2 moles increased to 4 moles or more moles on right *(1)*

Equilibrium moves to the left OR backwards, OR Equilibrium moves to oppose change OR to reduce pressure *(1)*

*If “Yield statement” incorrect allow max one if number of moles change is correct.*

(b) **Equilibrium yield:**

Unaffected or equilibrium unchanged *(1)*

Rate or speed increased *(1)*

Forward and backwards reactions equally or by the same amount *(1)*

**Amount of hydrogen produced:**

More hydrogen produced *(1)*