Answers

Level 3 Chemistry

91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

Credits: Five

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of thermochemical principles and the properties of particles and substances.	Demonstrate in-depth understanding of thermochemical principles and the properties of particles and substances.	Demonstrate comprehensive understanding of thermochemical principles and the properties of particles and substances

You should attempt ALL the questions in this booklet.

A periodic table is provided in the Resource Sheet.

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 – 11 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.

TOTAL

ASSESSOR'S USE ONLY

QUESTION ONE

(a) Complete the following table, using s, p, d notation.

| Symbol	Electron configuration
Al^{3+}	$1s^2\ 2s^2\ 2p^6$
Co	$[Ar]\ 4s^2\ 3d^7\ /\ [Ar]\ 3d^7\ 4s^2$
Fe^{3+}	$[Ar]\ 3d^5$

(b) Explain why a potassium ion is smaller than a potassium atom.

The K^+ ion has a smaller radius than the K atom, as the ion has lost an electron from the valence/outer energy level, and therefore has one shell less. Both species have the same number of protons / amount of nuclear charge. This results in greater attraction between the nucleus and the valence electrons of the ion, as the outer electrons are now closer to the nucleus.

(c) The graph shows the first ionization energies for six successive elements in the Periodic Table. The letters used are not their symbols.
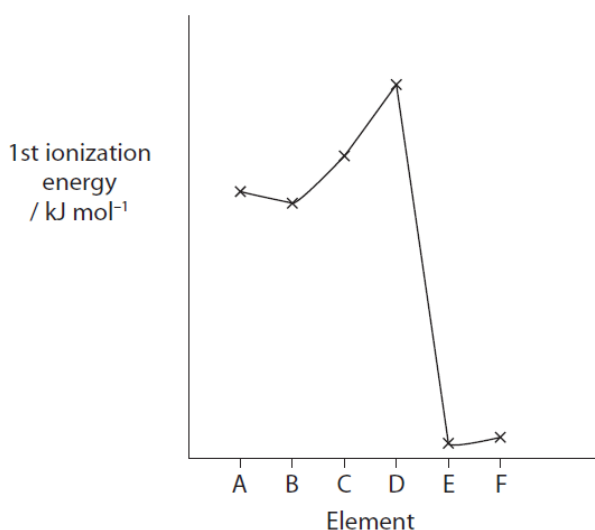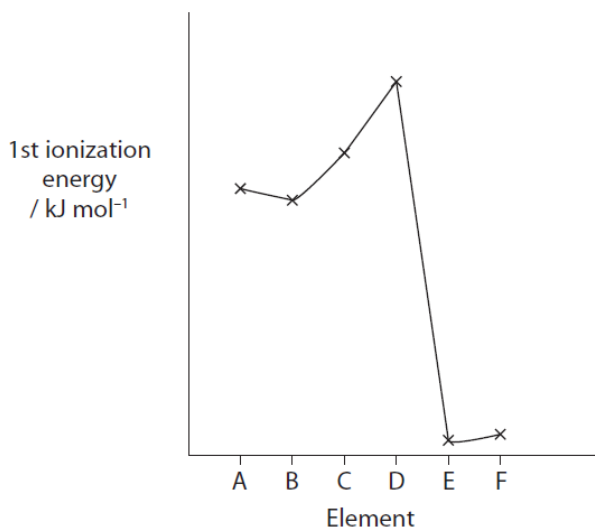

(i) Define the term **first ionization energy**.

First ionisation energy is the minimum energy required to remove one mole of electrons from one mole of gaseous atoms.

(ii)   Ionisation energies provide evidence for the arrangement of electrons in atoms.

Identify and justify which element (A – F) is potassium.

Element E is potassium. First ionisation energy increases across a period and the alkali metals / group 1 always have the lowest first ionisation energy. First ionisation energy increases (in general) across a period as there is an increase in the number of protons and thus the nuclear charge / attractive force of the nucleus. As the electrons are added to the same energy level. there is no increase in repulsion between energy levels. The nuclei with a greater number of protons have a stronger electrostatic attraction for the valence electrons.
Element E follows element D which has a very high first ionisation energy and is a noble gas / in group 18. First IE falls significantly at the start of a new period. It becomes easier to remove an electron down a group / first IE decreases down a group as the valence electrons are further from nucleus with greater repulsion / shielding from inner shells. so there is less electrostatic attraction between protons in the nucleus and valence electron to be removed.

Question Two

(a) Chlorine, Cl and fluorine, F are both halogens. A molecule of ClF_3 can react with a molecule of AsF_5 as shown in the following equation.
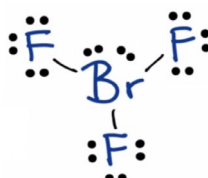
$$ClF_3 + AsF_5 \rightarrow ClF_2^+ + AsF_6^-$$
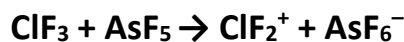
Complete the following table.

	AsF₅	ClF₂⁺
Lewis Diagram		
Name of shape	trigonal bipyramidal	v-shaped / bent

Bromine also forms compounds with other halogens.

(b) The Lewis diagram for the bromine trifluoride molecule is shown below.

Would you expect BF_3 to be soluble in water?

(Yes)   No

Explain your answer in terms of the shape and polarity of BF_3.

There is an electronegativity difference between Br and F (F is more electronegative), so the Br-F bonds are polar covalent. The five regions of electron density around the central Br atom arrange themselves as far apart as possible to minimise repulsion, into a trigonal bipyramidal arrangement. However, 2 regions are non- bonding, and 3 are bonding so the shape of the molecule is T-shaped. Since this is not a symmetrical shape, the bond dipoles do not cancel out, so BF_3 is a polar molecule. Water is a polar solvent. Polar molecules like BrF_3 are attracted to polar molecules like water, therefore, BrF_3 would be soluble in water.

(c) Fluorine reacts with hydrogen to form hydrogen fluoride (HF). The boiling points of fluorine and hydrogen fluoride are $-188^{\circ}C$ and $19.5^{\circ}C$ respectively.
Explain the difference in the boiling points of fluorine and hydrogen fluoride by comparing and contrasting the relative strengths of all the attractive forces involved between the molecules.

The weaker the attraction between the molecules, the lower the boiling point.

Temporary dipole-temporary dipole (temporary dipole-induced dipole / instantaneous dipole- instantaneous dipole) attractions depend on a large extent on the number of electrons. F_2 has 18 electrons while HF has just 10, so the temporary dipole-temporary dipole attractions will be greater between F_2 molecules.
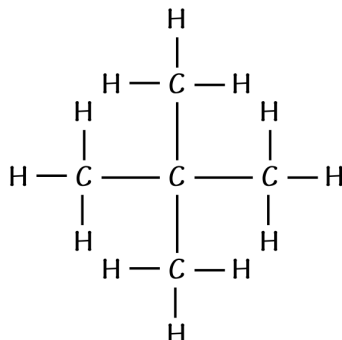
However, F_2 is a non-polar molecule and therefore temporary dipole-temporary dipole attractions are the only weak intermolecular attractions occurring which explains its very low boiling point. H-F is a polar molecule since F is more electronegative than H, resulting in the molecule having permanent dipole.

However H-F has hydrogen bonds present which are stronger than permanent dipole-permanent dipole attractions, require more energy to break them and so HF has the much higher boiling point of the pair.

(d) The following table shows the boiling points of some straight-chain alkanes.

	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}
Boiling point /°C	-162	-88	-42	-1	36

(i) The following compound is an isomer of one of the alkanes in the table. It has a boiling point of 9.5° C.

```
              H
              |
          H — C — H
      H       |       H
      |       |       |
  H — C ——— C ——— C — H
      |       |       |
      H       |       H
          H — C — H
              |
              H
```

Discuss why the boiling point of this compound is lower than that of its straight-chain isomer.

The two molecules have the same mass, and so the same number of electrons involved in the weak instantaneous dipoles.
However, the 2,2-dimethylpropane molecule has a much more spherical shape than the pentane. It has side chains and so the 'main chains' cannot get close to each other (more steric hindrance, less surface area), thus the instantaneous dipoles are weaker /less than can occur in the straight chain pentane, and therefore the boiling point is lower.

(ii) Both C_3H_8 and C_4H_{10} can be liquefied and used as fuels for camping stoves. Suggest, with a reason, which of these two fuels is liquefied more easily.

Both molecules are essentially non-polar and the only forces of attraction between them would be temporary dipole-temporary dipole attractions.
Since butane is the larger molecule it has more electrons / it is more polarisable / has a greater molar mass, so its temporary dipole attractions are stronger.
Therefore when cooled, butane will turn to a liquid more easily than propane.

QUESTION THREE

Cracking is the process whereby organic molecules are broken down into simpler molecules

The equation for a cracking reaction of butane is

$$C_4H_{10}(g) \rightarrow CH_4(g) + C_3H_6(g)$$

(a) Use the following standard enthalpy changes of combustion to calculate the enthalpy change of this cracking reaction.

$$\Delta_cH^o(CH_4(g)) = -890 \text{ kJ mol}^{-1}$$

$$\Delta_cH^o(C_4H_{10}(g)) = -2877 \text{ kJ mol}^{-1}$$

$$\Delta_cH^o(C_3H_6(g)) = -2058 \text{ kJ mol}^{-1}$$

Make sure to:

- show your method.
- include a sign and units in your answer.

$$C_4H_{10}(g) \rightarrow CH_4(g) + C_3H_6(g)$$

$CO_2 + 2H_2O \rightarrow CH_4 + 2O_2$	+890
$C_4H_{10} + 6.5\,O_2 \rightarrow 4CO_2 + 5H_2O$	-2877
$3CO_2 + 3H_2O \rightarrow C_3H_6 + 4.5\,O_2$	+2058

$\Delta_rH = +890 + (-2877) + 2058 = 71.0 \text{ kJ mol}^{-1}$.

Propane is sold in small cylinders. It is used as a fuel in camping stoves. The enthalpy change of combustion of propane can be measured by experiment using one of these cylinders.
A known mass of propane is burned to heat a container of water. The temperature rise of the water is measured.

If 0.328 g of propane is burned, the temperature of 100 g water increases from 19.5 °C to 43.0 °C.

(b) (i) Using these results, calculate the experimental value for $\Delta_cH(C_3H_8(g))$.
The specific heat capacity of water is 4.18 J g^{-1} °C^{-1}.
$M(C_3H_8)$ = 44.0 g mol^{-1}.

$Q = mc \, \Delta T$

$Q = 100 \times 4.18 \times (43.0–19.5) = 9823$ J $= 9.832$ kJ

Since exothermic…. $= -9.832$ kJ

$n(C_3H_8) = m/M = 0.328/ 44.0 = 7.45 \times 10^{-3}$ mol.

$\Delta_cH(C_3H_8(g)) = -9.832/7.45 \times 10^{-3} = -1318$ kJ $mol^{-1} = -1320$ kJ mol^{-1} (3 s.f.)

(ii) The results of this experiment are inaccurate due to heat loss.
Suggest **one** other source of error, other than measurement errors and limitations of the equipment.

Incomplete combustion which means the temperature of the water doesn't increase as much leading to a less negative enthalpy.
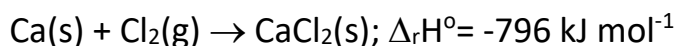Conditions were not standard / needed to carry out under standard conditions.

(c)   Calcium chloride, $CaCl_2$ can be formed by burning calcium metal in chlorine gas.

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s); \Delta_rH^\circ= \text{-796 kJ mol}^{-1}$$
$$\Delta S^\circ{}_{system} = \text{-101.8 J mol}^{-1} K^{-1}$$
$$\Delta S^\circ{}_{surroundings} = \text{+2670 J mol}^{-1} K^{-1}$$

(i)   Explain fully why the standard entropy change of the system $\Delta S^\circ{}_{system}$ has a negative value.

The sign is negative because a solid and a gas are reacting to form a solid and there are fewer ways of arranging particles in a solid than a gas / there is a decrease in disorder as solid more ordered than gas. The number of moles/molecules decreases. All of these lead to a decrease in entropy.

(ii)   Explain fully why you would expect the standard entropy change of the surroundings $\Delta S^\circ{}_{surroundings}$, to have a positive value.

The reaction is combustion which is always exothermic and this can be seen from the negative value for the enthalpy change ($\Delta_rH^\circ= \text{-796 kJ mol}^{-1}$). This means heat is release into the surroundings. The surroundings therefore warm up / E_k increases and so the entropy of the surroundings increases so the value for $\Delta S^\circ{}_{surroundings}$ is positive.

(iii)   The total entropy change, ΔS° total can be calculated by using the following equation:
$$\Delta S^\circ{}_{total} = \Delta S^\circ{}_{surroundings} + \Delta S^\circ{}_{system}$$

The total entropy change for this reaction is:
$$\text{+2670 + (-101.8) = +2568.2 = +2570 J mol}^{-1} K^{-1} \text{ (3 s.f.)}$$

What does $\Delta S^\circ{}_{total}$ tell you about the spontaneity of this reaction?

Since $\Delta S^\circ{}_{total}$ is > 0 / is positive the reaction will be spontaneous. As long as the positive entropy of either the system or surroundings (the surroundings in this case) compensates for the negative entropy change of the other (the system in this case), then the reaction will be spontaneous.

Extra paper if required.

Write the question number(s) if applicable