Level 2 Chemistry, 2015

91164 Demonstrate understanding of bonding, structure, properties and energy changes

9.30 a.m. Monday 23 November 2015
Credits: Five

<table>
<thead>
<tr>
<th>Achievement</th>
<th>Achievement with Merit</th>
<th>Achievement with Excellence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrate understanding of bonding, structure, properties and energy changes.</td>
<td>Demonstrate in-depth understanding of bonding, structure, properties and energy changes.</td>
<td>Demonstrate comprehensive understanding of bonding, structure, properties and energy changes.</td>
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Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

A periodic table is provided on the Resource Sheet L2–CHEMR.

If you need more room for any answer, use the extra space provided at the back of this booklet and clearly number the question.

Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.
QUESTION ONE

(a) Draw the Lewis structure (electron dot diagram) for each of the following molecules.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>O₂</th>
<th>OCl₂</th>
<th>CH₄O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td>O=O</td>
<td>:Cl−O−Cl:</td>
<td>H−C−H</td>
</tr>
</tbody>
</table>

(b) Carbon atoms can bond with different atoms to form many different compounds.
The following table shows the Lewis structure for two molecules containing carbon as the central atom, CCl₄ and COCl₂. These molecules have different bond angles and shapes.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>CCl₄</th>
<th>COCl₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td>:Cl</td>
<td>:Cl−C−Cl:</td>
</tr>
<tr>
<td></td>
<td>:Cl</td>
<td>:Cl−C−Cl:</td>
</tr>
</tbody>
</table>

Evaluate the Lewis structure of each molecule to determine why they have different bond angles and shapes.

In your answer, you should include:
- the approximate bond angle in each molecule
- the shape of each molecule
- factors that determine the shape and bond angle for each molecule.

CCl₄ is trigonal planar and has a bond angle of 109°/10°. The C-Cl bonds are polar as they have a different electronegativity, but as carbon has few electron densities around it, which are all bonding, its shape is trigonal planar with a bond angle of 109°.

COCl₂ is a trigonal pyramid with a bond angle of 109°. The C-Cl and C-O bonds are polar as they differ in electronegativity as well. The C has four electron densities around it, which are all bonding, but two of which are to the O making it polar.

(c) BeCl₂ and BF₃ are unusual molecules because there are not enough electrons for the central atoms, Be and B, to have a full valence shell. Their Lewis structures are shown below.

::Cl−Be::Cl: ::F−B−F::

Both molecules have the same polarity.

Circle the word that describes the polarity of these molecules.

polar  non-polar

Justify your choice.

Both BeCl₂ and BF₃ are polar molecules. The Be-Cl bonds in BeCl₂ and the B-F bonds in BF₃ are polar due to the difference in electronegativity. The Be has two bonding electron densities around it forming two chlorine to be symmetrical. B has three electron densities around it which are all bonding but the F atoms cannot be symmetrical. As there are not enough electrons for the central atoms and BF₃ is not symmetrical, the bond dipoles must cancel out making both of these molecules polar.
(d) Ethene gas, $\text{C}_2\text{H}_4(g)$, reacts with bromine gas, $\text{Br}_2(g)$, as shown in the equation below.

$$\text{C} = \text{C} (g) + \text{Br} = \text{Br} (g) \rightarrow \text{H} - \text{C} - \text{C} - \text{H} (g)$$

Calculate the enthalpy change, $\Delta H^\circ$, for the reaction between ethene and bromine gases, given the average bond enthalpies in the table below.

Show your working and include appropriate units in your answer.

<table>
<thead>
<tr>
<th>Bond</th>
<th>Average bond enthalpy/kJ mol$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Br-Br</td>
<td>193</td>
</tr>
<tr>
<td>C-C</td>
<td>346</td>
</tr>
<tr>
<td>C-Br</td>
<td>285</td>
</tr>
<tr>
<td>C-H</td>
<td>414</td>
</tr>
</tbody>
</table>

$\Delta H^\circ = \text{bonds broken} - \text{bonds formed}$

$4 \times \text{C} - \text{H} = 414 \times 4 = 1656$

$1 \times \text{C} = \text{C} = 614 \times 1 = 614$

$1 \times \text{Br} = \text{Br} = 193 \times 1 = 193$

$1656 + 614 + 193 = 2463$

$1656 + 570 + 314 = 2570$

$\Delta H^\circ = 2463 - 2570$

$\Delta H^\circ = -107 \text{kJ mol}^{-1}$

**QUESTION TWO**

(a) Hand warmers contain a supersaturated solution of sodium ethanoate which, when activated, crystallises and releases heat.

Circle the term that best describes this reaction.

- exothermic
- endothermic

Give a reason for your choice.

Exothermic reactions give off heat.

(b) (i) Glucose is made in plants during photosynthesis when carbon dioxide gas, $\text{CO}_2(g)$, and water, $\text{H}_2\text{O}(l)$, react to produce glucose, $\text{C}_6\text{H}_{12}\text{O}_6(aq)$, and oxygen gas, $\text{O}_2(g)$. The photosynthesis reaction can be represented by the following equation:

$$6\text{CO}_2(g) + 6\text{H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + 6\text{O}_2(g) \quad \Delta H^\circ = 2803 \text{ kJ mol}^{-1}$$

Circle the term that best describes this reaction.

- exothermic
- endothermic

Give a reason for your choice.

Heat is absorbed in this reaction making a positive enthalpy. Positive = endothermic

(ii) Calculate how much energy is absorbed or released in the photosynthesis reaction if 19.8 g of carbon dioxide gas, $\text{CO}_2(g)$, reacts completely with excess water, $\text{H}_2\text{O}(l)$, to form glucose, $\text{C}_6\text{H}_{12}\text{O}_6(aq)$, and oxygen gas, $\text{O}_2(g)$.

Show your working and include appropriate units in your answer.

$$M(\text{CO}_2) = 44.0 \text{ g mol}^{-1}$$

$$n = \frac{m}{M}$$

$$n = 19.8 \text{ g}$$

$$19.8 \text{ g } 44.0 \text{ g mol}^{-1}$$

$$= 0.45\text{ mol}$$

$$0.45\text{ mol} \times 2803 \text{ kJ mol}^{-1} = 1261.35$$

$$= 1261 \text{ kJ mol}^{-1}$$

is absorbed.
(c) A small camp stove containing butane gas, \( \text{C}_4\text{H}_{10}(g) \), is used to heat some water, as shown in the diagram below. A student measures the temperature change in the water and calculates that when 3.65 g of butane is combusted, 106 kJ of heat is released.

The reaction for the combustion of butane is shown in the equation below:

\[
2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l)
\]

(i) Calculate the enthalpy change (\( \Delta H \)) for this reaction, based on the above measurements.

\[
\Delta H \approx \frac{0.0629 \times 106}{58.0 \text{ g mol}^{-1}} \approx 6.67 \text{ kJ mol}^{-1}
\]

(ii) The accepted enthalpy change for the combustion reaction of butane gas, \( \text{C}_4\text{H}_{10}(g) \), is \( \Delta H = -5754 \text{ kJ mol}^{-1} \).

Explain why the result you calculated in part (c)(i) is different to the accepted value. In your answer, you should include at least TWO reasons.

(iii) Complete, including labels, the energy diagram for the combustion of butane gas showing reactants, products, and the change in enthalpy.
(iv) Butane gas is a useful fuel because when it undergoes combustion, energy is released.

Explain why energy is released in this reaction, in terms of making and breaking bonds. No calculations are required.

Energy is released in this reaction as it is exothermic. The C-H bonds are broken along with the O-O bonds which form new bonds between C-O and H-O, this releases energy therefore making it useful when it undergoes combustion.

<table>
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<th>Solid</th>
<th>Type of solid</th>
<th>Type of particle</th>
<th>Attractive forces between particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(s) (copper)</td>
<td>Metallic</td>
<td>atom</td>
<td>van der Waals forces</td>
</tr>
<tr>
<td>PCl₅(s) (phosphorus trichloride)</td>
<td>molecular</td>
<td>molecule</td>
<td>intermolecular forces</td>
</tr>
<tr>
<td>SiO₂(s) (silicon dioxide)</td>
<td>covalent network</td>
<td>atom</td>
<td>covalent bonds</td>
</tr>
<tr>
<td>KCl(s) (potassium chloride)</td>
<td>ionic</td>
<td>ion</td>
<td>ionic bonds</td>
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(b) Phosphorus trichloride, PCl₅, is a liquid at room temperature, and does not conduct electricity.

Explain these two observations in terms of the particles, structure, and bonding of PCl₅.

As PCl₅ is a molecular solid it does not conduct electricity. The molecules form a 3D lattice meaning there are no free moving electrons that conduct the electricity. It's weak intermolecular forces means that bonds can easily be broken within the molecule, but at room temperature when PCl₅ is a liquid there are still no freely moving particles within the molecule so it can not conduct electricity.
(c) Consider each of the solids copper, Cu, silicon dioxide, SiO₂, and potassium chloride, KCl.

Complete the table below by identifying which of these solids have the listed physical properties:

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>The solid is insoluble in water and is malleable.</td>
<td>Cu</td>
</tr>
<tr>
<td>The solid is soluble in water and is not malleable.</td>
<td>KCl</td>
</tr>
<tr>
<td>The solid is insoluble in water and is not malleable.</td>
<td>SiO₂</td>
</tr>
</tbody>
</table>

Justify TWO of your choices in terms of the particles, structure, and bonding of these solids. You may use diagrams in your justification.

Cu is insoluble in water as it is a metallic solid. The atoms within Cu form a 3D lattice which cannot be broken, so it is insoluble in water. Although it is not soluble, it is malleable. The bonds within this 3D lattice are able to be hit and still remain attached. This just changes the shape of the Cu solid.

KCl is soluble in water as it is able to convert into a liquid. The ionic solid forms a 2D lattice where the bonds are easily broken making KCl soluble in water. KCl is not malleable as the bonds within the 3D lattice are easily broken so you cannot change its shape.
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High Achievement

TOTAL 12
QUESTION ONE

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<tr>
<td>Lewis structure</td>
<td>:O::O:</td>
<td>:Cl::O:</td>
<td>H::C::O::H</td>
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(b) Carbon atoms can bond with different atoms to form many different compounds. The following table shows the Lewis structure for two molecules containing carbon as the central atom, CCl₄ and COCl₂. These molecules have different bond angles and shapes.

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<th>Molecule</th>
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<th>COCl₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td>:Cl::C::Cl: (tetravalent)</td>
<td>:O::C::Cl: (trigonal planar)</td>
</tr>
<tr>
<td>Bond angle</td>
<td>109°</td>
<td>120°</td>
</tr>
</tbody>
</table>

Evaluate the Lewis structure of each molecule to determine why they have different bond angles and shapes.

In your answer, you should include:
- the approximate bond angle in each molecule
- the shape of each molecule
- factors that determine the shape and bond angle for each molecule.

- In the CCl₄ molecule there are 4 regions of electrons surrounding each of the atoms. These will arrange themselves in a trigonal pyramidal arrangement because of the repulsion of the electrons. Therefore the bond angle will approximately be 109°.
- In the COCl₂ molecule there are only 3 regions of electrons surrounding the 4 atoms. To minimise repulsion

(c) BeCl₂ and BF₃ are unusual molecules because there are not enough electrons for the central atoms, Be and B, to have a full valence shell. Their Lewis structures are shown below.

:Cl-Be-Cl:

:Cl-Be-Cl:

:Cl-Be-Cl:

BF₃:

Both molecules have the same polarity.

Circle the word that describes the polarity of these molecules.

polar  non-polar

Justify your choice.
- Each of these molecules are non-polar molecules. They each have an even distribution of charge throughout the molecule. In the BeCl₂ the molecule is arranged linear because each of the chlorine atoms have the same amount of electrons surrounding them, this therefore gives an even distribution of charge and a non-polar molecule. The BF₃ has 3 regions of electron density and each of the surrounding F atoms have the same number of electrons surrounding the B atom. Therefore there is an even distribution of charge, meaning it is a non-polar molecule.
(d) Ethene gas, C₂H₄(g), reacts with bromine gas, Br₂(g), as shown in the equation below.

\[ \text{H} \quad \text{H} \]
\[ \text{C} = \text{C} \quad \text{Br} - \text{Br} \quad \rightarrow \quad \text{H} \quad \text{C} - \text{C} = \text{H} \quad \text{Br} \]

Calculate the enthalpy change, Δ_H°, for the reaction between ethene and bromine gases, given the average bond enthalpies in the table below.

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<th>Bond</th>
<th>Average bond enthalpy/kJ mol⁻¹</th>
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<tr>
<td>Br-Br</td>
<td>193</td>
</tr>
<tr>
<td>C-C</td>
<td>346</td>
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<tr>
<td>C-Br</td>
<td>285</td>
</tr>
<tr>
<td>C-H</td>
<td>414</td>
</tr>
</tbody>
</table>

Show your working and include appropriate units in your answer.

\[ \Delta H° = (\text{bonds broken}) - (\text{bonds made}) \]

\[ \begin{align*}
(C=\text{C}) + 4(C-\text{H}) + (\text{Br}-\text{Br}) - (C-C) + 2(C-\text{Br}) + 4(C-\text{H}) \\
= (614) + 4(414) + (193) - (346) + 2(285) + 4(414) \\
= (614) + (1656) + (193) - (346) + (570) + (1656) \\
= 2463 \quad - \quad 2572 \\
= -109 \text{ kJ mol}⁻¹
\end{align*} \]

(ii) Calculate how much energy is absorbed or released in the photosynthesis reaction if 19.8 g of carbon dioxide gas, CO₂(g), reacts completely with excess water, H₂O(l), to form glucose, C₆H₁₂O₆(aq), and oxygen gas, O₂(g).

Show your working and include appropriate units in your answer.

\[ M(\text{CO}_2) = 44.0 \text{ g mol}⁻¹ \]
\[ n = \frac{19.8}{44.0} = 0.45 \text{ mol} \]

\[ \Delta H = \frac{0.45 \text{ kJ}}{0.45 \text{ mol}} \]

\[ \Delta H = 97.8 \text{ J} \]
(c) A small camp stove containing butane gas, $\text{C}_4\text{H}_{10}(g)$, is used to heat some water, as shown in the diagram below. A student measures the temperature change in the water and calculates that when $3.65 \text{ g}$ of butane is combusted, $106 \text{ kJ}$ of heat is released.

The reaction for the combustion of butane is shown in the equation below.

$$2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l)$$

(i) Calculate the enthalpy change ($\Delta H$) for this reaction, based on the above measurements.

$$M(\text{C}_4\text{H}_{10}) = 58.0 \text{ g mol}^{-1}$$

$$n = \frac{m}{M} = \frac{3.65}{58.0}$$

$$n = 0.063 \text{ mol}$$

$$\Delta H = \Delta H \times n = 106 \times 0.063$$

$$\Delta H = 6.678 \text{ kJ mol}^{-1}$$

(ii) The accepted enthalpy change for the combustion reaction of butane gas, $\text{C}_4\text{H}_{10}(g)$, is $\Delta H = -5754 \text{ kJ mol}^{-1}$.

Explain why the result you calculated in part (c)(i) is different to the accepted value. In your answer, you should include at least TWO reasons.

- The two answers will be different because of factors such as the environment.
- Heat given out by the reaction will not all go into heating the water.
- Also, the combustion reaction may not be complete, the reactants might not fully react to produce as much heat, there the $\Delta H$ will be less.

(iii) Complete, including labels, the energy diagram for the combustion of butane gas showing reactants, products, and the change in enthalpy.
Butane gas is a useful fuel because when it undergoes combustion, energy is released. Explain why energy is released in this reaction, in terms of making and breaking bonds. No calculations are required.

Butane combustion reaction is useful because the energy from breaking the bonds is more than forming the bonds, therefore there can be more energy released in the reaction to give out heat.

<table>
<thead>
<tr>
<th>Solid</th>
<th>Type of solid</th>
<th>Type of particle</th>
<th>Attractive forces between particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(s) (copper)</td>
<td>metallic</td>
<td>atom (metal)</td>
<td>metallic bonds</td>
</tr>
<tr>
<td>PCl₃(s) (phosphorus trichloride)</td>
<td>molecule</td>
<td>molecules (atoms)</td>
<td>molecular bonds</td>
</tr>
<tr>
<td>SiO₂(s) (silicon dioxide)</td>
<td>covalent network</td>
<td>atomes</td>
<td>Covalent bonds</td>
</tr>
<tr>
<td>KCl(s) (potassium chloride)</td>
<td>ionic</td>
<td>Ions</td>
<td>Ionic bonds</td>
</tr>
</tbody>
</table>

(b) Phosphorus trichloride, PCl₃, is a liquid at room temperature, and does not conduct electricity. Explain these two observations in terms of the particles, structure, and bonding of PCl₃.

PCl₃ is a molecule, it has weak intermolecular bonds holding the structure together. At room temperature these bonds are strong enough to hold the molecule together because there is no heat acting on it. This molecule doesn't conduct electricity because there are no free moving valence electrons, therefore there is no way for electricity to travel through the molecule.
(c) Consider each of the solids copper, Cu, silicon dioxide, SiO₂, and potassium chloride, KCl.

Complete the table below by identifying which of these solids have the listed physical properties:

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>The solid is insoluble in water and is malleable.</td>
<td>Copper, Cu</td>
</tr>
<tr>
<td>The solid is soluble in water and is not malleable.</td>
<td>Potassium Chloride, KCl</td>
</tr>
<tr>
<td>The solid is insoluble in water and is not malleable.</td>
<td>Silicon dioxide, SiO₂</td>
</tr>
</tbody>
</table>

Justify TWO of your choices in terms of the particles, structure, and bonding of these solids. You may use diagrams in your justification.

- Copper is insoluble in water because of the ionic bond between the metal solid; these bonds are strong enough that the water will not affect the bonds and it won't dissolve. Copper is malleable because it has free valence electrons that are able to slide over each other when pressure is applied, therefore the solid is malleable.

- Potassium is insoluble in water because the weak ionic bonds are affected by the molecular bonds in the water molecule. Therefore, this solid will dissolve in water. KCl is not malleable because it has no free moving valence electrons. When pressure is applied, the solid will break because the particles within the solid are unable to slide of moved across each other.
Extra paper if required.
Write the question number(s) if applicable.