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NZQA

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Chemistry 2024

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.

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 and other reference material are provided in the Resource Booklet L3–CHEMR.

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

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

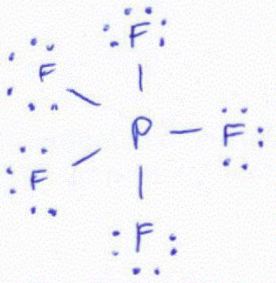
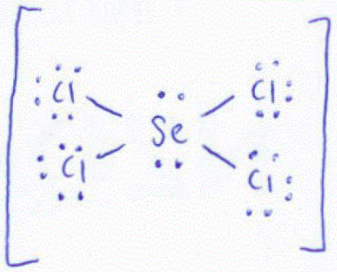
Do not write in any cross-hatched area (▨). This area will be cut off when the booklet is marked.

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

Excellence TOTAL 20

QUESTION ONE

(a) Complete the table below.

	PF_5 5+(5×7)=	$SeCl_4^{2-}$ 6+(4×7)+2
Lewis structure		
Shape	trigonal bipyramidal	square planar

(b) (i) The reaction between chlorine trifluoride, $ClF_3(g)$, and hydrazine, $N_2H_4(\ell)$, is explosive. It was investigated as a potential rocket fuel. The reaction is shown below.

$$4ClF_3(g) + 3N_2H_4(\ell) \rightarrow 12HF(g) + 3N_2(g) + 2Cl_2(g)$$

Calculate $\Delta_r H^\circ$ for the reaction, given the following data.

×3	$N_2H_4(\ell) + O_2(g) \rightarrow N_2(g) + 2H_2O(\ell)$	$\Delta_r H^\circ = -623$ kJ mol^{-1}
×2	$2ClF_3(g) + 2NH_3(g) \rightarrow 6HF(g) + N_2(g) + Cl_2(g)$	$\Delta_r H^\circ = -1200$ kJ mol^{-1}
rev	$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$	$\Delta_r H^\circ = -1270$ kJ mol^{-1}
×6	$H_2O(\ell) \rightarrow H_2O(g)$	$\Delta_{vap} H^\circ = 40.7$ kJ mol^{-1}

$3N_2H_{4(\ell)} + 3O_{2(g)} \rightarrow 3N_{2(g)} + 6H_2O_{(\ell)}$ $\Delta_r H^\circ = -1869$ kJ mol^{-1}

$4ClF_{3(g)} + 4NH_{3(g)} \rightarrow 12HF_{(g)} + 2N_{2(g)} + 2Cl_{2(g)}$

~~$2N_{2(g)} + 6H_2O_{(g)} \rightarrow 4NH_{3(g)} + 3O_{2(g)}$~~ $\Delta_r H^\circ = -2400$ kJ mol^{-1}

$2N_{2(g)} + 6H_2O_{(g)} \rightarrow 4NH_{3(g)} + 3O_{2(g)}$ $\Delta_r H^\circ = +1270$ kJ mol^{-1}

$6H_2O_{(\ell)} \rightarrow 6H_2O_{(g)}$ $\Delta_{vap} H^\circ = +244.2$ kJ mol^{-1}

$4ClF_{3(g)} + 3N_2H_{4(\ell)} \rightarrow 3N_{2(g)} + 12HF_{(g)} + 2Cl_{2(g)}$

$\Delta_r H^\circ = -2754.8$ kJ mol^{-1}

$= -2750$ kJ mol^{-1} (3 s.f.)

(ii) Justify, in terms of the entropy changes of the system and the surroundings, why the reaction between chlorine trifluoride and hydrazine is spontaneous.

$$4ClF_3(g) + 3N_2H_4(\ell) \rightarrow 12HF(g) + 3N_2(g) + 2Cl_2(g)$$

The entropy of the system increases.
3 mols of more ordered liquid reactant and 4 mols of gaseous reactant produce 17 mols of more disordered gaseous products. Hence there is greate dispersal of matter and energy in the system.
The entropy of the surroundings increases.
The reaction is exothermic, meaning heat energy is released into the surroundings, so the particles in the surroundings gain kinetic energy. Hence there is greater dispersal of matter and energy in the surroundings.
As both the entropy of the system and the surroundings increases, the total entropy increases / the total entropy change is positive, Hence the reaction is spontaneous.

QUESTION TWO

(a) (i) The table below gives the electron configurations of three elements.

Argon, Ar	Neon, Ne	Phosphorus, P
$1s^2 2s^2 2p^6 3s^2 \mathbf{3p^6}$	$1s^2 2s^2 2p^6$	$1s^2 2s^2 2p^6 3s^2 3p^3$

When considering the $3p^6$ part of the electron configuration of argon, what is represented by the following?

3 3rd energy level

p the p orbital

6 6 electrons occupying this orbital

(ii) Arrange the three elements Ar, Ne, and P, in order of decreasing first ionisation energy.

Use your knowledge of periodic trends to justify your order.

Ne > Ar > P

The first ionisation energy is the minimum amount of energy required to remove 1 mol of electrons from 1 mol of gaseous atoms.

Both Ne and Ar are in the same group, group 18.

Down a group, the number of energy levels increases, meaning the valence electron to be removed occupies a higher energy level so it is further away from the nucleus. The shielding of the nuclear attraction by the inner levels increases. Although the number of protons increases down the group, this effect is offset by the valence electrons being further away from the nucleus with increased shielding from inner levels. Hence the nuclear attraction decreases, so less energy is required to remove an electron, so the first ionisation energy decreases. Hence Ar has a lower first ionisation energy compared to Ne.

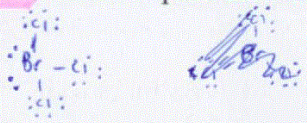
(Ar has 3 energy levels while Ne has 2)

Both P and Ar are in the same period, so their valence

electrons occupy the same energy level with the same shielding from inner levels. Across the period, the number of protons and thus the nuclear charge increases. Hence the nuclear attraction increases, as the outer electrons can be attracted more strongly to the nucleus, so more energy is required to remove an electron meaning the first ionisation energy increases. Hence Ar has a greater first ionisation energy compared to P. So Ne has the highest first ionisation energy, followed by Ar and then P.

(b) The two possible shapes of bromine trichloride, $BrCl_3$, are T-shaped and trigonal planar. Both of these shapes are based on the trigonal bipyramidal arrangement of electron pairs around the central atom.

Research shows that the $BrCl_3$ molecule is polar.



Compare the two possible shapes of the $BrCl_3$ molecule to identify which shape would result in the $BrCl_3$ molecule being polar.

Your answer should refer to bond polarity and the arrangement of the bond dipoles.

$BrCl_3$ has polar covalent Br–Cl bonds due to the difference in electronegativity between atoms, with Cl being more electronegative than Br.

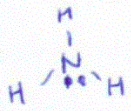
If $BrCl_3$ is T-shaped: The bond dipoles are arranged unevenly due to $BrCl_3$'s asymmetric T-shaped shape (which has 3 bonding regions and 2 lone pairs) meaning the bond dipoles do not cancel, so $BrCl_3$ is a polar molecule.

If $BrCl_3$ is trigonal planar: However, despite $BrCl_3$'s polar-covalent bonds, the bond dipoles are distributed evenly due to $BrCl_3$'s symmetric trigonal planar shape. Hence the bond dipoles cancel so $BrCl_3$ is a non-polar molecule.

There fore if $BrCl_3$ is T-shaped it will be a polar molecule, as T-shape is an asymmetric shape while trigonal planar is a symmetric shape. So the bond dipoles will not cancel if $BrCl_3$ is T-shaped, whereas in contrast they will cancel is $BrCl_3$ is trigonal planar. This means $BrCl_3$ will only be polar with a T-shaped molecular geometry.

QUESTION THREE

(a) (i) Identify all the types of attractive forces between particles of the following substances in their liquid state in the table below.



Substance	Boiling point / °C	Attractive forces
Ammonia, NH_3	–33	temporary dipole-dipole attractions permanent dipole-dipole attractions hydrogen bonding
Sulfur dioxide, SO_2	–10	temporary dipole-dipole attractions permanent dipole-dipole attractions
Pentane, $CH_3CH_2CH_2CH_2CH_3$	36	temporary dipole-dipole attractions

(ii) Explain the difference in the boiling points of ammonia and sulfur dioxide.

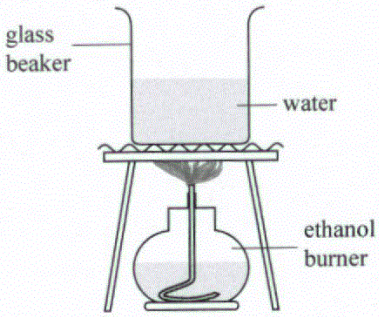
Both NH_3 and SO_2 are polar molecules with temporary and permanent dipole-dipole attractions. However, NH_3 also has strong hydrogen bonding due to the strong N-H dipole, where there is a large electronegativity difference between N and H as N is more electronegative than H. Despite this, SO_2 has a significantly larger molar mass and thus a larger electron cloud size compared to NH_3, meaning its temporary dipole-dipole attractions are significantly stronger than NH_3. Hence the strength of the intermolecular attractions between SO_2 molecules require more heat energy to overcome compared to the sum of the temporary dipole attractions, permanent dipole attractions, and hydrogen bonding between NH_3 molecules. Hence SO_2 has a higher boiling point compared to NH_3 (-10°C compared to -33°C)

(iii) Explain why the boiling point of pentane is higher than that of sulfur dioxide.

Both pentane and SO_2 have temporary dipole-dipole attractions. However, SO_2 is a polar molecule while pentane is a non-polar molecule (being an alkane), meaning SO_2 also has strong permanent dipole-dipole attractions between molecules. However, despite pentane only having temporary dipole-dipole attractions, pentane has a significantly larger molar mass / electron cloud size (having a very long carbon chain) compared to SO_2. This means the temporary dipole-dipole attractions between pentane molecules are significantly stronger than the temporary dipole-dipole attractions between SO_2 molecules. Hence the temporary dipole attractions between pentane molecules require more heat energy to overcome compared to the sum of the temporary and permanent dipole attractions between SO_2 molecules, so pentane has a higher boiling point compared to SO_2 (36 °C compared to -10 °C).

Question Three continues on the next page.

(b) The enthalpy of combustion of ethanol, C_2H_5OH, was determined experimentally using the apparatus below. The ethanol was completely combusted to heat some water in a beaker.



The following data was recorded:

- initial water temperature = 22.1 °C
- final water temperature = 31.2 °C
- initial mass of burner and ethanol = 59.2 g
- final mass of burner and ethanol = 58.7 g

$\Delta T = 31.2 - 22.1 = 9.1\,°C$

mass of ethanol: $59.2 - 58.7 = 0.5\,g$

The student calculated the experimental enthalpy change for the combustion of liquid ethanol, $\Delta_c H(C_2H_5OH(\ell))$, to be $-770\ kJ\ mol^{-1}$.

The specific heat capacity of water is $4.18\ J\ g^{-1}\ °C^{-1}$.

$M(C_2H_5OH) = 46.0\ g\ mol^{-1}$

(i) Use the information provided to calculate the mass of the water that was in the beaker.

mass of ethanol = $59.2 - 58.7 = 0.5\,g$

$n = \frac{m}{M} = \frac{0.5}{46.0} = 0.0109\ mol$ (3s.f)

$\Delta_r H^\circ = \frac{-q}{n}$

$-770 = \frac{-q}{0.0109}$

$q = 770 \times 0.0109 = 8.3696$ kJ of energy released

$= 8369.6$ J of energy released

$q = mc\Delta T$

$8369.6 = m \times 4.18 \times (31.2 - 22.1)$

$8369.6 = m \times 4.18 \times 9.1$

$m = \frac{8369.6}{4.18 \times 9.1} = 220\,g$ (3s.f)

(ii) Which of these quantities calculated would have been a source of error in the calculated enthalpy value?

Circle your answer.

temperature change of water **mass of fuel combusted**

Explain your choice.

The ethanol was completely combusted so there was no incomplete combustion meaning all the ethanol was used up in the reaction. This means the mass of fuel combusted should not be a source of error in the calculated enthalpy value. However the temperature change of the water would have been a source of error as some heat energy may have been lost to the surroundings eg absorbed by the equipment, making the enthalpy value ~~temperature change of the water~~ loner than the theoretical value.

Excellence

Subject: Chemistry

Standard: 91390

Total score: 20

Q	Grade score	Marker commentary
One	E8	Applied Hess' Law to an enthalpy change calculation and justified the spontaneity of a reaction based on the entropy changes of the system and the surroundings.
Two	M6	Justified the periodic trends in 1st ionisation energy in terms of the number of energy levels, nuclear charge, repulsion from inner energy levels, and the electrostatic attraction between the nucleus and valence electrons. Explained the polarity of molecular shapes by recognising the symmetry of the shape.
Three	M6	Explained differences in boiling points by comparing the strength of the intermolecular forces, including linking the strength of temporary dipole attractions to the surface area of the molecules. Calculated the mass of water in a calorimetry calculation and explained procedural limitations to a calorimetric procedure.