1) Atoms, Moles and Stoichiometry

Answers: 1) Atoms, Molecules and Stoichiometry

1	A	2	C	3	D	4	D	5	A
6	D	7	C	8	C	9	D	10	B
11	B	12	D	13	A	14	D	15	B
16	A	17	B						

1) Atoms, Moles and Stoichiometry

1

Amount of KOH used for complete neutralisation = $\frac{25}{1000} \times 1.0 \times 10^{-2}$

$= 2.5 \times 10^{-4}$ mol

Amount of H+ in the resin = 2.5×10^{-4} mol

$Ca^{2+} \equiv 2H^{+}$

Amount of Ca^{2+} in 50 cm^3 sample = $2.5 \times 10^{-4} \div 2 = 1.25 \times 10^{-4}$ mol

Concentration of Ca^{2+} in original sample = $\frac{1000}{50} \times 1.25 \times 10^{-4} = 2.5 \times 10^{-3}$ mol

dm^{-3}

Ans: A

2

Amount of NaOH used = $\frac{25.80}{1000} \times 0.100 = 2.58 \times 10^{-3}$ mol

Total amount of H^{+} used = $\frac{50}{1000} \times 0.050 = 2.5 \times 10^{-3} \times 2 = 5 \times 10^{-3}$ mol

Amount of H+ that reacted with NH_3 = $5 \times 10^{-3} - 2.58 \times 10^{-3} = 2.42 \times 10^{-3}$ mol

$NH_3 + H^{+} \rightarrow NH_4^{+}$

Amount of NH_3 passed into H_2SO_4 = 2.42×10^{-3} mol

$(NH_4)_2SO_4 \equiv 2\ NH_3$

Amount of $(NH_4)_2SO_4$ in 25.0 cm^3 = $2.42 \times 10^{-3} \div 2 = 1.21 \times 10^{-3}$ mol

Amount of $(NH_4)_2SO_4$ in 250 cm^3 = $1.21 \times 10^{-3} \times 10 = 1.21 \times 10^{-2}$ mol

Mass of $(NH_4)_2SO_4$ in 250 cm^3 = $1.21 \times 10^{-2} \times 132.1 = 1.598g$

Percentage by mass of $(NH_4)_2SO_4 = \frac{1.598}{5} \times 100\% = 31.96\% \approx 32.0\%$

Ans: C

3

A) If water evaporated from the solution, the concentration of the barium hydroxide will increase and a larger volume of HC*l* will be used to titrate instead.

B) A possible answer, but we will look for more scientific answers.

C) Having less water of crystalisation than stated does not affect the amount of $Ba(OH)_2$

D) Barium hydroxide is basic and it reacts with carbon dioxide to form barium carbonate which will be seen as a solids in the water.

Ans: D

4

At rtp, 1 mole of oxygen gas contains 24 000 cm^3

Amount of O_2 present in 24 $cm^3 = \frac{24}{24000} = 1 \times 10^{-3}$ mol

Each O_2 contains 2 atoms of O, and 1 mole contains 6.02×10^{23} atoms

Number of oxygen atoms present in 24 cm^3 of oxygen gas

$= 6.02 \times 10^{23} \times 2 \times 1 \times 10^{-3} = 1.204 \times 10^{21}$

Ans: D

5 Given the density of mixture is 1.82 g dm^{-3} , and that Argon's density is 1.78 g dm^{-3}, the gas mixed should have a higher molar mass of Argon at 39.9 g mol^{-1}. Hence, the answer is CO_2 which has a molar mass of 44 g mol^{-1}.

Ans: A

6 [Hint: C in CO_2 and H in H_2O come from the iron organic compound only]

Mass of C in the iron organic compound = $\frac{12}{44}$ × 2.23 = 0.6082 g (4.s.f)

Mass of H in the organic compound = $\frac{2}{18}$ × 0.457 = 0.05078 g (4.s.f)

Mass of Fe in the organic compound = 0.944 − 0.6082− 0.05078= 0.2850 g

	C	H	Fe
Mass	0.6082	0.05078	0.2850
Ar	12	1.0	55.8
mole	0.05068	0.05078	0.005108
÷ by smallest no.	10	10	1

Hence empirical formula of **X** = $FeC_{10}H_{10}$

Ans: D

7

PV=nRT

$100000 \times 20 \times 10^{-6} = \frac{0.0337}{Mr} \times 8.31 \times 300$

M_r = 42.0

	$C_xH_y(g)$	+	$(x + \frac{y}{4})$ $O_2(g)$	□	x $CO_2(g)$	+	$\frac{y}{2}$ $H_2O(l)$
Reacting vol ratio / cm^3	20		excess		40		20
Mole ratio	$\frac{20}{20}$ = 1				$\frac{40}{20}$ = 2		$\frac{20}{20}$ = 1

x=2 , $\frac{y}{2}$=1 □ y = 2

Hence, empirical formula = C_2H_2

However, as M_r is 42, there is short of 16, which constitutes an O.

Hence, ans is C_2H_2O

Ans: C

8

Mass of CO_2 in $CaCO_3$ = $\frac{44}{100.1}$ × 0.05 = 0.02198 g

Amount of CO_2 = $\frac{0.02198}{44}$ = 5×10^{-4} mol

Volume of CO_2 at r.t.p = $5 \times 10^{-4} \times 24 = 0.012$ dm^3

Percentage by volume of CO_2 = $\frac{0.012}{10} \times 100 = 0.12\%$

Ans: C

9

Cu^{2+} has been reduced to Cu^+, which reacts with the unreacted I^- to for the white precipitate CuI.

$Cu^{2+} + e \rightarrow Cu^+$

$2I^- \rightarrow I_2 + 2e$

Overall: $2Cu^{2+} + 2I^- \rightarrow 2Cu^+ + I_2$

Assuming only half of the I^- reacts =[$\frac{10}{1000} \times 0.2$] ÷ 2 = 1×10^{-3} mol

Amount of I_2 that reacts with $S_2O_3^{2-}$ = $1 \times 10^{-3} \div 2 = 5 \times 10^{-4}$

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$$

Amount of $S_2O_3^{2-}$ required for reaction = $2 \times 5 \times 10^{-4} = 1 \times 10^{-3}$ mol

Volume of required $S_2O_3^{2-}$= $\frac{1 \times 10^{-3}}{0.04} \times 1000 = 25.0$ cm^3

Ans: D

10

No. of I_2 particles = $\frac{600}{253.8} \times 6.02 \times 10^{23} = 1.423 \times 10^{24}$

No. of H_2O particles = $\frac{50}{18} \times 6.02 \times 10^{23} = 1.672 \times 10^{25}$

No. of HC*l* particles = $\frac{50}{22.7} \times 6.02 \times 10^{23} = 1.326 \times 10^{24}$

No. of CH_3CO_2H particles = $\frac{550}{1000} \times 2.5 \times 6.02 \times 10^{23} = 3.311 \times 10^{23}$

Ans: B

11

Option A: $\frac{91.1}{100} \times 28 + \frac{7.9}{100} \times 29 + \frac{1}{100} \times 30 = 28.099$

Option B: $\frac{92.2}{100} \times 28 + \frac{4.7}{100} \times 29 + \frac{3.1}{100} \times 30 = 28.109$

Option C: $\frac{95}{100} \times 28 + \frac{3.2}{100} \times 29 + \frac{1.8}{100} \times 30 = 28.039$

Option D: $\frac{96.3}{100} \times 28 + \frac{0.3}{100} \times 29 + \frac{3.4}{100} \times 30 = 28.071$

Ans: B

12

No. of molecules in 28.0 g sample of $^{14}N_2 = 6.02 \times 10^{23}$

No. of atoms in 28.0 g sample of $^{14}N_2 = 6.02 \times 10^{23} \times 2 = 1.20 \times 10^{24}$

No. of atoms in 24.0 g of $^{12}C = 6.02 \times 10^{23} \times 2 = 1.20 \times 10^{24}$

No. of atoms in 4.0 g of $^{4}He = 6.02 \times 10^{23}$

No. of atoms in 32.0 g of $^{16}O_2 = 6.02 \times 10^{23}$

Ans: D

13

One mole of metal atoms = 6.02×10^{23}

Option A: No. of atoms of $^1/_2$ mol of hydrogen gas = 6.02×10^{23}

Option B: No. of atoms of $^1/_{12}$ mol of $^{12}C = \frac{1}{12} \times 6.02 \times 10^{23} = 5.02 \times 10^{22}$

Option C: False. Mass of 1 mol of hydrogen atoms 2 g

Option D: False. There are different metals with different oxidation states

Ans: A

14

Option A: Electronic Configuration of Fe^{2+}: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8$

Option B: angle of deflection $\alpha \frac{charge}{mass}$ False as $^{56}_{26}Fe^{2+}$ is heavier than $^{54}_{26}Fe^{2+}$ hence the angle of deflection is lesser for $^{56}_{26}Fe^{2+}$.

Option C: Both have same no. of protons.

Option D: Total no. of protons and electrons in $Fe^{2+} = 26 + 24 = 50$

Nucleon number = 56

Ans: D

15

Volume of H_2O = 24 cm^3
Final volume of residual gases = 64 – 24 =40 cm^3
Residual gas consist of CO_2 + H_2O
Volume of CO_2 = $\frac{60}{100}$ × 40 = 24 cm^3
By comparing volume of H_2O to CO_2,
Empirical formula = CH_2
Ans: B

16 Amount of NaOH that reacted with H_2SO_4 =$\frac{40}{1000}$ × 0.875 × 2 = 0.07 mol
Amount of NaOH that reacted with both CO_2 and NO_2
= 0.25 – 0.07 = 0.18 mol
Amount of NO_2 is 0.02 mol
Amount of NaOH that react with CO_2 = 0.18 – 0.02 = 0.16 mol
Amount of CO_2 = 0.16 ÷ 2 = 0.08
x= 0.08 ÷ 0.02 = 4

Phosphorus pentoxide reacts with the H_2O
The increase in mass of 1.15g = H_2O
Amount of H_2O = $\frac{1.15}{18}$ = 0.06389 mol
y/2 = 0.06389 ÷ 0.02 ≈ 3.1945 ∴ y=6.389

4:6.4 ≈ 2:3
Ans:A

17

Amount of O_2 = $\frac{26}{24000}$ = 1.083 × 10^{-3} mol
H_2O_2 → O_2 + $2H^+$ + 2e
Amount of MnO_4^-= 1.083 × 10^{-3} mol
Concentration of MnO_4^- =$\frac{1000}{25}$ × 1.083 × 10^{-3} = 4.33 x 10^{-2} mol dm^{-3}
Ans: B

Section B

1(a)

Amount of Fe^{2+} = $\frac{0.50}{55.8+32.1+16.0\times4+7\times18}$ = 1.80×10^{-3} mol

$Fe^{2+} \rightarrow Fe^{3+} + e$

$MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$

$MnO_4^- + 8H^+ + 5\ Fe^{2+} \rightarrow Mn^{2+} + 5\ Fe^{3+} + 4H_2O$

Amount of MnO_4^- = $1.80 \times 10^{-3} \div 5 = 3.6 \times 10^{-4}$ mol

Volume of $KMnO_4$ required = $\frac{3.6\times10^{-4}}{0.02}$ ×1000 = 18 cm^3

1 (b)

Mass of Cu_2S present = $\frac{0.77}{100}$ × 5000 × 1000 = 38500g

Max mass of copper produced = $\frac{63.5\times2}{63.5\times2+32.1}$ × 38500 = 30732 g ≈ 30 700g

2

(i)

Flow rate of HCl=$\frac{3.65}{35.5+1.0}$ = 0.1 mol min^{-1}

Flow rate of ethene = 0.1 ÷ 2 = 0.05 mol min^{-1}

(ii)

Amount of HNO_3 present = $\frac{2.5}{1000}$ × 0.100 = 2.5×10^{-4} mol

Amount of NaOH in 10 cm^3 sample = 2.5×10^{-4} mol min^{-1}

No. of moles of unreacted NaOH = $\frac{1000}{10}$ × 2.5×10^{-4} =0.025 mol

(iii)

No. of moles of NaOH that react with the HCl = 0.100 – 0.025 = 0.075 mol

No. of moles of HCl that emerged from reaction chamber = 0.075 mol

(iv)

Based on the amount of HCl that reacted.

Conversion percentage = $\frac{0.025}{0.100}$ × 100% = 25%

(v)

Any **one** of the following:

- All the HC*l* emerged from chamber was absorbed by NaOH
- C_2H_4 does not undergo combustion inside the chamber

3

(a)

Mn^{2+} / observe colour change from colourless to pale pink.

(b)

[R] $MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$

[O] $C_2O_4^{2-} \rightarrow 2\ CO_2 + 2e$

Overall: $2\ MnO_4^- + 16\ H^+ + 5\ C_2O_4^{2-} \rightarrow 10\ CO_2 + 2\ Mn^{2+} + 8\ H_2O$

(c) Amount of MnO_4^- = 0.0205 x(4.88 x 10^{-5}) = 1.00 x 10^{-6} mol

Amount of $C_2O_4^{2-}$ = 5/2 x(1.00 x 10^{-6}) = 2.5 x 10^{-6} mol

Amount of Ca^{2+} in 1 cm^3 of blood = **2.5 x 10^{-6} mol** [$Ca^{2+} \equiv C_2O_4^{2-}$]

Mass of Ca^{2+} in 1 cm^3 of blood = 2.5 x 10^{-6} x 40.0 = 1.00 x 10^{-4} g = 0.100 mg

Concentration of Ca^{2+} = 0.100 x 100 = **10.0 mg per 100 m*l***

4 **(i)**

Relative atomic mass of an element is defined as the ratio of the average mass of one atom of the element to $^1/_{12}$ the mass of an atom of ^{12}C.

Let the percentage abundance of Ga-69 be *x*.

69x + (1 - x)71 = 69.7

x = 0.65

Percentage abundance of Ga-69 is *65%;* percentage abundance of Ga-71 is *35%.*

2) Redox

Answers
Redox

(1	**B**	**(2)**	**A**	**(7)**	**B**	**(10)**	**D**	**(13)**	**C**	**(16)**	**D**	**(19)**	**D**
(3	**C**	**(4)**	**A**	**(8)**	**C**	**(11)**	**C**	**(14)**	**B**	**(17)**	**C**	**(20)**	**A**
(5	**D**	**(6)**	**D**	**(9)**	**D**	**(12)**	**C**	**(15)**	**D**	**(18)**	**B**	**(21)**	**C**

MCQ

1

$MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$

Amount of MnO_4^- = $\frac{10}{1000} \times 0.10 = 1 \times 10^{-3}$ mol

Amount of electrons = $1 \times 10^{-3} \times 5 = 5 \times 10^{-3}$ mol

Amount of **B**Cl_2 = $\frac{25}{1000} \times 0.1 = 2.5 \times 10^{-3}$ mol

By conservation of electrons

No. of electrons given out per $\mathbf{B}^{2+}$ = $5 \times 10^{-3} \div 2.5 \times 10^{-3} = 2$

Final O.S of B = +4

Ans: B

2

Ammonium is present in the ammonium cyanate as NH_4^+

There are 1 C, 1 O, 2 N and 4 H, hence cyanate should have CNO as the atoms.

Since NH4+ has a charge of +1, then CNO will be −1.

Ans: A

3

Amount of Zn = 0.5 ÷ 65.4 =7.645 × 10^{-3} mol

$Zn \rightarrow Zn^{2+} + 2e$

Amount of electrons given out by Zn = 7.645 × 10^{-3} × 2 = 0.01529 mol

Amount of $\mathbf{A}O_2^+ = \frac{25.50}{1000} \times 0.200 = 5.10 \times 10^{-3}$ mol

No. of electrons taken in per A = 0.01529 ÷ 5.10 × 10^{-3} = 2.998 ≈ 3

O.S of **A** in $\mathbf{A}O_2^+$ = +5

Final O.S = +2

Ans: C

4

Amount of electrons taken in by MnO_4^- = 0.004 × 5 = 0.02 mol

No. of electrons given out per Y^{2+} = 0.02 ÷ 0.01 =2

Final O.S of **Y** = +4

Ans: A

5

Amount of $Fe^{2+} = \frac{100}{1000} \times 0.020 = 0.002$ mol

$Fe^{2+} \rightarrow Fe^{3+} + e$

No. of electrons given out per Fe^{2+} = 0.002

Amount of $XO_3^- = \frac{50}{1000} \times 0.020 = 0.001$ mol

No. of electrons taken in per XO_3^- =0.002 ÷ 0.001 = 2

Final O.S of X = +5 – 2 = +3

Ans: D

6

The methyl group CH_3 of the benzene ring is oxidised to a carboxylic acid COOH.

O.S in CH_3 = −3

O.S in COOH = +3
6 electrons must be removed from methylbenzene when it forms benzoic acid.
Ans: D

7

Amount of MnO_4^- = $\frac{37.5}{1000}$ × 0.02 = 7.5×10^{-4} mol

Amount of electrons taken in = $7.5 \times 10^{-4} \times 5 = 3.75 \times 10^{-3}$

No. of electrons given out per MO_3^- = $3.75 \times 10^{-3} \div 1.25 \times 10^{-3} = 3$

Final O.S of M in MO_3^- =+5

Initial O.S of M = +2

Ans: B

8

Carbonate did not change in O.S to CO_2 as +4 is the highest O.S.

Oxygen was present in the reagents in its element form, so it will undergo reduction.

Chromium took in oxygen, so it oxidised.

Titanium also took in oxygen so it oxidised.

Ans: C

9

Amount of $KMnO_4$ = $\frac{15}{1000}$ × 0.0200 = 3.00×10^{-4} mol

Amount of electrons taken in by $KMnO_4$ = $3.00 \times 10^{-4} \times 5$

= 1.5×10^{-3} mol

Amount of Zn oxidised to Zn^{2+} = $1.5 \times 10^{-3} \div 2 = 7.5 \times 10^{-4}$ mol

Mass of Zinc = 7.5×10^{-4} × 65.4 = 0.04905 ≈ 0.0491g

Ans: D

10

Amount of $K_2Cr_2O_7$ = $\frac{25}{1000}$ × 0.130 = 3.25×10^{-3}

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

Amount of electrons = 0.0195 mol

Amount of SO_2 collected = 218.4 ÷ 22700 = 9.621×10^{-3}

Each SO_2 takes in = $0.0195 \div 9.621 \times 10^{-3}$ = 2.02 ≈2

Final O.S = +4 +2 = +6

Ans: D

11

Amount of $SO_3^{2-} = \frac{25}{1000} \times 0.100 = 2.5 \times 10^{-3}$ mol

Amount of electrons given out = $2.5 \times 10^{-3} \times 2 = 5.0 \times 10^{-3}$ mol

Amount of a metallic ion, $M^{n+} = \frac{50}{1000} \times 0.100 = 5.0 \times 10^{-3}$ mol

No. of electrons taken in per metallic ion, M^{n+} = $5.0 \times 10^{-3} \div 5.0 \times 10^{-3}$

=1

Original O.S of metal = +3 +1 = +4

Ans:C

12

Amount of $KMnO_4$ = 8.00×10^{-3} mol

Amount of electrons taken in = $8.00 \times 10^{-3} \times 5$ = 0.04 mol

No. of electrons given out per $\mathbf{L}_2O_n$ = 0.04 ÷ 0.01 = 4

For each L, 2 electrons are given out

Final O.S of **L** in $H\mathbf{L}O_4^{2-}$= +5

Initial O.S of **L** = +3

Ans: C

13

1 mole of iodide I^- can give 0.5 mol of iodine I_2, and give out 1 mol of electrons. The O.S of changes from −1 to 0.

0.1 mol of iodine I_2 is formed from compound X, which will take in the 1 mol of electrons. Hence, the O.S changes from +5 to 0.

The compound with I having an O.S of +5 is KIO_3

Ans: C

14

I^- can reduce Cl^-
Fe^{2+} can reduce Cl^-
I^- can reduce Fe^{3+}
Ans:B

15

$Fe^{2+} \rightarrow Fe^{3+} + e$
3 moles of electrons are given out in the reaction

Hence, 3 electrons are taken in per Mn.
Final O.S = +7 – 3 = +4

Ans:D

16

Amount of $Na_2S_2O_3$ used = $\frac{8}{1000} \times 0.5 = 4 \times 10^{-3}$ mol

$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$

Amount if iodine liberated = $4 \times 10^{-3} \div 2 = 2 \times 10^{-3}$ mol

$2I^- \rightarrow I_2 + 2e$

Amount of electrons given out in the formation of iodine = $2 \times 10^{-3} \times 2$

$= 4 \times 10^{-3}$

Amount of $\mathbf{A}O_4^{3-} = \frac{5}{1000} \times 0.400 = 2 \times 10^{-3}$ mol

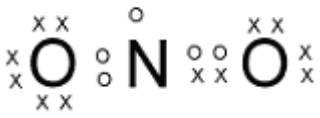
No. of electrons taken in per $\mathbf{A}O_4^{3-} = 4 \times 10^{-3} \div 2 \times 10^{-3} = 2$

Final O.S of A = +5 −2=+4

Ans:D

17

Option A: SO_2 is oxidized to form SO_3 in the atmosphere, which dissolves to make sulfuric acid

Option B: 

Option C: NO is gaseous and is hence a homogenous catalyst
Option D: True. NO_2. N is +4. NO, N is +2.

Ans: C

18

Amount of iodine produced from the conversion of excess IC*l*
= $1.39 \times 10^{-3} \div 2 = 6.95 \times 10^{-4}$ mol
Amount if IC*l* that did not react = 6.95×10^{-4} mol
Amount of IC*l* that reacted with the fatty acid
= $1.72 \times 10^{-3} - 6.95 \times 10^{-4} = 1.025 \times 10^{-3}$ mol
Mass of iodine for 0.100g of fatty acid = $1.025 \times 10^{-3} \times 126.9 = 0.130$
Mass of iodine for 100g of fatty acid = $0.130 \times 1000 = 130$

Ans: B

19

1: Cl changes from 0 to −1 in forming NaC*l*
Cl changes from 0 to +5 in forming $NaClO_3$

2: It is a comproportionation, where the oxidation states of the element in 2 different compounds become the same oxidation state.
I in changes from +5 to 0
I in I^- changes from −1 to 0

3. It is a comproportionation, where the oxidation states of the element in 2 different compounds become the same oxidation state.
Se changes from 0 to the O.S of $Se_8[AlCl_4]_2$
Se changes from +4 in $SeCl_4$ to the O.S of $Se_8[AlCl_4]_2$

Ans: D

20

Amount of sodium thiosulfate = $\frac{30}{1000} \times 0.1 = 3 \times 10^{-3}$ mol

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

Amount of iodine liberated = $3 \times 10^{-3} \div 2 = 1.5 \times 10^{-3}$ mol

Amount of iodate = $1.5 \times 10^{-3} \div 3 = 5 \times 10^{-4}$ mol

Concentration of iodate = $\frac{1000}{10} \times 5 \times 10^{-4} = 0.05$ mol dm^{-3}

Ans: A

21

$Fe^{2+} \rightarrow Fe^{3+} + e$

$C_2O_4^{2-} \rightarrow 2CO_2 + 2e$

Amount of electrons required to oxidised the 2 species
= 0.05 x 3 = 0.15 mol

Amount of $KMnO_4$ = 0.15 ÷ 5 = 0.03 mol

Concentration of $KMnO_4 = \frac{1000}{25} \times 0.03 = 1.2$ mol dm^{-3}

Ans: C

Structured Questions

1 (a)

$KNO_3 \equiv KNO_2$

Maximum mass of KNO_2 obtained = 85.1 / 101.1 x 1.55 = **1.30** g

(b)

(i) Construct a half-equation for the oxidation of NO_2^- to NO_3^-.

$$NO_2^- + H_2O \rightarrow NO_3^- + 2\,H^+ + 2e^-$$

(ii) Hence, write a balanced equation for the reaction between KNO_2 and $KMnO_4$. [2]

$2MnO_4^- + 5\,NO_2^- + 6\,H^+ \rightarrow 2\,Mn^{2+} + 5\,NO_3^- + 3\,H_2O$

(c)

(i) Calculate the mass of KNO_2 present in the residue.

No of moles of $KMnO_4$ reacted = 0.02890 x 0.0150 = **4.335×10^{-4}**

mol $2MnO_4^- \equiv 5\,NO_2^-$

η_{KNO_2} in 25.0 cm^3 solution = 5/2 x 4.335 x 10^{-3} = 0.00108 mol

η_{KNO_2} in residue or 250 cm^3 solution = 0.0108 mol

mass of KNO_2 in residue = 0.0108 x 85.1 = **0.922** g

(ii) Use the result obtained in parts (**a**) and **(c)(i)** to calculate the percentage conversion of KNO_3 to KNO_2 in this experiment.

[3]

Percentage conversion of KNO_3 = 0.922 / 1.30 x 100 = **70.9**%

2

$KNO_3 \equiv KNO_2$

Maximum mass of KNO_2 obtained = 85.1 / 101.1 x 1.55 = **1.30** g

(a) What is the oxidation state of bismuth in $NaBiO_3$? [1]

+5

(b) **(i)** Given that the bismuthate ion is reduced to Bi^{3+}, write the half-equation for this reduction reaction.

$BiO_3^- + 6\ H^+ + 2\ e^- \longrightarrow Bi^{3+} + 3\ H_2O$

(ii) Hence, write an overall balanced equation for the oxidation of manganese(II) to manganate(VII) by bismuthate ions in acidic solution.

[2]

$2\ Mn^{2+} + 5\ BiO_3^- + 14\ H^+ \longrightarrow 2\ MnO_4^- + 5\ Bi^{3+} + 7\ H_2O$

(c) Calculate the percentage by mass of manganese in the steel sample.

[3]

$Fe^{2+} \longrightarrow Fe^{3+} + e^-$

$MnO_4^- + 5\ Fe^{2+} + 8\ H^+ \longrightarrow Mn^{2+} + 5\ Fe^{3+} + 4\ H_2O$

$MnO_4^- \equiv 5Fe^{2+}$

η_{Mn} in sample = $\eta_{MnO_4^-}$ required

$= \frac{1}{5} \times \eta_{Fe^{2+}} = \frac{1}{5} \times 0.10 \times \frac{36.00}{1000}$ = **7.20×10^{-4}** mol

∴ mass of Mn in sample = 0.000720 x 55= **0.0396** g

∴ % of Mn in sample = $\frac{0.0396}{1.00} \times 100$ = **3.96**%

3

$ClO_2^-(aq) + Cl^- + 2H^+(aq) \rightarrow Cl_2(aq) + H_2O(l)$

$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

From equations: $ClO_2^-(aq) \equiv Cl^- \equiv Cl_2(aq) \equiv I_2(aq) \equiv 2S_2O_3^{2-}(aq)$

η_{ClO^-} in 25.0 cm^3 of diluted solution = η_{I_2} produced = 2 x $\eta_{S_2O_3^{2-}}$ used

= 2 x 18.50/1000 x 0.200 = 1.85×10^{-3} mol

$[ClO_2^-(aq)]$ in household bleach= $\dfrac{1.85 \times 10^{-3} \times \frac{250}{25}}{\frac{25.0}{1000}}$ = **0.740** mol dm^{-3}

4

(i) State the change in oxidation number for manganese

The oxidation number of Mn decreases from +7 in MnO_4^- to +2 in Mn^{2+}.

(ii) Write an ionic equation for the oxidation of oxalate ion to carbon dioxide.

$C_2O_4^{2-} \rightarrow 2CO_2 + 2e$

(iii) Write an overall equation for the reaction between potassium manganate(VII) and iron(II) oxalate.

$5Fe^{2+} + 5C_2O_4^{2-} + 3MnO_4^- + 24H^+ \rightarrow 5Fe^{3+} + 10CO_2 + 3Mn^{2+} + 12H_2O$

(iv) Calculate the concentration of iron(II) oxalate in the original sample.

$5FeC_2O_4 \equiv 3MnO_4^-$

$\eta_{Fe_2C_2O_4}$ in 25.0 cm^3 portion = $\frac{5}{3} \times \frac{20.80}{1000} \times 0.025$ = 8.667×10^{-4} mol

$\eta_{Fe_2C_2O_4}$ in original sample = $\frac{250}{25.0} \times 8.667 \times 10^{-4}$ = 8.667×10^{-3} mol

Original $[Fe_2C_2O_4]$ = $\dfrac{8.667 \times 10^{-3}}{50/1000}$ = **0.173** mol dm^{-3}

(v) State the colour change at the end point of the titration.

Pale yellow to pale pink

[Total:5]

5

(a) Write a balanced ionic equation for the reaction between chlorate(V) ions and hydrogen peroxide.

[1]

$2H^+ + ClO_3^- + e \longrightarrow ClO_2 + H_2O$;

$H_2O_2 \longrightarrow O_2 + 2\,H^+ + 2e$

Overall: $2H^+ + 2\,ClO_3^- + H_2O_2 \longrightarrow 2ClO_2 + O_2 + 2\,H_2O$

(b)

(i) Explain what disproportionation means. [1]

Element undergoes reduction and oxidation at the same time.

(ii) Using the above information, calculate the volume of ClO_2 disproportionated at room temperature and pressure. [2]

$6\,OH^- + 6ClO_2 \longrightarrow Cl^- + 5ClO_3^- + 3\,H_2O$

$Cl^- + Ag^+ \longrightarrow AgCl$

$\eta_{ClO_2} = 6 \times \eta_{Ag^+} = 6 \times 20/1000 \times 0.05 = 6.00 \times 10^{-3}$ mol

Volume of $ClO_2 = 6.00 \times 10^{-3} \times 24.0 =$ **0.144** dm^3

(iii) Write an overall equation for the reaction between potassium manganate(VII) and iron(II) oxalate.

$5Fe^{2+} + 5C_2O_4^{2-} + 3MnO_4^- + 24H^+ \text{ --> } 5Fe^{3+} + 10CO_2 + 3Mn^{2+} + 12H_2O$

(iv) Calculate the concentration of iron(II) oxalate in the original sample.

$5FeC_2O_4 \equiv 3MnO_4^-$

$\eta_{Fe_2C_2O_4}$ in 25.0 cm^3 portion $= \frac{5}{3} \times \frac{20.80}{1000} \times 0.025 = 8.667 \times 10^{-4}$ mol

$\eta_{Fe_2C_2O_4}$ in original sample = $\frac{250}{25.0} \times 8.667 \times 10^{-4}$ = 8.667 x 10^{-3} mol

Original [Fe2C2O4] = $\frac{8.667 \times 10^{-3}}{50/1000}$ = **0.173** mol dm^{-3}

(v) State the colour change at the end point of the titration.

Purple to yellow or purple to colourless

[5]

5

(i) Write the equation for the reaction involved in **Step I**.

$K_2Cr_2O_7$ + 2 HBr −−> 2 $KCrO_3Br$ + H_2O

(ii) Is the reaction in **Step I** a redox one? Give your reasoning.

No, oxidation no. of Cr doesn't change, **remains at +6**

(iii) Using relevant $E^{\ominus}$ data for the reaction in **Step I**, suggest what you might have expected the products to be instead of $KCrO_3Br$.

$E^{\ominus}_{cell}$ = +1.33 – (+1.07) = +0.26 V **> 0**

Products should be **Cr^{3+}(aq) and Br_2(*l*)**

(iv) Suggest a reason why the reaction does not go in the way $E^{\ominus}$ data indicate.

Reaction didn't take place at standard condition.

OR activation energy of this reaction is too high therefore rate is too slow to be observable.

(v) Identify compound **C**.

AgBr

(vi) Explain the type of reaction that occurred in **Step III**.

Cr is **reduced** from +6 (orange solution of $Cr_2O_7^{2-}$) to **+3** in Cr^{3+} (dark green solution)

7

(i) The brown solid **Y** contains 63.8% by mass of manganese and 36.2% by mass oxygen. Using these information, determine the empirical formula of **Y**.

	Mn	O
% by mass	63.8	36.2
relative mole	1.16	2.26
ratio	1	2

empirical Formula: **MnO_2**

(ii) Suggest the identity of **Z** and state the type of reaction that occurs at step **II**. Construct a balanced equation for the reaction.

Identity of **Z**: **MnO_4^-** type of reaction: **disproportionation;**

Equation: **$3MnO_4^{2-} + 2H_2O \dashrightarrow 2MnO_4^- + MnO_2 + 4OH^-$**

8

(i) Calculate the DOC of the sample of pond water, in mg dm^{-3}.

$n(O_2) = \frac{1}{4} n(S_2O_3^{2-}) = \frac{1}{4} (\frac{18.60 \times 0.001}{1000}) = 4.65 \times 10^{-6}$

$[O_2] = (4.65 \times 10^{-6}) \times \frac{1000}{20} = 2.325 \times 10^{-4}$ $moldm^{-3}$

$[O_2] = (2.325 \times 10^{-4}) \times 32000 = 7.44$ $mgdm^{-3}$

(ii) Comment on whether there is enough dissolved oxygen in the pond water for the carps to survive.

The carps will be able to survive as the DOC (7.44 mg dm^{-3}) is higher than the minimum required (5 mg dm^{-3} for fish to survive).

9

$H_2S + \frac{1}{2} O_2 \dashrightarrow H_2O + \frac{1}{8} S_8$

Amt of $H_2S = 1000 \times 10^3 / 34.0 = 2.94 \times 10^4$ mol

Mass of S_8

$= 1/8 \times 2.94 \times 10^4 \times (32.0 \times 8)$

$= 9.41 \times 10^5$ g or 941 kg

Answers: 3) Atomic Structure

MCQ

1	B	5	C	9	C	13	A
2	C	6	B	10	D	14	B
3	C	7	B	11	D	15	D
4	D	8	B	12	D		

Atomic Structure Answer

1 Answer: B

A $_{31}Ga$: Gp 13. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} \mathbf{4s^2 4p^1}$ $_{31}Ga^-$:$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$

↑	↑	

Valence shell: $_{31}Ga$ $\mathbf{4s^2 4p^1}$

$_{31}Ga^-$: $4s^2 4p^2$ 2 unpaired electrons

B $_{34}Se$: Gp 16.

Valence shell: $_{34}Se$ $\mathbf{4s^2 4p^4}$

↑↓	↑↓	↑

$_{34}Se^-$:$4s^2 4p^5$ 1 unpaired electron

C $_{52}Te$: Gp 16.

↑↓	↑	↑

Valence shell: $_{52}Te$ $\mathbf{5s^2 5p^4}$

$_{34}Te^+$:$5s^2 5p^4$ 2 unpaired electrons

D $_{33}As$: Gp 15.

Valence shell: $_{33}As$ $\mathbf{4s^2 4p^3}$

↑	↑	

$_{33}As^+$:$4s^2 4p^2$ 2 unpaired electrons

2 Answer: C

	Atom	Electronic configuration	Unpaired electrons	Paired electrons
A	Boron	$1s^2 2s^2 2p^1$	1	4
B	Carbon	$1s^2 2s^2 2p^2$	2	4
C	Nitrogen	$1s^2 2s^2 2p^3$	3	4
D	oxygen	$1s^2 2s^2 2p^4$	2	6

3 $^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{1}_{1}H + {}^{17}_{8}O$

Answer: C

Follow rule of conservation for sum of nucleons and the sum of protons

4 Answer: D.

A False. All Cr isotopes and ions have the same number of protons.

B False. ^{52}Cr atom: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

$^{52}Cr^{3+}$ ion is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$

C False. Same electronic configurations for $^{52}Cr^{3+}$ ion and $^{53}Cr^{3+}$ ion.

D True. angle of deflection depends on $\frac{Charge}{mass}$ $of\ ion.$
Since $^{50}Cr^{3+}$ ion has a smaller mass, it has a greater angle of deflection than $^{52}Cr^{3+}$ ion in an electric field.

5 Answer: C

A **False.** $2s^2 2p^4$: O
B **False.** $2s^2 2p^6$: Ne
C **True.** $3s^2 3p^4$:S SF_4, SF_6, SO_2, SO_3
D **False.** $3s^2 3p^6$: Ar

6 Answer: B
Largest jump between 4th and 5th ionization energies implies the 5th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 4 valence electrons, hence group 14.

7 Answer: B
Largest jump between 3rd and 4th ionization energies implies the 4th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 3 valence electrons, hence X is group 13, point B in Figure 2.

8 Answer: B
Proton A has a significantly higher Second ionisation energy compared to the rest of the other proton numbers. Hence A must be in Group 1 where the 2nd IE involves removal of electrons from the inner principal quantum shell/electronic shell. Hence proton number B is group 2.

9 Answer: C

Element	Group	valance shell electronic configuration
S	Group 16	$3s^2 3p^4$
P	Group 15	$3s^2 3p^3$

1st IE of S involves the removal of the electron that is paired in the 3p orbital which experiences inter-electronic repulsion, while that of P is an unpaired electron in the 3p orbital. The electronic repulsion offsets the higher nuclear charge of S, then lower effective nuclear charge/ nuclear attraction for the most loosely held electron in S, thus require less energy to be removed.

10 Answer: D
Largest jump between 6h and 7th ionization energies implies the 7th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 6 valence electrons, hence group 16. To be ionic compound, need metal and non-metal (Group 16). Hence Na_2**Z**

11. angle of deflection depends on $\frac{Charge}{mass}$ $of\ ion.$
Cations (positive charge) deflect towards negative place and vice versa for anions. angle for R is comparable to angle S and angle T is twice that of S,

Answer: D

$^{15}O^-$	$^{15}O^+$	$^{14}C^+$	$^{14}N^-$	$^{28}Si^+$	$^{28}Si^{2+}$	$^{28}Si^{4+}$
-1/15	+1/15	+1/14	-1/14	+1/28	+2/28	+4/28
-0.0667	+0.0667	+0.0714	-0.0714	0.0357	0.0714	0.1428

12 Answer: D

For element B, largest jump between 3rd and 4th in ionization energies implies the 4th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 3 valence electrons, hence B is group 13.

Element	A	B	C	D	E
Group	12	13	14	15	16
valance shell electronic configuration	$3s^2$	$3s^23p^1$	$3s^23p^2$	$3s^23p^3$	$3s^23p^4$

1 1st IE of **B** is lower than that of **A**.

Less energy is required to remove the electron in higher energy p subshell for B compared to electron in the lower energy s subshell for A.

2 $\mathbf{C^-}$ has a half–filled *p* subshell. True

3 The compound formed from **D** and **E** is covalent. True. P_2O_5 or P_4O_{10}

13. Answer: A

1 True. Principal quantum shell = 2, $2s^22p^6$. maximum eight electrons.

2 True.

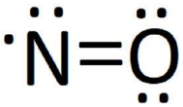
3 True. S orbital is spherical, p orbital is dumb-bell shape.

14. Answer: B

1 False. Cu+ : [Ar] $3d^{10}$, Cu: [Ar] $3d^{10}4s^1$

2 True. $\bullet CH_3$

3 True. A molecule of NO



15. Answer: D

	X	**Y**
Proton number (nuclear charge)	n	n + 1
Charge	+1	+2
No. of electrons	n-1	n-1 (isoelectronic)

1 True. **Y** has a smaller radius than **X**.

Higher nuclear charge for **Y, attracting same no. of electrons.**

2 False.

More energy is required to overcome the stronger nuclear attraction for the most loosely electron in Y as it has a higher nuclear charge.

3 False.
More energy is released when electron is added to Y as there is a stronger nuclear attraction for the incoming electron in Y as it has a higher nuclear charge.

Structured

1(a) $S^{+}(g) \rightarrow S^{2+}(g) + e$

(b)(i) **D**. The sharp drop from **G** to **H** indicates that **G** is Group 1 where its 2nd IE involves the removal of an electron from the inner quantum shell, which is much closer to the nucleus. Hence **D** is in Group 16 and is sulfur.

(ii) The second IE generally increases from **A** to **G** because from **A** to **G**, there is an increase in nuclear charge while shielding effect is almost constant. Hence nuclear attraction for the most loosely held electron increases and more energy is required to remove it.

Second IE of **B** is lower than that of **A** as the electron in $\mathbf{B}^{+}$ is removed from the 3p subshell which is further away from the nucleus than the electron from the 3s subshell in $\mathbf{A}^{+}$. This outweighs the increase in nuclear charge from **A** to **B** to give a lower nuclear attraction for the most loosely held electron in $\mathbf{B}^{+}$.

Second IE of **E** does not increase as much (similar to **D**) as the electron removed from $\mathbf{E}^{+}$ is paired in the 3p orbital and experiences inter-electronic repulsion. This offsets the increase in nuclear charge from **D** to **E** to give similar nuclear attraction for the most loosely held electron, thus they require similar energy to be removed.

2 (i) The 3rd electron from **Z** is removed from an inner principal quantum shell, which is much closer to the nucleus and experienced much weaker shielding effect. The nuclear attraction experienced by the electron is much stronger, more energy is required to remove it and hence higher I.E.

(ii) There are 2 sharp jumps in successive I.E., indicating that there are 3 occupied principal quantum shells.

(iii) Total number of electrons = 12
Electronic configuration = **$\underline{1s^2\ 2s^2\ 2p^6\ 3s^2}$**

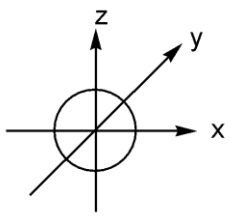
3(a)(i) $Mg^{+}(g) \rightarrow Mg^{2+}(g) + e^{-}$

(ii) The second ionisation involves removal of an electron from the 3p subshell in Si^+, and the 3s subshell from Al^+. Since 3p subshell is further from the nucleus / at a higher energy level than those in the 3s subshell, this outweighs the increase in nuclear charge (from Al to Si) to give weaker nuclear attraction for the electron removed from Si^+ and hence requires less energy to remove.

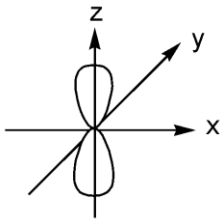
(**b**) Neon, being a gas, is ionised first and emits light. Na, being a solid, takes time to be vaporised before it can be ionised.

OR Neon has a higher first ionisation energy than sodium. The initial power surge when the light is turned on is able to ionise neon, giving rise to the red light, after which the power drops and is only enough to ionise sodium, giving rise to the orange light.

4(a



s (orbital)



p (orbital)

[1] diagram + label

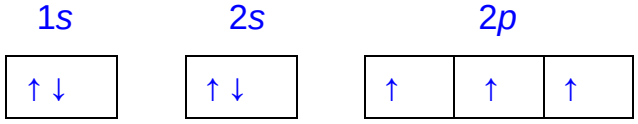
(b) **(i)** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

(ii) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$

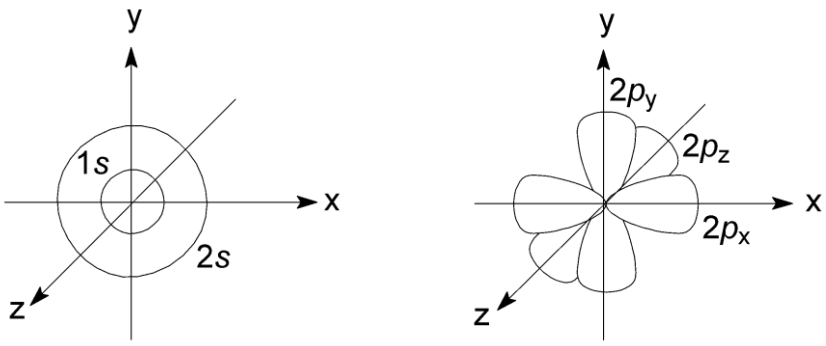
(c) **Mg has a higher nuclear charge than Na.** the **most loosely held electron in Mg** experiences **similar shielding effect by inner shell electrons and distance from the nucleus** as Na. Hence the most loosely held electron in Mg **experiences stronger nuclear attraction**, thus has higher first ionisation energy than that of Na.

The **3p electron to be removed from Al** has at a **higher energy level (further away from nucleus) than the 3s electron** to be removed from Mg. This outweighs higher nuclear charge of Al. Thus the most loosely held electron in Al experiences a weaker nuclear attraction, **less energy is required to remove it** and hence has a lower first ionisation energy of Al than that of Mg.

5 (i)



(ii)



Answers: 4) Physical Periodicity

MCQ

1	**C**	4	**C**	7	**C**	10	**A**
2	**B**	5	**A**	8	**A**	11	**D**
3	**D**	6	**D**	9	**B**		

1 Answer: C

2 Answer B

Refer to Data Booklet for the radii of Period 3 elements/ions

3 Answer D

A The ionic radii of the ions. Not true.

Anions are bigger than the cations in the same period.

B Melting points of the elements.

Melting point increases from Na to Al, peak at Si. Then melting point decreases in order: **S_8 >P_4>Cl_2>Ar**

C First ionisation energy of the elements.

Across the Period, nuclear charge increases (due to increasing number of protons in the nucleus), shielding effect remains relatively constant (due to the same number of inner shell electrons). Thus the most loosely held electron experiences stronger nuclear attraction and more energy is required to remove it, thus 1st IE increases. But there are **two anomalies,** between Group 2 and Group 13 and between Group 14 and group 15.

D Electronegativity of the atoms.

Across the Period, nuclear charge increases, shielding effect remains relatively constant, and hence the nuclear attraction for the shared pair of electrons in the covalent bond increases, resulting in higher electronegativity.

4 Answer C

For X: Largest jump between 5^{h} and 6th ionization energies implies the 6th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 5 valence electrons, hence X is in group 15.
For Y: Largest jump between 7^{h} and 8th ionization energies implies the 8th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 7 valence electrons, hence Y is in group 17.
Hence Statements A, B and D are true. X is a simple covalent molecule. Statement C is false.

5 Answer A

Element	Difference between 1st IE and 2nd IE	Difference between 2nd IE and 3rd IE	Difference between 3rd IE and 4th IE
W	1689	2676	2358
X	1871	2170	3249
Y	4066	2348	2633
Z	713	6282	2810

For Y: Largest jump between 1st and 2nd ionization energies implies the 2nd electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 1 valence electrons, hence Y is in group 1.
Since **W**, **X**, **Y** and **Z** are four consecutive elements, Z is in group 2. W is group 17.

6 Answer D

A The ionic radius of Na^+ ion is greater than that of Cl^- ion.

False. Refer to Data Booklet for ionic radius. Anions are bigger than the cations in the same period.

B The electronegativity of phosphorus is greater than that of nitrogen.

False. Across the Period, nuclear charge increases, shielding effect remains relatively constant, and hence the nuclear attraction for the shared pair of electrons in the covalent bond increases, resulting in higher electronegativity.

C The first ionisation energy of magnesium is less than that of aluminium.

False. The most loosely held electron from Al is in the 3p subshell while that of Mg is in the 3s subshell. 3p subshell is **further away from the nucleus** (and at a higher energy level) than 3s subshell. This **outweighs the increase in nuclear charge** from Mg to Al, resulting in **weaker nuclear attraction**. Hence less energy is required to remove the 3p electron from Al.

D The energy required to remove an electron from F^- is less than that for Ne atom.

F^- and Ne are isoelectronic. F- has a lower nuclear charge than Ne. Since both have same number of electrons, shielding effect remains relatively constant. Hence nuclear attraction for the most loosely held electron is lower in F-, resulting in less energy to remove an electron from F-.

7 Answer C

For Z: Largest jump between 4th and 5th ionization energies implies the 5th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 4 valence electrons, hence Z is in group 14.
Z: $1s^2 2s^2 2p^2$ Z^{2-}: $1s^2 2s^2 2p^4$

8 Answer: A

A Sb, Te Sb: $5s^2\ 5p^3$ Te: : $5s^2\ 5p^4$
There is **inter-electronic repulsion** between the paired electrons in the p subshell in Te, which outweighs the higher nuclear charge of Te, resulting in weaker nuclear attraction. Thus, **less energy is required to remove one of the paired electrons in Te**, compared to the unpaired p electron in Sb. Hence 1st IE for Sb (1st species) is higher.

B Kr, Ar **Kr has one more filled electronic shell** than Ar. Hence the most loosely held electrons in Kr are **further away from the nucleus**, this **outweighs** the higher nuclear charge of Kr. Hence, the most loosely held electron in Kr experiences **weaker nuclear attraction** and less energy is required to remove it, 1st IE of Kr is lower. **2nd species is higher**

C Mg^+, Al^+ Mg^+: [Ar] $3s^1$ Al^+ :[Ar] $3s^2$
Shortcut: Refer to 2nd IE in Data Booklet. Al+ > Mg+
Al^+ has a higher **nuclear charge** while similar **shielding effect as** Mg^+**.** Hence the most loosely held electron in Al^+ experiences **stronger nuclear attraction** and more energy is required to remove it, hence 1st IE of Al^+ is higher**.**
2nd species is higher

D Se, Se^+ Se: $4s^2\ 4p^4$ Se^+: $4s^2\ 4p^3$

Refer to answer for A. in addition, Se and Se+ have the same nuclear charge. More energy is required to remove an electron from a positively charged cation compared to its own atom. **2nd species is higher**

9 Answer B

Square element: Largest jump between 6th and 7th ionization energies implies the 7th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 6 valence electrons, hence group 16. First 4 IE is higher than that of triangle element, hence Period 2 oxygen. [**has one less filled electronic shell**. Hence the most loosely held electrons are **nearer nucleus**, this **outweighs** the lower nuclear charge. Hence, electrons experiences **stronger nuclear attraction** and more energy is required.]

triangle element: Largest jump between 4th and 5th ionization energies implies the 5th electron is removed from an inner principal quantum shell/ electronic shell. Hence there are 4 valence electrons, hence group 14. First 4 IE is lower than that of square element, hence Period 3 Silicon

10 Answer A

1 Atomic radius of Period 2 elements
Across the period, nuclear charge increases, **shielding effect remains relatively constant**. Electrons experience **stronger nuclear attraction** and are pulled closer to the nucleus, hence atomic radius **decreases**.

2 Melting point of Group 1 elements
Mp decreases because of ***weaker metallic bond strength*** between cations and sea of delocalized electrons. [Same no. of electrons donated per cation while charge density of cations decreases due to increase in cation radii.]

3 Electronegativity of Group 17 elements

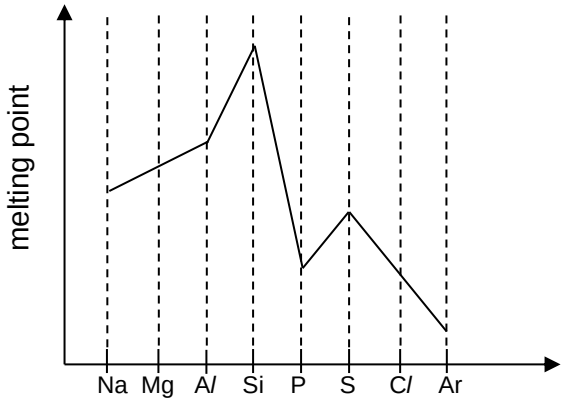
Down the group, **nuclear charge increases**, however, there are **increasing number of filled electronic shells and** the valence electrons are **further away from the nucleus**. This **outweighs** the increase in nuclear charge. Hence, **nuclear attraction** for the shared pairs of electrons in the covalent bond decreases, resulting in lower electronegativity down the group.

11. Answer D

	M	N	
1	S^-	P^-	True. S^-: [Ne] $3s^2 3p^5$ One unpaired electron P^-: [Ne] $3s^2 3p^4$ two unpaired electron Higher nuclear charge for S^-, shielding effect remains relatively constant. Electrons experience stronger nuclear attraction and are pulled closer to the nucleus, hence smaller radii for S^-.
2	Mg	Al	Not true. Mg: [Ne] $3s^2$ zero unpaired e Al: [Ne] $3s^2 3p^1$ One unpaired electron Higher nuclear charge for Al, shielding effect remains relatively constant. Electrons experience stronger nuclear attraction and are pulled closer to the nucleus, hence atomic radius smaller for Al than Mg.
3	Zn^{2+}	Cu^+	Not true. Zn^{2+}: [Ar] $3s^2 3p^6 3d^{10}$ zero unpaired e Cu^+: [Ar] $3s^2 3p^6 3d^{10}$ zero unpaired e

Structured

1 (a)(i) melting point

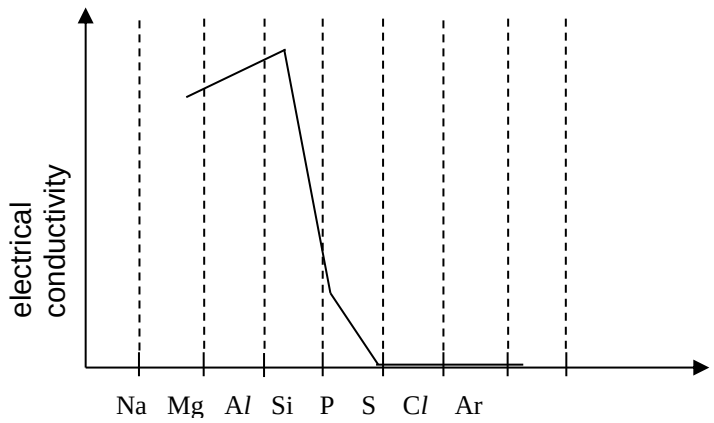


Melting point increases from Na to Al because strength of metallic bonds increases with increasing number of delocalised valence electrons and increasing charge of cations.

Melting point is the highest at Si as Si has a giant covalent lattice structure. Much energy is required to overcome the strong and extensive covalent bonds between Si atoms.

Melting point drops sharply from Si to P as the remaining elements have a simple molecular structures with weak instantaneous dipole-induced dipole (id-id) attraction between molecules. Less energy is needed to break weaker id-id attractions as size of electron cloud decreases from S_8> P_4> Cl_2> Ar, hence the trend of melting point.

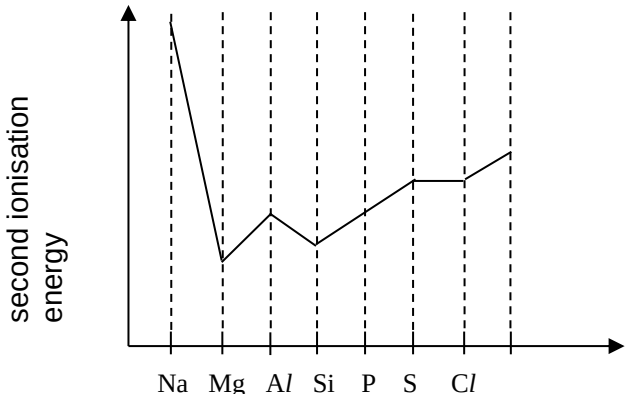
(ii) electrical conductivity



Electrical conductivity increases from sodium to aluminium because number of delocalised electrons (mobile charge carriers) increases.

Electrical conductivity drops sharply from aluminium to silicon because the latter is a metalloid and it has poor electrical conductivity,
Electrical conductivity decreases to zero from phosphorus to argon because they do not have mobile charge carriers. All valance electrons involved in bonding.

(b)(i)



(ii)

The 2nd ionisation energy of aluminium is greater than that of silicon.

Al^+ $1s^2 2s^2 2p^6 3s^2$ Si^+ $1s^2 2s^2 2p^6 3s^2 3p^1$

2nd IE involves removal of 3p electron from Si^+ vs 3s electron from Al^+. The electron in the 3p orbital is at a higher energy level than that of 3s orbital, this outweighs the higher nuclear charge of Si to give a weaker nuclear attraction for the most loosely held electron in Si^+. Hence less energy is required to remove a 3p electron from Si^+.

2 (i) As the electrons are removed, there are fewer number of electrons attracted by the same number of protons (nuclear charge remains constant). The remaining electrons experienced stronger nuclear attraction, hence more energy is required to remove the next electron.

(ii) Mn^{2+}: **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$**

Fe^{2+}: **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$**

(iii) Inter–electronic repulsion between the paired electrons in the 3d orbital in Fe outweighs the higher nuclear charge of Fe to give a weaker nuclear attraction for the most loosely held electron in Fe^{2+}. Hence less energy is required to remove the electron from Fe^{2+}, 3rd IE of Fe is smaller than that of Mn.

Answers: 5) Ideal Gases

1	A	6	C	11	B	16	D	21	B	26	A	31	A
2	A	7	A	12	D	17	B	22	C			32	B
3	D	8	A	13	C	18	D	23	D	28	B	33	C
4	C	9	B	14	C	19	B	24	D	29	B	34	B
5	B	10	A	15	B	20	C	25	D	30	B		

Explanation to MCQs

Question 1

PV = nRT where n (fixed mass of ideal gas) and T are fixed.

Identify what are kept constant in each option, rearrange the variables putting the constants together and identify the variables in the X and Y axis.

Hence PV = constant, should give a horizontal graph when PV is the y axis plotted against either P or Vol on the x axis.

Hence **A is the answer**.

Question 2

PV = nRT where n (fixed mass of ideal gas) and T are fixed.

- Graph A is wrong as PV = constant, should give a horizontal graph when PV is the y axis plotted against either P or V on the x axis.
- Graph C gives the correct relationship where PV shows a constant value on the y axis when plotted against V.
- Graph B is correct:

$$V = nRT\,(1/P)$$
$$Y = m X + c$$

Hence V gives a linear graph with constant gradient of nRT passing through origin as c = 0.

- Graph D is correct because PV is constant, which implies that as P increases, V will decreases by the same proportion, implying that they are inversely proportional to each other.

Option A is the answer.

Question 3

PV = nRT where n (fixed mass of ideal gas) is fixed.

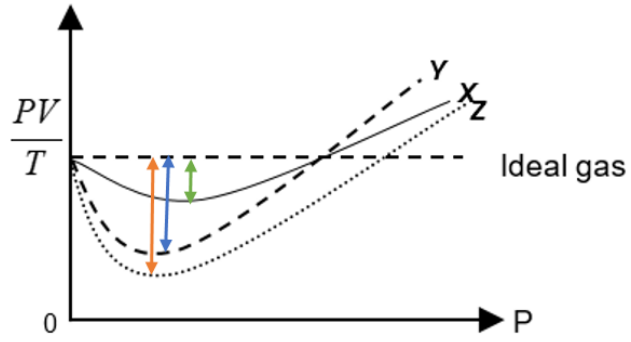
Identify what are kept constant in each option, rearrange the variables putting the constants together and identify the variables in the X and Y axis.

- Graph A is wrong.
  V = (nR/P) T where n and P are fixed.
  Y = m X + c
  Graph A should be a linear graph pass through origin since V ⟨ T with m = (nR/P)
- Graph B is wrong.
  PV = nRT where n and T are fixed.
  Hence P and V is inversely proportional to each other but graph B shows a directly proportional relationship, therefore not correct
- Graph C is wrong.
  PV = nRT where n and T are fixed.
  P = nRT (1/V)
  Y = m X + c
  Graph C should be a linear graph pass through origin since P ⟨ (1/V) with m = (nRT)

- **Graph D is correct.**

Question 4
PV = nRT where n (fixed mass of ideal gas) and T are fixed.
Hence PV should be a constant value at a particular temperature. i.e. horizontal graph when PV plotted against P.
Since $T_1 > T_2$, $PV = nRT_1$ should be larger than $PV = nRT_2$.
Hence **Graph C is the correct answer**

Question 5
Extent of deviation from ideal gas behaviour: Z > Y > X



Extent of deviation depends on the strength of intermolecular force (IMF)
Stronger IMF greater deviation from ideal gas behaviour.

	NH_3	CO_2	N_2	
Mr	17.0	44.0	28.0	

IMF	H -bonding	Instantaneous dipole induced dipole (IDID)	IDID	
IMF strength	1 (strongest)	2	3(weakest)	

Hence **option B is the answer**.

Question 6

Option A: Gas X and gas Y has the same no of moles but temperature of gas Y > temperature of gas X but not doubled. Values of gas X and Y at the y axis should correspond to ideal gas.

PV = nRT

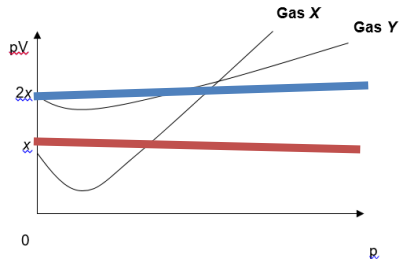
PV values for gas X and gas Y is twice, implying that the T for gas X and Y must be twice.

But (50 + 273) ≠ (25 + 273). Hence option A not correct.

Option B, same temperature but mole of gas X is ½ of mole of gas Y.

This explains why the PV value of gas X is ½ of gas Y.

However, IMF of H_2 weaker than IMF of SO_2 but graph shows that gas X shows greater deviation implying stronger IMF hence gas X cannot be H_2.



Pv should give a constant value for gas X and gas Y if they are ideal gas.

Option C is correct as the mole of gas X is ½ of gas Y and gas X has stronger IMF (IDID + PDPD) than H_2 accounting for greater deviation from ideal gas behaviour for gas X.

Option D is wrong as gas X should have no of moles ½ not twice of gas Y.

Question 7

Total volume after connection = 3 dm^3

After connection, He and Ne are mixed together, both are inert gas, hence no chemical reaction between the two gases.

$P_{He} + P_{Ne} = P_{total}$

At constant temp, for He, $P_1V_1 = P_2V_2$

$2 (1) = P_2 (3)$ Hence $P_2 = P_{He}$ after mixing is 2/3

At constant temp, for Ne, $P_1V_1 = P_2V_2$

2 (1) = P_2 (3) Hence $P_2 = P_{Ne}$ after mixing is 2/3
Hence P_{total} = 2/3 + 2/3 = 4/3 kPa
option A is correct.

Question 8
When the 3 vessels are connected and cooled to room temp, only Ar gas left while iodine fumes and water vapour becomes solid and liquid respectively at room temperature.
For Ar: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$= \frac{101 \times 4}{(150+273)} = \frac{P_2\,(0.09+4+10)}{(20+273)}$
= 19.8 kPa recall that room temperature from Data Booklet is 20 °C.
Hence **option A is the correct answer**.

Question 9
$P_A = \frac{n_a}{n_{total}} P_{total}$
Total mole of gas = 2/ 4 + 32/32.0 = 1.5 mol
P_{He} = 0.5/1.5 x 300 = 100 Pa
Option B is the correct answer.
Question 10
For constant temperature,
$P_{Ne} + P_{He} = P_{total}$ after connection
At constant temp, for He, $P_1V_1 = P_2V_2$
3 (4) = P_2 (3 + V) Hence $P_2 = P_{He}$ after mixing is $\frac{12}{(3+V)}$
At constant temp, for Ne, $P_1V_1 = P_2V_2$
2 (V) = P_2 (3 + V) Hence $P_2 = P_{Ne}$ after mixing is $\frac{2V}{(3+V)}$
$\frac{12}{(3+V)} + \frac{2V}{(3+V)} = 3.5$
12 + 2V = 3.5 (3 + V)
12 + 2V = 10.5 + 3.5V
1.5 = 1.5 V
4V = 1 dm^3
Option A is correct.

Question 11
PV = nRT
n = (7.75 x 10^3 x 1.8 x 10^{-3})/ 8.31 x (273 + 200)
= 3.549 x 10^{-3} (this is the total amt of gas present in the mixture ($GaCl_3$ + Ga_2Cl_6)

$$2GaCl_3 \rightleftharpoons Ga_2Cl_6$$
$$3.745 \times 10^{-3} - 2x \qquad + x$$

Total amt of gas = $3.745 \times 10^{3} - x = 3.549 \times 10^{-3}$
$4x = 1.9595 \times 10^{-4}$

Fraction dimerised = $(1.9595 \times 10^{-4} \times 2)/ 3.745 \times 10^{-3}$
= 0.1046
Option B is the correct answer.

Question 12
$PV = nRT$
$n = (101325 \times 46 \times 10^{-6})/ 8.31 \times (273 + 100)$
$= 1.5037 \times 10^{-3}$ mol.
Molar mass of liq X = $0.16/1.5037 \times 10^{-3} = 106.4$
Option D is the correct answer.

Question 13
$P_{N2} = 150$kPa, hence $P_{O2} = 200 - 150 = 50$kPa.
Under the same temperature in the same vessel, P ⟨ mole
Molar ration of N_2 to O_2 = 150 : 50
= 3:1
Hence **option C is the correct answer**.

Question 14
$PV = nRT$
For fixed vol and mass, V ⟨ T
$V_1/T_1 = V_2/T_2$
$1/293 = 2/T_2$
$T_2 = 2 \times 293 = 586$ K
$T_2 = 313^oC$.
Hence **option C is the correct answer**.

Question 15
P = nRT/V where 2g of H_2 = 1 mole of gas.
For option A:
Same volume, Mole of $H_2 = 0.5$ mole of $D_2 = ¼ = 0.25$,
total mole = 1, hence pressure ¾ of original.

For option B:
Same volume, Mole of H_2 = 0.5 mole of D_2 = 2/4 = 0.5,
Total mole = 1, hence pressure is the same.
For option C:
Mole of H_2 = 0.5 mole of D_2 = 2/4 = 0.5,
total mole = 1, but V is 2x, hence pressure is halved.
For option D:
Mole of H_2 = 1 mole of D_2 = 2/4 = 0.5,
Total mole = 1.5, but V is 2x, hence pressure is ¾ of original.
Option B is correct.

Question 16
P = nRT/V where 3g of H_2 = 1.5 mole of gas.
P = 1.5 (RT/V)
For option A:
Same volume, mole of D_2 = ¾ = 0.75,
total mole ¯1.5, hence pressure ½ of original.

For option B:
Mole of T_3= 5/6 but vol = 1/3 V
P = $\frac{\frac{5}{6}RT\times 3}{V}$ = 2.5 (RT/V)
For option C:
Same vol but Total mole = ¼ + 1/6 = 0.4167 ¯1.5 mole
For option D:
Same volume, total mole = 4/4 + 3/6 = 1.5 mole
pressure = 1.5 (RT/V), same as original.
Hence **option D is the answer**.

Question 17
Notice that “R” is missing from the expression.
For 1 mole of gas under s.t.p., P = 1bar, Vol= 22700cm^3
No need to convert to standard units, just follow the units given in the answer options and the question stem.
PV =nRT
R = (1bar x 22700cm^3)/ 273 K
To determine the no of moles of organic compound
PV = nRT
n = $\frac{pbar\times Vcm^3}{R(TK)}$ where R = (1bar x 22700cm^3)/ 273 K

4n = $\frac{pbar \times V cm^3 \times 273K}{1bar \times 22700 cm^3 (TK)}$

n = $\frac{pV \times 273}{22700(T)}$ mass of org compound = $\frac{pV \times 273}{22700T} \times M$

Density = mass/V = $\frac{p \times 273}{22700T} \times M$

Hence **option B is correct**.

Question 18

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$V_2 = \frac{P_1V_1}{T_1}\frac{T_2}{P_2} = \frac{101325 \ 100}{(20+273)}\frac{(273+6)}{25000}$

= 386 cm^3

Hence **option D is correct**.

Question 19

PV = nRT

n = (3590 x 188 x 10^{-6}) / 8.31 x (273 +25)

= 2.725 x 10^{-4} mol

Molar mass = 0.0145 / 2.725 x 10^{-4}

= 53.2 g mol^{-1} Which corresponds to the Mr of **option B**.

Question 20

V= nRT/P

= (1 x 8.31 x (273 + 27))/ 1.5(101325)

= 0.0164 m^3 = 16.4 dm^3

Gas A behaves more like an ideal gas compared to gas B as the volume of gas A measured closer to predicted by ideal gas eqn.

Hence **option C is the correct option** as intermolecular force of He is more negligible than CO_2 since the M_r of He is 4 while that of CO_2 is 44. Hence IDID between the non-polar CO_2 molecules are stronger and more significant hence will deviate more from ideal gas behavior. That is why gas B has a volume << vol predicted by ideal gas eqn.

Question 21

Option B is the correct answer. Option B implies that there are a lot of spaces between the gas molecules. This allows molecules to move towards each other when the volume of the vessel is reduced.

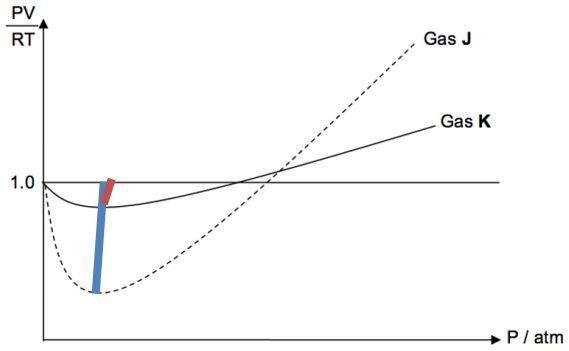
Question 22

A real gas deviate least from ideal gas behavior at high temperature and low pressure. At high temperature, average KE of the gas particles are high, able to overcome the intermolecular forces (IMF) making IMF more negligible, deviate less form ideal gas behavior.
At low pressure, it means that the gas particles are far apart, hence they (i) experience negligible IMF (ii) volume of the gas particles is more negligible to the volume of the vessel.
Hence **option C is the correct answer**.

Question 23
For gases that are more easily liquefy, it means that their intermolecular force (IMF) are stronger.
Option A is wrong. Magnitude of pressure on the wall depends on the KE of the gas particles, not the molecular volume.
Option B is wrong. Under standard temperature and pressure, PV of real gas < PV ideal due to significant IMF.
Option C is wrong. The spread of KE depends on temperature, not on the nature of gas.
Option D is correct. Under the same conditions, gases which are more difficult to liquefy will have weaker and more negligible IMF. Hence deviates from ideal gas behavior less.

Question 24
$PV = nRT$
$PV = (m/M)\ RT$
$P = (m/V)\ RT/M$ where m/V = density (ρ)
$\rho = PM/RT$ where P, M and R are constants.
Hence $\rho = k/T$. ρ is inversely proportional to T.
Hence **correct graph is option D**.

Question 25



Gas K deviates less from ideal gas behavior, hence it could be a gas at higher temperature and of weaker intermolecular force (IMF).
Option A is wrong as Gas J and K are the same gas but J is at higher temperature which should result in smaller not greater deviation from the ideal gas behavior.
Option B and C are wrong because H_2 (M_r = 2) and Ne (M_r = 20.2) have weaker and thus more negligible IMF compared to CO_2 (M_r = 44), this causes gas J to deviate less not more from ideal gas behavior.
Hence **option D is the correct answer**, same gas but gas K which is at higher temperature will have more KE to overcome the IMF making IMF more negligible hence deviate less from ideal gas behavior.

Question 26
Strength of intermolecular force (IMF) :
CH_4 (IDID)< N_2 (IDID) < C_2H_4 (IDID) < NH_3 (hydrogen bonding)
IDID increases with M_r (electron cloud size) N_2 and C_2H_4 has the same M_r but C_2H_4 has greater surface area of contact (more atoms making up one molecule) for more IDID to act on hence stronger IDID.
Since IMF of NH_3 strongest, it deviates most from ideality.
Option **A is the correct answer**.

Question 28
Statement 1 is correct as PV/T = nR, for fixed mass of gas, nR is a constant value, hence pV/T is constant.
Statement 2 is correct.
PV =(m/M) RT
P = (m/V) RT/M where m/V = density (⟩)
⟩ = PM/RT where P, M and R are constants.
Hence ⟩ = k/T. ⟩ is inversely proportional to T.
Statement 3 is incorrect. **Volume is proportional to temp** for a fixed mass of ideal gas under constant pressure. Changing temperature from ^oC to Kelvin, (50 + 273) ≠ 2 x (25 + 273), hence volume of gas is not doubled.

Hence **option B is correct**.

Question 29

Statement 1 is correct as at high pressure, volume of the gas particles becomes significant to the volume of vessel and the IMF becomes significant since the gas molecular are closer to each other. At low temperature, KE of the particles cannot overcome IMF, making IMF more significant hence deviate more from ideal gas behavior.

Statement 2 is correct.

PV =(m/M) RT

P = (m/V) RT/M where m/V = density (⟩)

⟩ = PM/RT where P, M and R are constants.

Hence ⟩ = k/T. ⟩ is inversely proportional to T.

Statement 3 is incorrect. Volume is proportional to temp for a fixed mass of ideal gas under constant pressure. Changing temperature from ^{o}C to Kelvin, (50 + 273) ¯ 2 x (25 + 273), hence volume of gas is not doubled.

Hence **option B is correct**.

Question 30

Statement 1 is correct as an ideal gas can never be liquefy due to the fact that it is has negligible intermolecular force (IMF).

Statement 2 is correct.

PV = nRT where T and n are kept constant. This means that PV = constant value. Hence P must be inversely proportional to V i.e. As P increases, V should decrease by the same proportion to keep PV constant.

Statement 3 is wrong.

Ideal gas should experience negligible intermolecular force.

Option B is correct.

Question 31

Statement 1 is correct. When equal volume of **V** and **W** are mixed together, they are mixed in equimolar ratio, this means that they exert same partial pressure, giving total pressure of 1 bar (100kPa) under s.t.p. conditions.

Hence partial pressure of **V** = partial pressure of **W** = 50kPa.

Statement 2 is correct. Equal volume means **V** and **W** are present in equimolar ratio. Since molar mass of **V** is 4x of **W**, then it is true that mass of 1 dm^3 of **V** is 4x the mass of 1 dm^3 of **W**.

Statement 3 is correct. Since both gases are under the same temperature, the average energy of gas **V** and **W** should be the same.

Option A is correct.

Question 32

When the 2 containers are connected, gas mixture of A and B exerts their own partial pressure.

$P_1V_1 = P_2V_2$ since temp constant and no of moles of **A** and **B** unchanged when containers are connected.

For gas **A**, P_2 = 30/50 x 5atm = 3atm

For gas **B**, P_2 = 20/50 x 15 atm = 6atm

P_{total} = 9atm

Hence statement 1 and 2 are correct.

Option B is correct.

Question 33

Mole of Ne = 20/20 = 1

Mole of He = 20/4 = 5

Statement 1 is wrong as P_{He} should be 1/6 (p)

Statement 2 is correct, sum of partial pressure of each gas in the mixture should add up to total pressure.

Statement 3 is correct, since mole of He is 5x of Ne, P_{He} should be 5x of P_{Ne}.

Option C is correct.

Question 34

A gas deviates from ideal gas behavior when there is significant intermolecular forces and when volume of gas particles becomes significant to the volume of vessel.

Hence statement 1 and 2 explain why real gas deviates from ideal gas behavior.

Option B is correct.

Structured question

1(a)(i) $pV = nRT$

$$P = \frac{nRT}{V} = (0.200+0.800)(8.31)(127+273)/20.0 \times 10^{-3}$$

$$= 166200 = 1.66 \times 10^5 \text{ Pa}$$

(ii) partial pressure of radon $= \frac{0.2}{1.0} \times 166200 = 33240 = 3.32 \times 10^4$ Pa

Partial Pressure of fluorine = 166200 – 33240 = 132960 = 1.33 x 10^5 Pa

(or use partial pressure to find)

(iii)

	Rn	+	F_2	→	RnF_2
initial mol	0.2		0.8		0
final mol	0		0.8 - 0.2 = 0.6		0.2

Total amount of gases = 0.6 + 0.2 = 0.8

$p(20 \times 10^{-3}) = 0.8 \times 8.31 \times 400$

p = 132960Pa or 133000 Pa (to 3 s.f.)

2(a)(i) $V_1/T_1 = V_2/T_2$ $V_2 = 115/298 \times 986 = 380.50\ cm^3$

(ii) pV=nRT, p = 12.5 atm = 1266.25 x 10^3 Pa, V = 380.5 x 10^{-6} m^3

$n = pV/RT = [(1266.25)(380.5) \times 10^{-3}]/[8.314(986)] = 0.05877$ mol

(iii) Final volume is 400 cm^3,

Final $n = pV/RT = 1266.25 \times 400 \times 10^{-3}/(8.314 \times 986) = 0.06179$ mol

Increase in amt of gas, $\Delta n = 0.06179 - 0.05877 = 3.016 \times 10^{-3}$ mol

(iv) $C_8H_{18}(g) + 25/2\ O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g)$

Increase in amt of gas per mol of reaction is 17 – 13.5 = 3.5 mol

Each mol of C_8H_{18} combusted gives 3.5 mol increases in amt of gas.

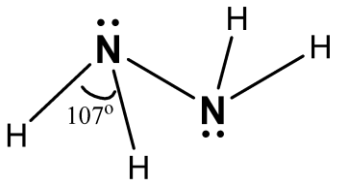
Therefore amt of C_8H_{18} combusted = $3.016 \times 10^{-3}/3.5 = 8.618 \times 10^{-4}$ mol

3(a) pV = nRT

$$pV = \frac{m}{M_r}RT$$

$$\rho = \frac{m}{V} = \frac{pM_r}{RT} = \frac{(1.01\times10^5)(64.1)}{(8.31)(298)}$$ = 2.61x10^{-3} g cm^{-3}

(b) At a higher temperature (50 ^{0}C), SO_2 molecules have greater kinetic energy to overcome the intermolecular force (IMF). Hence, the IMF become less significant, and SO_2 gas behaves more ideally.

4.(a) 

Trigonal pyramidal about each N

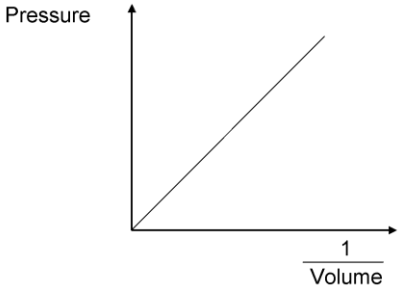
(b)(i) PV = nRT

$1.5 \times 10^5 \times V = 1 \times 8.31 \times 300$

$V = 0.0166\ m^3$ (or $16.6\ dm^3$)

(ii) This is due to the presence of H bonding between the hydrazine molecules**,** the intermolecular forces of attraction becomes significant, causing the gas to occupy a smaller volume than predicted by ideal gas eqn.

(iii) High temperature, low pressure.

(iv) 

5(i) $p = \frac{mRT}{MV}$ **=** $\frac{2.58 \times 10^3 \times 8.31 \times 293}{44.0 \times 5 \times 10^{-3}}$ **= <u>2.86 x 10^7 Pa</u>**

(ii) CO_2 does not behave like an ideal gas at high pressure.

(iii) Mass of CO_2 at saturation level = $\frac{500}{1000} \times 1.5$ = 0.75 g

Mass of CO_2 evolved = = 1.833 g

Total mass dissolved = 0.75 + 1.833 = <u>2.58 g</u>

(iv) No. of bottled cola = $\frac{2.58 \times 10^3}{2.583}$ = 998 mol

6. (a)(i) Nitroglcerine : Gaseous products

4 : 29

4/29 : 1

$(101000)(83 \times 10^{-3}) = n \times 8.31 \times 773$

n = 1.305

$n_{nitroglycerine}$ = 4/29 x 1.305 = 0.1800 mol

Mass of nitroglycerine = 0.1800 x 227 = 40.86 g

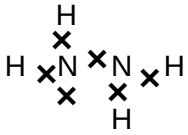
(ii) A large volume of gaseous products formed, resulting in high pressure leading to an explosion

(b) $N_2(g)$, smallest M_r and smallest electron cloud size; intermolecular forces are relatively negligible compared to other gases as it has the weakest instantaneous dipole-induced dipole forces.

(c) $P = 5.82 \times 10^4 / 112 = 519.6 = 520$ kPa

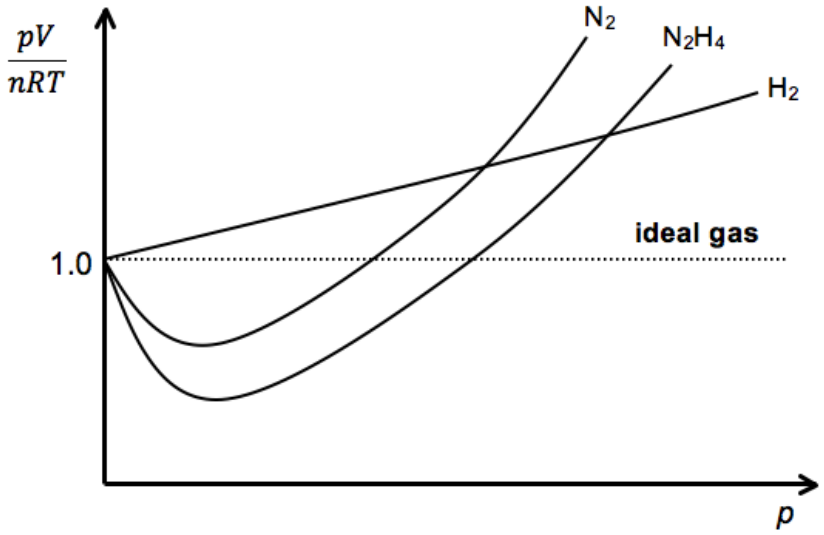
7

(a)

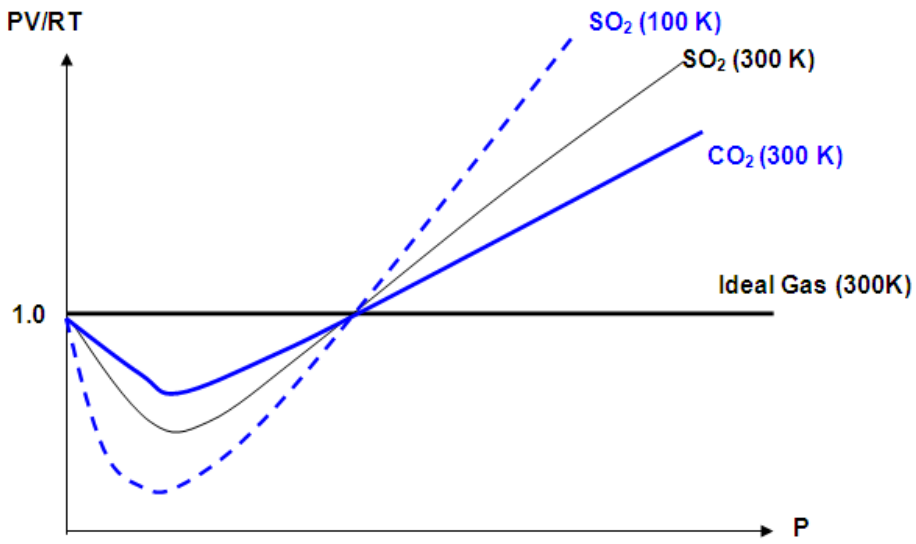


(b) sp^3 ; 107°

(c)



8 (i)



(ii) SO_2 deviates more from ideal gas behaviour because ideal gas behaviour assumes negligible intermolecular forces of attraction.

The permanent dipole-dipole interactions (and id-id) between SO_2 molecules are stronger than the instantaneous dipole-induced dipole (id-id) interactions between CO_2 molecules.
OR SO_2 has a larger M_r and larger electron cloud than CO_2, hence the id-id interactions between SO_2 molecules are stronger than that between CO_2 molecules.

(iii) At lower temperature of 100K, the SO_2 molecules possess less kinetic energy and they move slower.
Thus, intermolecular forces between SO_2 molecules becomes significant.
Hence, greater deviation from ideality.

Answers: 6) Chemical Bonding

1	**A**	**5**	**C**	**9**	**B**	**13**	**A**	**17**	**C**
2	**C**	**6**	**B**	**10**	**B**	**14**	**D**	**18**	**A**
3	**A**	**7**	**A**	**11**	**C**	**15**	**D**	**19**	**A**
4	**D**	**8**	**A**	**12**	**D**	**16**	**C**		

1 Answer: A

Angle E: trigonal planar wrt Carbon. 120^o
Angle F: trigonal pyramidal wrt N (3 bond pairs, 1 lone pair). 107^o

2 Answer: C

A	PH_3	3 bond pairs, 1 lone pair; trigonal pyramidal, 107^o
B	$SiCl_4$	4 bond pairs, 0 lone pair; tetrahedral, 105^o
C	IF_2^-	2 bond pairs, 3 lone pairs; linear, 180^o
D	IF_4^-	4 bond pairs, 1 lone pair; see-saw

3 Answer: A

A	NCl_3 3 bond pairs, 1 lone pair; trigonal pyramidal	$BrCl_3$ 3 bond pairs, 2 lone pairs; T-shaped
B	CO_3^{2-} 3 bond pairs, 0 lone pair; trigonal planar	BBr_3 3 bond pairs, 0 lone pair; trigonal planar
C	$BeCl_2$ 2 bond pairs, 0 lone pair; linear	$BrCl_2^-$ 2 bond pairs, 3 lone pairs; linear
D	SiF_4 4 bond pairs, 0 lone pair; tetrahedral	PF_4^+ 4 bond pairs, 0 lone pair; tetrahedral

4

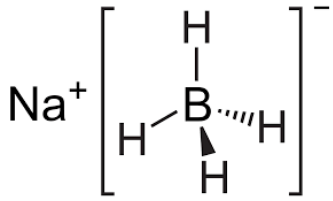
1	XeF_4 4 bond pairs, 2 lone pair; square planar, 90 º (smaller)	SeF_2 2 bond pairs, 2 lone pairs; bent, 105 º
2	CrO_4^{2-} 4 bond pairs, 0 lone pair; tetrahedral,109.5 º	SO_3^{2-} 3 bond pairs, 1 lone pair; trigonal pyramidal, 107º
3	BH_3 3 bond pairs, 0 lone pair; trigonal planar, 120 º	AsH_3 3 bond pairs, 1 lone pair; trigonal pyramidal, 107º

Answer: D

5 Answer: C

A	NCl_3 3 bond pairs, 1 lone pair; trigonal pyramidal, 107º	H_2O 2 bond pairs, 2 lone pairs; bent, 105 º
B	BF_4^- 4 bond pairs, 0 lone pair; tetrahedral,109.5 º	SCl_2 2 bond pairs, 2 lone pairs; bent, 105 º
C	PCl_6^- 6 bond pairs, 0 lone pair; octahedral, 90º	ClO_2^- 2 bond pairs, 2 lone pairs; bent, 105 º **Larger angle**
D	Br_2O 2 bond pairs, 2 lone pairs; bent, 105 º	SF_6 6 bond pairs, 0 lone pair; octahedral, 90º

6 Answer: B



ionic bonding, covalent bonding

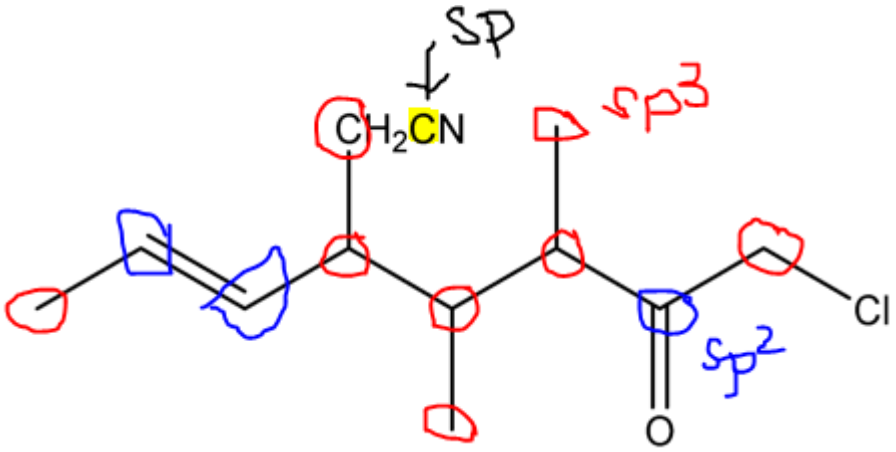
7 Answer: A

A	AlF_3 Ionic bonding between ions in giant ionic lattice	$AlCl_3$ Instantaneous dipole-induced dipole attraction between simple covalent molecules
B	Diamond Covalent bonds between C atoms in a giant covalent lattice structure	SiC Covalent bonds between Si and C atoms in a giant covalent lattice structure
C	MgF_2 Ionic bonding between ions in giant ionic lattice	BaI_2 Ionic bonding between ions in giant ionic lattice
D	PH_3 permanent dipole- permanent dipole attraction between simple covalent molecules	$SiCl_3H$ permanent dipole- permanent dipole attraction between simple covalent molecules

8 Answer: A

A	Al giant metallic lattice structure	SiO_2 Giant molecular structure
B	Al_2O_3 giant ionic lattice structure	$AlCl_3$ simple covalent molecules
C	Si Giant molecular structure	Cl_2 simple covalent molecules
D	Si Giant molecular structure	$SiCl_4$ simple covalent molecules

9 Answer: B



10 Answer: B

11 Answer: C

1	$C_6H_5CH_3$	Non-polar. C-H bonds can be considered non-polar.
2	CH_3OCH_3	Bent wrt O. Dipole moments do not cancel out. Polar
3	SF_4	See-saw. Dipole moments do not cancel out. Polar.

12 Answer: D

A $C_6H_5CH_3$ tetrahedral wrt Carbon in methyl group

B $[CuCl_4]^{2-}$ tetrahedral

C C_6H_{14} tetrahedral wrt to all carbons.

D O_3 bent (hence planar)

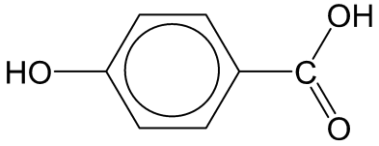
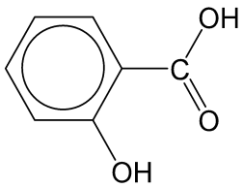
13 Answer: A

A	$C_6H_5CH{=}CH_2$	PCl_3
	Planar	Trigonal pyramidal. Dipole moments do not cancel out. Polar.
B	$C_6H_5CH{=}CH_2$	CCl_4
	Planar	Tetrahedral. Non-polar.
C	CH_3COCH_3	PCl_3
	Non-planar. Tetrahedral wrt C in methyl group	Trigonal pyramidal. Dipole moments do not cancel out. Polar.
D	CH_3COCH_3	CCl_4
	Non-planar. Tetrahedral wrt C in methyl group	Tetrahedral. Non-polar.

14 Answer: D

Oxazolidine has hydrogen bonding between molecules and W does not have hydrogen bonding. W is polar, has permanent dipole-permanent dipole interactions between its molecules.

15 Answer: D

A	$CH_3CH_2OCH_3$ Polar. permanent dipole-permanent dipole interactions	$CH_3CH_2NHCH_3$ Polar. Hydrogen bonding (stronger) => higher melting point
B	$(CH_3)_3CH$ Branched isomer. Same number of electrons.	$CH_3CH_2CH_2CH_3$ Straight chain isomer => higher surface area of contact between molecules → instantaneous dipole-induced dipole more easily induced stronger id-id interactions → higher melting point
C	RbC*l*	KC*l*
	Both are ionic, with same charges for cations and anions. Since Rb+ has a larger ionic radius than K+, and Lattice energy α $\left\|\frac{q_+q_-}{r_+ + r_-}\right\|$, both have same product of charges while interionic distance of RbCl is smaller. Thus magnitude of LE of RbC*l* is smaller. Less energy is required to overcome the weaker ionic bonds in RbCl, lower melting point.	
D		
	intramolecular hydrogen bonding is not possible. forms more extensive intermolecular hydrogen bonding. More energy is required to overcome the stronger intermolecular forces, leading to its higher boiling point.	Forms intramolecular hydrogen bonding due to close proximity of -OH and –COOH groups. Hence less sites available for intermolecular hydrogen bonding.

16 Answer: C

ionic charge: 1+ for Na^+; 2+ for Mg^{2+} 1– for F^- ; 2– for O^{2-}

relative ionic size: Na^+(0.095nm) is larger than Mg^{2+}(0.065nm)
F^- (0.136nm) is smaller than O^{2-} (0.140nm)

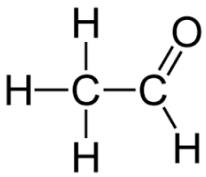
Since Lattice energy α $\left|\frac{q_+q_-}{r_++r_-}\right|$, product of charges of MgO is 4 times that in NaF and the interionic distance of MgO is smaller. Thus magnitude of LE of MgO is larger.

17 Answer: C

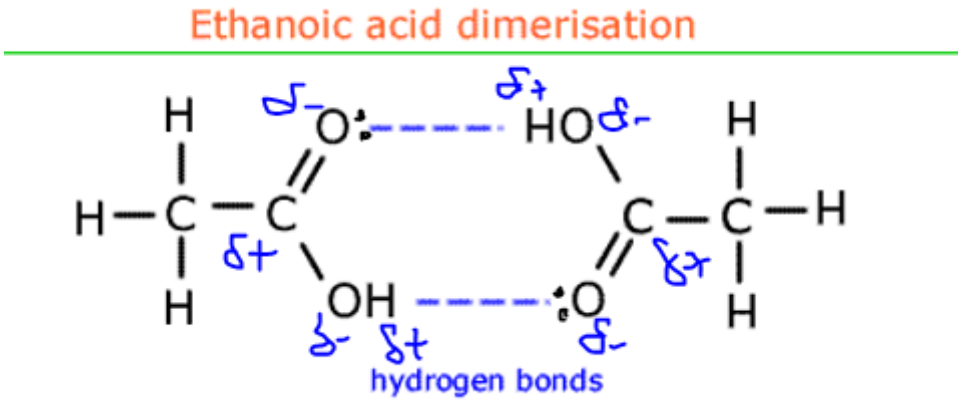
A In ice, each O has a tetrahedral geometry. Hydrogen bonding causes the water molecules to arrange in a regular lattice. In this ordered structure, the water molecules are further apart (i.e. ice has an "open structure") than they are in liquid water. Thus ice has a lower density than water.

B 2-nitrophenol forms intramolecular hydrogen bonding due to close proximity of -OH and $–NO_2$ groups. intramolecular hydrogen bonding is not possible in 4-nitrophenol. Hence less sites available for intermolecular hydrogen bonding in 2-nitrophenol. Less energy is required to overcome the weaker intermolecular forces, leading to its lower boiling point.

C Ethanol (CH_3CHO) and dimethyl ether have no hydrogen bonding.



D



18 Answer: A

1 From Na to Al: Increase in number of electrons donated per atom to form the sea of delocalised electrons. Cationic radii decreases and there are more charges per unit volume. Thus the electrostatic forces of attraction between the cations and the delocalised electrons are stronger, more energy is needed to break the stronger metallic bonds, which accounts for the increasing boiling point.

2 NH_3 has the highest boiling point as more energy is required to overcome the strong hydrogen bonding between the molecules than the weaker id-id interactions in PH_3 and AsH_3.

AsH_3 has more electrons, hence a larger electron cloud, id-id interactions more easily induced. More energy is required to overcome the stronger id-id interactions between AsH_3 molecules than PH_3, hence higher boiling point for AsH_3.

3 AlF_3 has the highest boiling point as more energy is required to overcome the strong ionic bonds between ions than the weaker id-id interactions in PH_3 and AsH_3.

BCl_3 has more electrons, hence a larger electron cloud, id-id interactions more easily induced. More energy is required to overcome the stronger id-id interactions between BCl_3 molecules than BF_3, hence higher boiling point for BCl_3.

19 Answer: A

Lattice energy α $\left|\frac{q_+q_-}{r_++r_-}\right|$,

Solid	Charges	Radius	
MZ	+2, -2	0.15, 0.15	
JX	+1, -1	0.14, 0.14	
LY	+1, -1	0.18, 0.18	

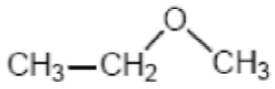
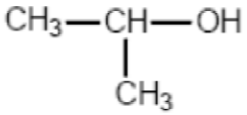
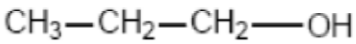
1. True. Since product of charges is the same for JX and LY, while interionic distance of JX is **smaller**. Thus magnitude of LE of JX is larger → stronger ionic bonds → higher melting point.

2. Since product of charges of MZ is **4 times that** in JX, this outweighs the larger interionic distance of MZ. Magnitude of LE of MZ is larger.

3. Hydration energy is dependable on charge density. Given that M^{2+} is doubly charged compared to singly charged J^+, this outweighs the slight larger radii of M^{2+}. M^{2+} has a higher charge density, thus larger magnitude in hydration energy.

Structured

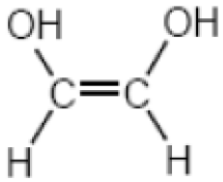
1(a)

X	Y	Z
		

(b)

- More energy is required to overcome the stronger intermolecular forces of attraction (hydrogen bonding) between Compounds **Y** and **Z** respective molecules [1] than the weaker instantaneous dipole – induced dipole forces of attraction between the **X** molecules. [1]
- Compound **Z** is straight chain while compound **Y** is branched. Hence the larger surface area of **Z** allows for stronger instantaneous dipole – induced dipole forces of attraction between its molecules than for Y. Hence **Z** has a higher boiling point than **Y**.

(c)



More extensive hydrogen bonds formed due to the additional –OH group, hence higher b.p.

2 I. Glycine has a much higher melting point than 1-aminobutane because the electrostatic attractions (ionic bonds) in the crystal lattice of the zwitterionic form of glycine is stronger than the intermolecular hydrogen bonding between 1-aminobutane molecules.

II. Propanoic acid has a higher melting point than 1-aminobutane. Both have hydrogen bonds between their molecules and similar Mr (similar strength of instantaneous dipole-induced dipole attraction) However, as oxygen is

more electronegative than nitrogen, the hydrogen bonds between propanoic acid is stronger than those of 1-aminobutane.

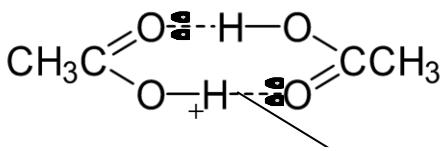
3(a) BF_3 has a simple molecular structure. The BF_3 molecules are held together by instantaneous dipole-induced dipole attraction. Little energy is required to break these weak intermolecular forces. Hence, BF_3 has a low melting point of -144 ^oC.

AlF_3 has a giant ionic structure. The Al^{3+} and F^- ions are held together by strong ionic bonds. A lot of energy is required to break these strong ionic bonds. Hence, AlF_3 has a high melting point of 1219 ^oC.

(b)(i) In water, ethanoic acid molecules form intermolecular hydrogen bonds with water molecules and exist as CH_3CO_2H. Hence its M_r is 60.

In a non-aqueous solvent, ethanoic acid molecules dimerise by forming intermolecular hydrogen bonds. Hence its M_r is twice that of CH_3CO_2H and becomes 120.

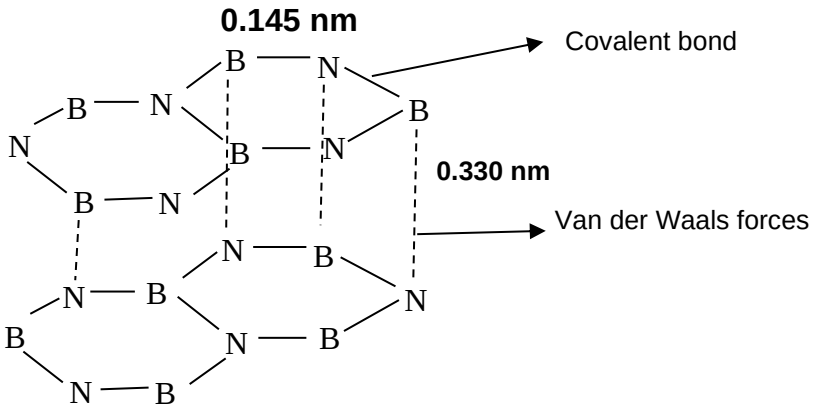
(ii)



Hydrogen bonding

4(a) Boron nitride has a giant covalent structure which consists of alternate B and N atoms held together by strong covalent bonds in an extensive 3-dimensional network where layers are held together by weak instantaneous dipole-induced dipole interactions.

(b)



(c) Absence of delocalised electrons makes boron nitride a poor conductor of electricity.

(d) Machinery lubricant

(e)

Alkali metal halide	Taste	Sum of ionic radii of ions
NaI	Salty	0.098 + 0.219 = 0.317nm
KCl		0.133 + 0.181 = 0.314nm
RbCl	Salty + Bitter	0.148 + 0.181 = 0.329nm
CsCl	Bitter	0.167 + 0.181 = 0.348nm
RbBr		0.148 + 0.196 = 0.344nm
NaBr	**Salty**	0.098 + 0.196 = **0.294nm**
KI	**Bitter**	0.133 + 0.219 = **0.352nm**

By observing the trend, as sum of ionic radii of ions increases, taste becomes more bitter. Hence NaBr has a salty while KI has a bitter taste.

5(i) **X**: Simple molecular structure

Y: Giant metallic structure

Z: Giant ionic structure

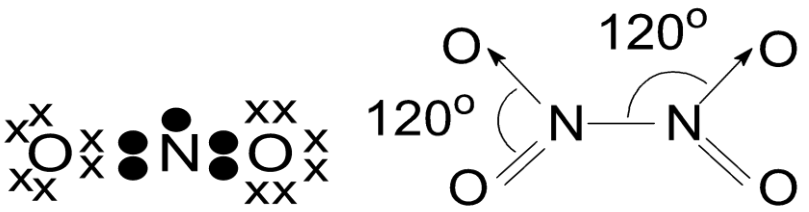
(ii) Good electrical conductivity of **Y**: Solid **Y** is a good conductor of electricity because of the presence of mobile electrons to conduct electricity.

Poor electrical conductivity of **Z**: **Z** is a poor conductor of electricity because ions can only vibrate about fixed positions and are not mobile to conduct electricity in the solid state.

(iii) **X** is soluble in non-polar solvent as favourable solvent-solute interactions are formed.

Z is soluble in water due to the formation of favourable ion-dipole interactions which results in the release of energy that breaks the giant ionic structure for hydration.

6



7(i) Both oxygen atoms have tetrahedral arrangement of its four electron pairs.

The O atom in isolated water molecule has 2 bond pairs and 2 lone pairs, thus it has a bent shape with bond angle 105°.

When water is a ligand, the O atom has 3 bond pairs and 1 lone pair, thus it has a trigonal pyramidal shape with bond angle 107°.

This is because lone pair-lone pair repulsion is greater than bond pair-lone pair repulsion which is greater than bond pair-bond pair repulsion.

(ii) sp^3

8(a) All 3 elements exist as simple molecular structures with instantaneous dipole-induced dipole attractions between molecules.

S_8 has the largest size of electron cloud compared to P_4 and Cl_2, that is easiest to be polarised(or distorted) giving rise to strongest instantaneous dipole-induced dipole attractions, hence largest amount of energy is needed to overcome these attractions.

Therefore, melting point of sulfur is the highest.

Cl_2 has the smallest electron cloud and, giving rise to weakest instantaneous dipole-induced dipole attractions, hence least amount of energy is needed to overcome these attractions.

Therefore, melting point of chlorine is the lowest.

(b) (i) SCl

(ii) Using ideal gas equation, pV = nRT

$$pV = \frac{\text{mass}}{\text{Mr}} RT$$

$$\text{Mr} = \frac{0.100 \times 8.31 \times 500}{100 \times 1000 \times 30.8 \times 10^{-6}} = 135$$

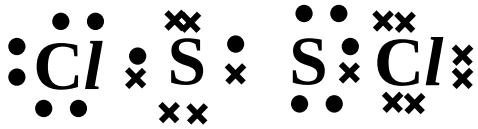
Let the molecular formula of the chloride be $(SiCl)_n$

$n(32.1 + 35.5) = 135$

$n = 2$

Molecular formula of the chloride is S_2Cl_2.

(iii)



Bent wrt to each S atom

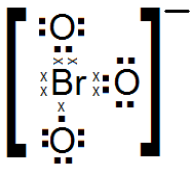
9 (i) $Br_2 + 2e^- \rightarrow 2Br^-$

$12OH^- + Br_2 \rightarrow 2BrO_3^- + 10e^- + 6H_2O$

$3Br_2 + 6OH^- \rightarrow 5\ Br^- + BrO_3^- + 3H_2O$ (overall)

Disproportionation reaction

(ii)



shape: trigonal pyramidal wrt Br

10(a)(i) Th e molecular formulae suggest that the structure of chlorosulfonic acid is derived from that of sulfuric acid, with 1 –OH group being replaced by –Cl.

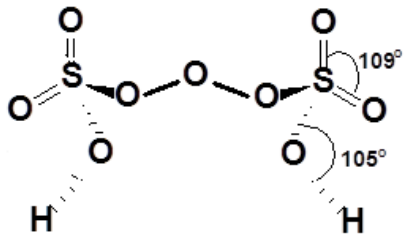
Hence the extent of hydrogen bonding is less between chlorosulfonic acid molecules which explains its lower boiling point.

[2]

(ii) *displayed formula with ALL bonds shown*

bond angle and tetrahedral shape with wedge formula around any one S

bond angle and bent shape around any one O.



(b)(i) Lattice energy is the heat evolved when one mole of an ionic solid is formed from its constituent gaseous ions under standard conditions.

(ii) F^- is a smaller ion.

Both O^{2-} and F^- are isoelectronic ions and hence shielding effect is similar for both ions.

However, F^- has a higher nuclear charge which causes its outermost electrons to experience a stonger nuclear attraction and be pulled closer to the nucleus. [2]

(iii) Lattice energy $\alpha \left|\frac{q_+q_-}{r_+ + r_-}\right|$

However, the higher charge of O^{2-} outweighs its larger ionic size than F^-.

Hence MgO has a stronger lattice energy. Hence MgO should be used as a refractory as it has a higher melting point OR lattice energy.

[2]

(c)(i) As Mg is less electronegative than S, the electronegativity difference between Mg and F is larger compared to that between S and F.

Hence MgF is ionic whereas SF_2 is covalent.

[1]

(ii) MgF_2 has a much higher melting point that SF_2.

OR MgF_2 conducts electricity in the molten state but SF_2 does not conduct electricity in any state.

[1]

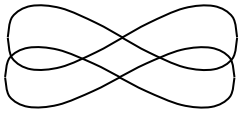
(iii) To form MgF_4, Mg^{2+} has to lose two more electrons from the quantum shell nearer the nucleus which results in a prohibitively high amount of energy required.

This cannot be compensated by the energy evolved from the formation of the ionic lattice of MgF_4.

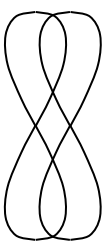
11(a) In H_2S, there are 2 bond pairs and 2 lone pairs of electrons around S. This results in a bent shape with bond angle about 105^o.

In SO_2, there are 2 bond pairs and 1 lone pair of electrons around S. This results in a bent shape with bond angle slightly < 120^o.

(b) **α-bond** is a covalent bond formed when orbitals overlap head-on.



π-bond is a covalent bond formed when orbitals overlap sideways.



(c) CO_2 has a simple molecular structure consisting of molecules held together by instantaneous dipole- induced dipole attraction. SO_2 has a simple molecular structure consisting of molecules held together by permanent dipole-permanent dipole attraction.

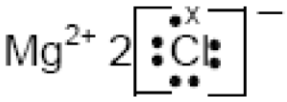
Since instantaneous dipole- induced dipole attraction are weaker than the permanent dipole- permanent dipole attraction, less energy is required to separate the CO_2 molecules.

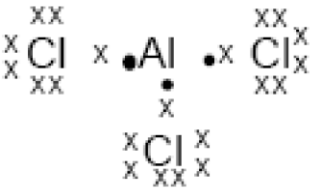
(d)(i) $MgCl_2$ has high melting point which indicates that there is strong electrostatic forces of attraction between the ions in the giant ionic structure.

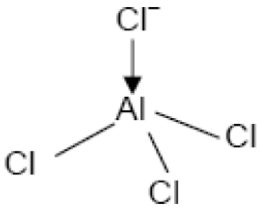
$AlCl_3$ sublimes at a low temperature, which indicates that there are only weak instantaneous dipole-induced dipole interactions between the simple covalent molecules.

Large amount of energy is needed to overcome the strong electrostatic forces of attraction between the ions in $MgCl_2$ compared to the weak instantaneous dipole-induced dipole interactions in $AlCl_3$.

(ii)



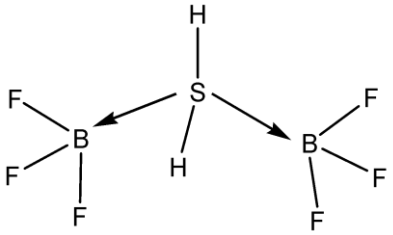




(iii)

Al does not have a full octet structure in $AlCl_3$ so it is able to accept another pair of electrons from Cl^-.

13(i)



Tetrahedral wrt S and B

The lone pairs on S of H_2S are donated into an empty orbital of **B** of BF_3 to form a dative bond. **B** of BF_3 is electron deficient and can achieve a stable octet configuration by forming the dative bond.

(ii) $H_2S(g) + H_2O(l) \rightleftharpoons HS^-(aq) + H_3O^+(aq)$

Note: Yellow universal indicator indicates a weakly acidic solution.

14(a) sp^3; sp

(b)

(c)

$C_2H_2 + NaNH_2 \rightarrow Na^+[C_2H]^- + NH_3$ **OR** $C_2H_2 + 2NaNH_2 \rightarrow Na_2C_2 + 2NH_3$

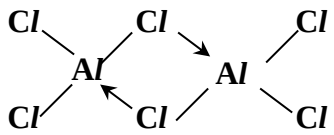
(d) The intermediate contains $[CH_5]^+$ which is unstable due to steric repulsion OR the carbon atom contains 5 covalent bonds(penta-valent).

(e) trigonal planar; 120°; octahedral; 90°

(f) Gas **A** is CH_4 , Positive ion is$(CH_3)_3C^+$

$\mathbf{C}(CH_3)_4 + HF\text{-}SbF_5 \rightarrow [\mathbf{C}(CH_3)_3(CH_4)]^+ [SbF_6]^- \rightarrow [(CH_3)_3C]^+ [SbF_6]^- + CH_4$

15 (a)(i) Tetrahedral wrt Al and bent wrt central Cl



(ii) Let x be the mole fraction of $AlCl_3$. Hence mole fraction of Al_2Cl_6 = 1 – x.

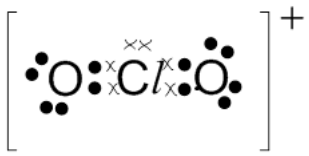
x(133.5) +(1–x)267 = 240

$-133.5x + 267 = 240$

$x = 0.202$, $1 - x = 0.797$

Composition of vapour is 0.202 of $AlCl_3$ and 0.797 of Al_2Cl_6

(b) Formulae of ions: **$[ClO_2]^+$ and $[ClO_4]^-$**



16(a) (i) O^{2-} in K_2O and O_2^{2-} in K_2O_2

(ii) L.E. $\alpha \frac{q^+q^-}{r^+ + r^-}$

Both O^{2-} and O_2^{2-} are **doubly charged / same charge**. Both salts have the same product of charges.

Since O^{2-} is **smaller** in size than O_2^{2-}, the interionic distance for K_2O is smaller. Hence, K_2O has a **larger** magnitude of lattice energy than that of K_2O_2 [or **stronger** ionic bonds / electrostatic forces of attraction in K_2O].

Melting point of K_2O is **higher** than that of K_2O_2.

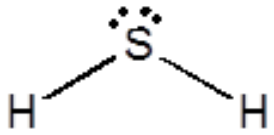
(b)(i) $K_2O_2 + 2H_2O \rightarrow 2KOH + H_2O_2$

(ii) **Little energy** is required to overcome the weak permanent **dipole–dipole interactions** between polar H_2S molecules. Thus, H_2S has a low boiling point.

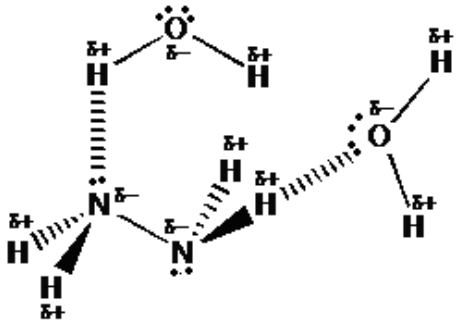
Both N_2H_4 and H_2O_2 molecules are held together by much stronger **hydrogen bonding**.

However, O atom being **more electronegative** than N atom causes O–H bond to be more polar than N–H bond. Thus, hydrogen bonding between H_2O_2 molecules is **stronger** than that between N_2H_4 molecules, leading to a higher boiling point.

(iii)

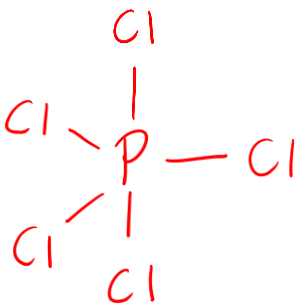


(iv)

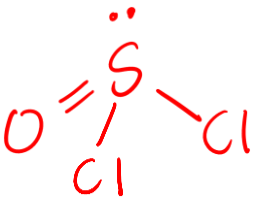


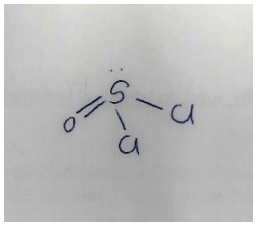
hydrogen bonding

17(a)



Trigonal bipyramidal





Trigonal pyramidal

(b) PCl_5 is **<u>soluble</u>** in tetrachloromethane. The weak instantaneous dipole-induced dipole interactions between PCl_5 molecules are **<u>similar in strength</u>** to the weak instantaneous dipole-induced dipole interactions between tetrachloromethane molecules. Tetrachloromethane can penetrate the PCl_5 crystal and solvate it via **<u>solvation</u>**.

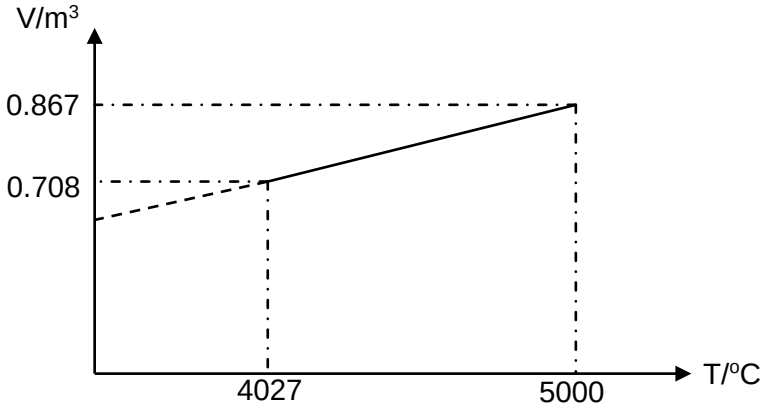
18 **(i)** The valence electron of **C** is in a quantum shell nearer the nucleus than that of Si. Hence the valence electron in **C** experiences a stronger nuclear attraction; more energy is required to remove the electron. Hence, higher 1st IE for carbon.

(ii) V = nRT/P

= 2(8.31)(4027+273)/101000 = 0.708 m^3 (3 s.f.)

(iii) V at (4027 °C) = 0.708 m^3

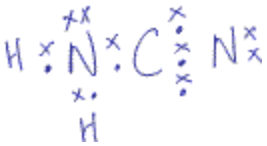
V at (5000°C) = 0.867 m^3

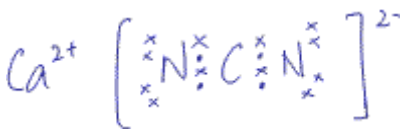


(iv) Less electrons in **C**(g) than in N_2(g)

Weaker intermolecular forces of attraction/ instantaneous dipole-induced dipole attraction in **C**(g).

(b) **(i)**





Shape of cyanamide: Trigonal pyramidal.

(ii) NH_2CN is a simple covalent molecule held by hydrogen bonds/ instantaneous dipole-induced dipole interactions.

CaNCN is a giant ionic lattice structure held by strong electrostatic forces of attraction between the oppositely charged ions.

The melting point of CaNCN is higher than NH_2CN as ionic bonding is stronger than instantaneous dipole-induced dipole interactions, thus more energy is required to break the ionic bonds.

(iii) NH_2CN can form intermolecular hydrogen bonds. Hence, it is expected to be soluble in water.

CaNCN can form ion-dipole interactions with water. Hence, it is expected to be soluble in water.

19(a) Metallic bonding - lattice of positive ions with delocalised electrons surrounding & delocalised. The ions are able to slide across each other without creating unfavourable repulsion forces.

(b) Covalent bonds vs pd-pd interactions**.**

(c) It has a high melting point / does not burn in high heat to produce poisonous fumes.

(d) MgO is brittle, can break easily. Copper tubing is ductile & malleable & resistant to corrosion.

20 (i) Silicon has a giant covalent structure while chlorine has a simple molecular structure.
Melting of silicon requires breaking the numerous strong covalent bonds between the atoms while melting of chlorine requires overcoming the weak instantaneous dipole-induced dipole interactions between the molecules.

Hence, more energy is required for silicon to melt.

(ii) Both aluminium and sodium have giant metallic structures with strong metallic bonds between the cations and delocalised sea of electrons.

Aluminium contributes more electrons to the sea of delocalised electrons for metallic bonding than sodium. Al^{3+} cation has smaller ionic radius, and there are more charges per unit volume. Hence the metallic bonds in aluminium are stronger and more energy is required for the fusion process.

21a)(i) There exists instantaneous dipole-induced dipole interactions between molecules of cyclohexane and hexane. However, shape of cyclohexane molecule allows (chair conformation) **more extensive** instantaneous dipole-induced dipole interactions to exist between them. Therefore, boiling point is higher as more energy is needed to overcome the more extensive instantaneous dipole-induced dipole interactions.

(ii) There exist stronger hydrogen bonding between molecules of ethanol and weaker instantaneous dipole-induced dipole interactions between molecules of hexane. Stronger intermolecular forces of attraction coupled with smaller molecular size of ethanol result in larger number of molecules

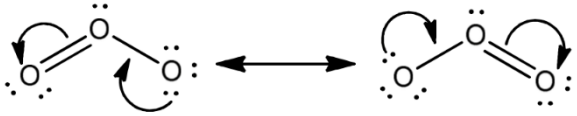
(or larger mass) of ethanol contained per unit volume **,** hence density is larger than hexane.

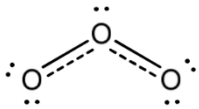
b) (i) instantaneous dipole-induced dipole interactions are formed between molecules of hexane/cylcohexane mixture and the energy given out is used to overcome intermolecular forces of attractions in hexane and cyclohexane that are of **similar strength**.

(ii) Heat will be absorbed. Heat is needed to overcome hydrogen bonding between ethanol molecules and this is not compensated by the heat released between ethanol and hexane interactions of very **dissimilar strength**.

22 H_2S has a simple covalent structure while NiS has a giant ionic lattice structure.
More energy is needed to overcome the stronger electrostatic attraction between oppositely charged Ni^{2+} and $S^{2\bullet}$ ions in NiS than the weak Instantaneous dipole-induced dipole interactions between H_2S molecules.

23 (i) Ozone exists as a resonance hybrid.





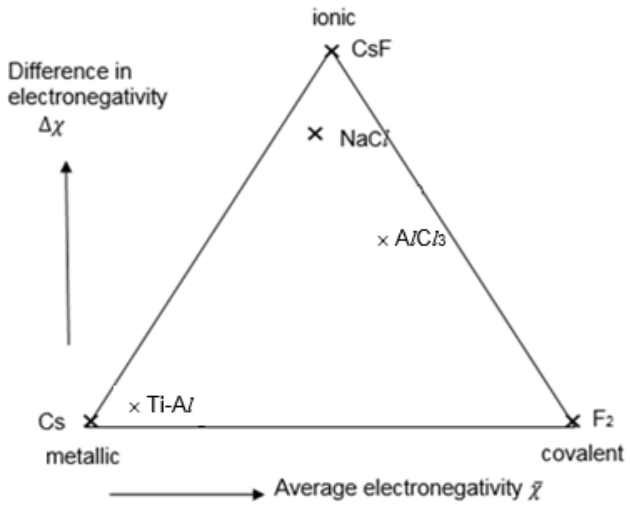
Show electron movement
Show 1.5 bond in ozone structure

(ii) 116 - 118^o

24
(i)

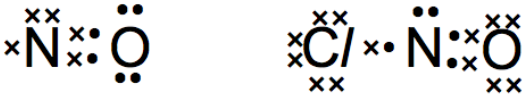
	Type of bonding	Position in the triangle
NaCl	Ionic	any point below CsF
$AlCl_3$	covalent	any point below and to the right of NaCl
Ti-Al alloy	Metallic	any point close to Cs

(ii)



25

(i)



Shape : **bent**
Bond angle : **110° < *x* < 120°**

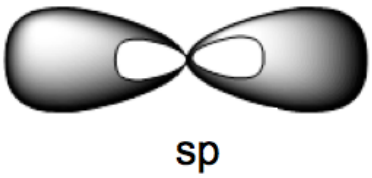
(ii) NO contains a single unpaired electron. Formation of N-C*l* bond allows N to achieve noble gas/ octet configuration drives the formation of C*l*NO.

26 (i) Both copper and calcium have giant metallic structure. In Cu, both the 4s and 3d electrons can be contributed to the sea of delocalised valence electrons as they are very close in energy. The resulting copper ions have a smaller ionic radius than Ca^{2+}. There are more charges per unit volume in Cu. A larger amount of energy is required to overcome the stronger electrostatic attraction between the copper ions and the delocalised electrons compared to that between Ca^{2+} and delocalised electrons.

(ii) Cu conducts electricity in the solid state due to the presence of mobile (delocalised) valence electrons that can migrate freely through the giant metallic structure when a potential difference is applied.

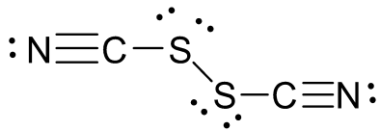
For CuO in solid state, the Cu^{2+} and O^{2-} ions are held in fixed positions in a giant ionic lattice structure and are not mobile.

27 (i)



sp

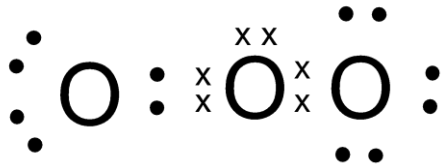
(ii)



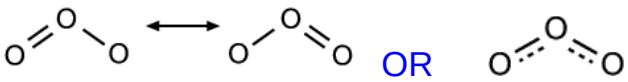
bent shape at sulphur (bond angle of 105º)
linear at CN
Lone pairs on N
Lone pairs on S

(iii) $2NaSCN + Cl_2 \rightarrow (SCN)_2 + 2NaCl$

28 (i)



(ii) O_3 forms resonance structures as shown below.



OR

(dative bonds acceptable)
Thus, the two oxygen-oxygen bonds are equivalent, shorter than oxygen-oxygen single bond in O_2^{2-} and longer than oxygen-oxygen double bond in O_2.

Answers

8) Energetics and Entropy MCQ

1	D	11	C	21	D	31	A	41	D		
2	B	12	B	22	A	32	C	42	C		
3	C	13	C	23	D	33	D	43	A		
4	A	14	D	24	B	34	B				
5	A	15	B	25	B	35	B	45	A		
6	A	16	A	26	B	36	B	46	C	51	A
7	A	17	D	27	A	37	C	47	B	52	C
8	A	18	A	28	C	38	C	48	D	53	A
9	C	19	D	29	C	39	A	49	C		
10	B	20	A	30	B	40	B	50	B		

MCQ

1 Ans: D

$\Delta H_r^{\ominus} = \sum n\, \Delta H_f^{\ominus}$ (products) – $\sum m\, \Delta H_f^{\ominus}$ (reactants)
– 27 = 3(– 394) – 3 (110) – x
x= – 825

2 Ans: B

$\Delta H_{sol}^{\ominus}$ = – L.E. + $\sum \Delta H_{hyd}^{\ominus}$ (ions)
–132 = – (–2526) + x + 2(–384)
x = –1890

3 Ans: c

$C_6H_4(OH)_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g)$ (1)
$H_2O_2(aq) \rightarrow H_2O(l) + ½\ O_2(g)$ (2)
$H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$ (3)

$C_6H_4(OH)_2(aq) + H_2O_2(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(l)$
ΔH_{rxn} = (1) + (2) + (3) = –204

4 Consider the following enthalpy changes for the two reactions of ethyne C_2H_2.

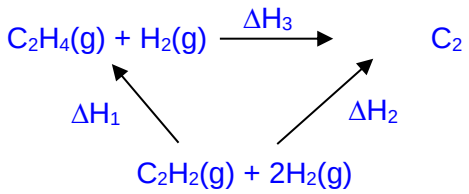
$C_2H_2(g) + H_2(g) \longrightarrow C_2H_4(g)$ ΔH_1

$C_2H_2(g) + 2H_2(g) \longrightarrow C_2H_6(g)$ ΔH_2

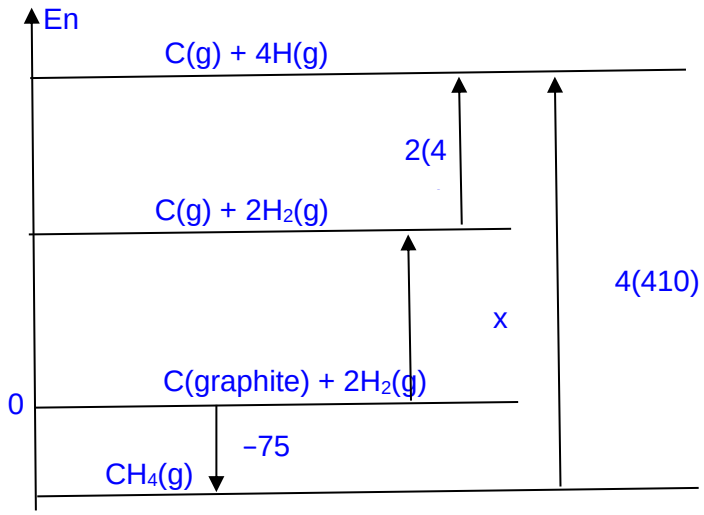
Which of the expressions represents ΔH_3?

$C_2H_4(g) + H_2(g) \longrightarrow C_2H_6(g)$ ΔH_3

A $\Delta H_2 - \Delta H_1$ **B** $\Delta H_1 - \Delta H_2$ **C** $-\Delta H_1 - \Delta H_2$ **D** $\Delta H_1 + \Delta H_2$

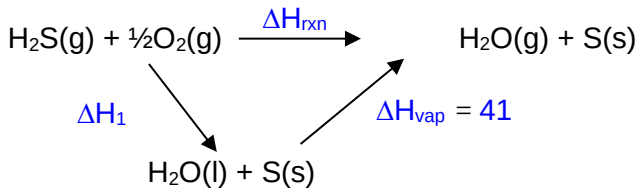


5 Ans: A



x = 4 x 410 – 2(436) –75 = +693

6 Ans: A

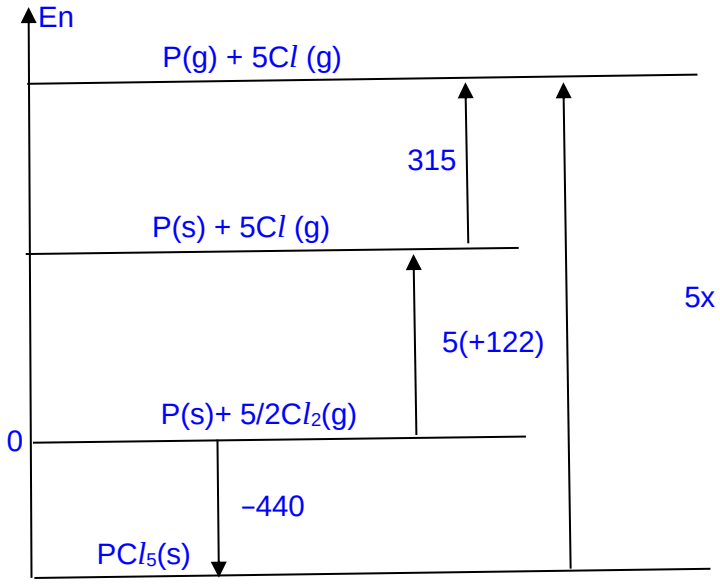


To find ΔH_1, apply $\Delta H_1 = \sum n\ \Delta H_f^{\ominus}$ (products) – $\sum m\ \Delta H_f^{\ominus}$ (reactants)
$\Delta H_1 = -286 + 21 = -265$
$\Delta H_{rxn} = -265 + 41 = -224$

7 Ans: A

$\Delta H_{rxn} = \sum n\ \Delta H_f^{\ominus}$ (products) – $\sum m\ \Delta H_f^{\ominus}$ (reactants)
$\Delta H_{rxn} = 2\ (-271) + (-1434) - (-1220) - (-814) = +58$

8 Ans: A



$5x = 440 + 5(122) + 315$

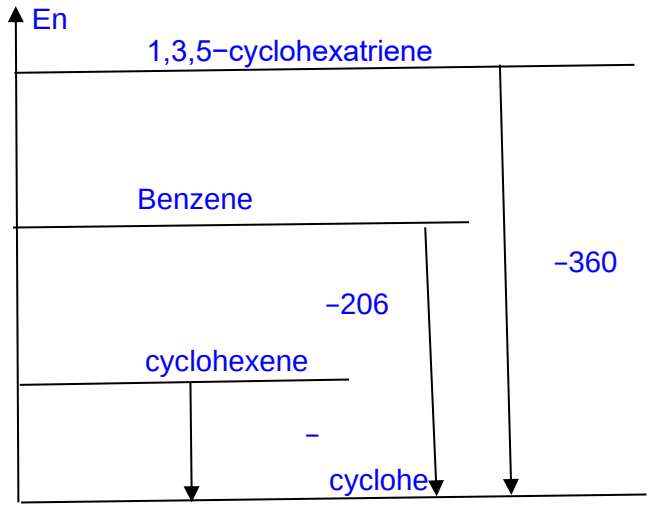
$x = 273$

9 Ans: C

Both reactions represent 2 x $\Delta H_{neutralisation}$ (since 2 mol of water is formed)

Therefore, ΔH_{rxn} = –114

10 Ans: B



11 Ans: C

ΔH_{hyd} is proportional to charge/size. The higher the charge/size, the more exothermic the ΔH_{hyd}.

Species	W^-	X^+	Y^{2+}	Z^{2+}
Charge/size	5.52	5.91	30.8	14.8

12 Ans: B

$\Delta H_{rxn} = \sum n\ \Delta H_f^{\ominus}$ (products) – $\sum m\ \Delta H_f^{\ominus}$ (reactants)
$\Delta H_{rxn} = \Delta H_f^{\ominus} (H_2(g)) + \Delta H_f^{\ominus} (Ca(OH)_2(s)) - 2\ \Delta H_f^{\ominus} (H_2O(l)) - \Delta H_f^{\ominus} (Ca(s))$

$\Delta H_f^{\ominus}$ of all elements in standard states = 0 kJ mol^{-1} => $\Delta H_f^{\ominus} (Ca(s))$, $\Delta H_f^{\ominus} (H_2(g)) = 0$
$\Delta H_f^{\ominus} (H_2O(l)) = \Delta H_{combustion}^{\ominus} (H_2(g))$

Since ΔH_{rxn} is known,
$\Delta H_{rxn} = \Delta H_f^{\ominus} (Ca(OH)_2(s)) - 2\ \Delta H_{combustion}^{\ominus} (H_2(g))$
$\Delta H_f^{\ominus} (Ca(OH)_2(s)) = \Delta H_{rxn} + - 2\ \Delta H_{combustion}^{\ominus} (H_2(g))$

13 Ans: C

$|L.E| \propto \frac{q_+ \times q_-}{r_+ + r_-}$

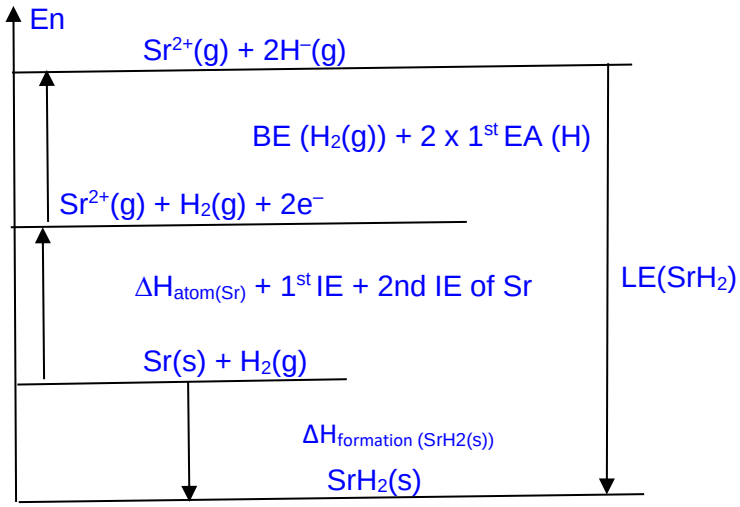
Charge product for all 3 ionic lattice = 1

Interionic distance:

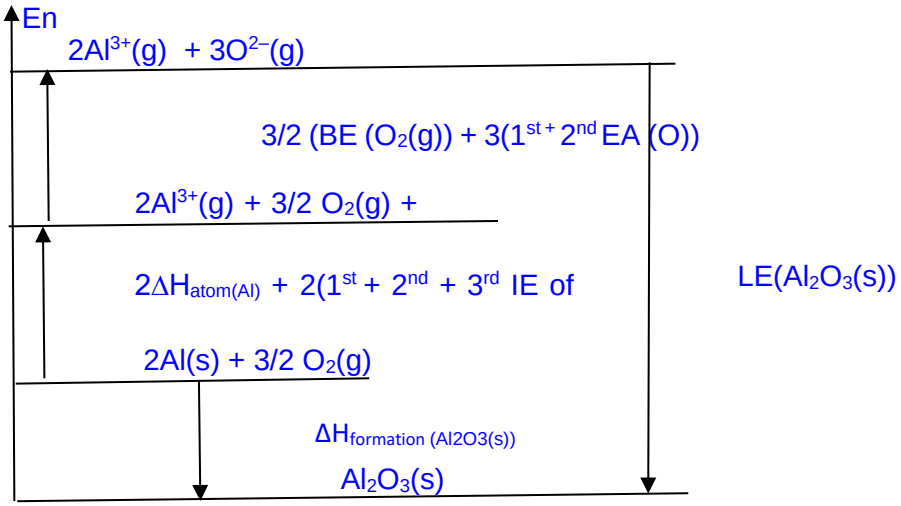
CsCl > CsF > RbF

|-650| < |Lattice energy of CsF| < |-760|

14 Ans: D



15 Ans: B



A: 2 x 5467 = 2x + (2(577+1820+2740)) => x = + 330

B: $2Al^{3+}(g) + 3O^{2-}(g)$ to $2Al(s) + 3/2\ O_2(g)$ = -13625, **Is NOT** enthalpy change of formation of aluminium oxide

C: Can observe that it is wrong from the length of the arrow from the above diagram

D: 3(897) = (3/2(496) + 3y) => y = 649

16 The standard enthalpy changes of formation of HC*l* and HI are –92 kJ mol^{-1} and +26 kJ mol^{-1} respectively.

Which statement is best explains the difference?

A The bond energy of HI is smaller than that of HC*l*.

True: Since formation of HI is endothermic while formation of HCl is exothermic, it mean that HI exist in a higher energy state and is less stable than HCl. This imply that the HI bond is weaker than the HCl bond.

B The bond energy of I_2 is smaller than that of Cl_2. Not inferred from the above.

C Chlorine is more electronegative than iodine. Not inferred from the above.

D The activation energy for the H_2/Cl_2 reaction is much less than that for the H_2/I_2 reaction.

Enthalpy change of reaction did not tell us the size of the activation energy.

17 Ans: D

Reaction is thermodynamically feasible but did not occur => reaction is kinetically not feasible => reaction has high activation energy.

18 Ans: A

Definition of $\Delta H_{formation}$: The heat absorbed or evolved when one mole of a substance is formed from its constituent elements in their standard states at 298 K and 1 bar

B: N_2H_4 is not element in natural state,

C : CO is not element in natural state

D: Sodium is solid, not gaseous in natural state

19 The standard enthalpy of formation, $\Delta H^{\ominus}_f$ for $O_3(g)$ is +142 kJ mol^{-1}.

Which statement about ozone is **incorrect**?

A Decreasing the temperature will increase the amount of O_2 gas in an equilibrium mixture containing only $O_2(g)$ and $O_3(g)$.

System tries to increase the T by favouring the exothermic reaction, thus, reaction shift LHS to partially offset the decrease in T, thus amount of O2 increase

B Decreasing the pressure will increase the amount of O_2 gas in an equilibriu mixture containing only $O_2(g)$ and $O_3(g)$.

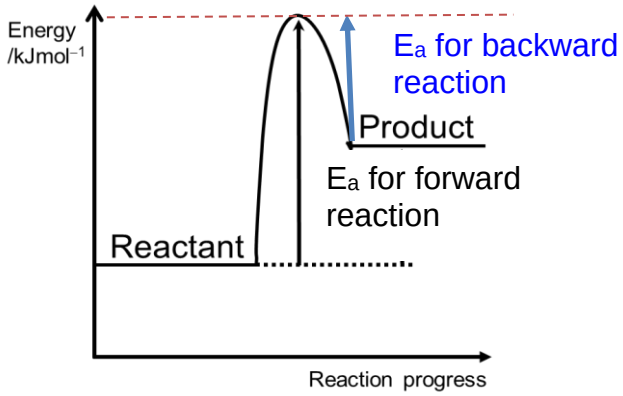
$\frac{3}{2} O_2 (g) \rightleftharpoons O_3 (g)$

System tries to increase pressure by favouring the side with more number of mol of gas molecules => shift LHS => amount of O_2 increase

C O_3 is energetically less stable than oxygen.

$\Delta H^{\ominus}_f$ for $O_3(g)$ is positive => energy level of O3 is higher than that of O_2 => O_3 is energetically less stable.

D The activation energy for converting O_3 to O_2 is higher than that for O_2 to O_3.



20 Ans: A

$\Delta H_c = -\frac{mC\Delta T}{n_{H2O}} = -\frac{30\ (4.2)\ (5)}{(\frac{10}{1000})}$

21 Ans: D

$\Delta H_{sol}^{\ominus}$ = − L.E. + $\sum \Delta H_{hyd}^{\ominus}$ (ions)

= (+918) + (−457) + (−390) = +71 kJ mol^{-1}

$+71000 = \frac{mCT}{n_{LR}} = \frac{250\ (4.2)\ (T)}{(\frac{8.4}{23+19})}$ => T = −13.52°C

ΔT= T_{final} - $T_{initial}$ = $T_{initial}$ = 33.52°C

22 Ans: A

$\Delta H = -\frac{mCT}{n_{LR}}$ => $\Delta H = -\frac{250(4.2)(15)}{0.2} = -78.8$ kJ mol^{-1}

23 Ans: D

$\Delta H = \frac{mCT}{n_{propanol\ burnt}} = \frac{300cT}{m/60} = \frac{300cT(60)}{m}$

% efficiency = $= \frac{Experimental\ \Delta H}{Theoretical\ \Delta H} = \frac{\frac{300cT(60)}{m}}{-2021 \times 1000}$

24 Ans:B

$\Delta H = \frac{mCT}{n_{propanol\ burnt}}$ => $\Delta T = \frac{H \times n_{LR}}{mc}$ = 6.8 °C

From the first experiment to the modified experiment, all variable are kept constant except m doubles,

$\Delta T = \frac{H \times n_{LR}}{2mc} = \frac{1}{2}(6.8)$ = 3.4 °C

25 Ans: B

A: correct, since T increase the avg KE of the molecules and increases way to rearrange the particles and energy

B: Incorrect, since pressure is kept constant

C: increase in number of gas molecules and thus increase in ways to rearrange the particles and energy

D: Same as C

26 Ans: B

$\Delta G^{\ominus}_f = \Delta H^{\ominus}_f - T\Delta S^{\ominus} = (+142.67 \times 1000) - (298)(-68.7) = +163\ kJ\ mol^{-1}$

27 Ans: A

A: Enthalpy change of combustion is always exothermic

B: Enthalpy change of solution can be either exothermic or endothermic

C: Enthalpy change of atomisation is always endothermic

D: Enthalpy change of formation can be either exothermic or endothermic

28 Ans: C

Use of change in number of mol of gas to deduce if reaction has positive or negative ΔS

29 Ans: C

Bonds broken (+)= 5(418)+ 5(x) + 840 + 410×2 = +3750+5x

Bonds formed (−)= −(460×2+ 805×4 + 5×944) = −8860

+3750+5x +−8860 = −1668

x = +686

30 Ans: B

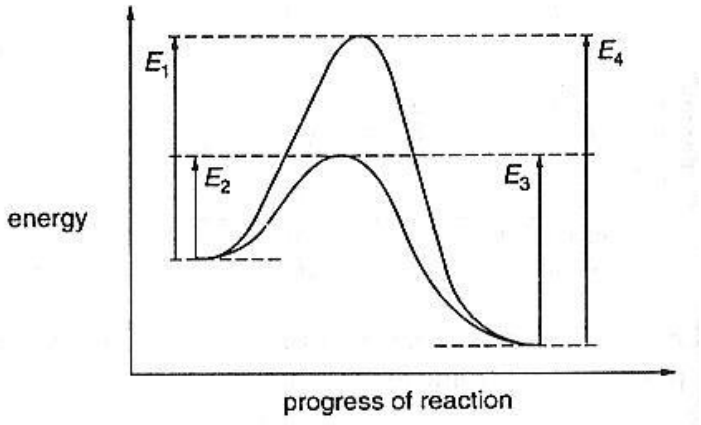
Bonds Broken	Bond Energy	Bonds Formed	Bond Energy
6 C−H		7 C−H	1 x 410
2 C−C		2 C−C	
C = O	740	1 C−O	360
H−H	436	1 O−H	460

Net change in type of bond= 740 + 436 –(410) −360−460= −54

31 Ans: A

Two step: 2 humps (1st step is slow step: bigger first hump- *to learn under reaction kinetics*)
Reaction is exothermic : Z energy level is lower than X

32 The energy diagram represents the reaction occurring with and without a catalyst.



Which of the following statements is correct?

A E_4 is the activation energy for the reverse catalysed reaction.

False:E_4 is the activation energy for the reverse uncatalysed reaction

B The forward reaction, with catalyst, is endothermic.

False: The energy level of the product is lower than the reactant, thus reaction is exothermic

C The enthalpy change of reaction is ($E_2 - E_3$).

Correct.

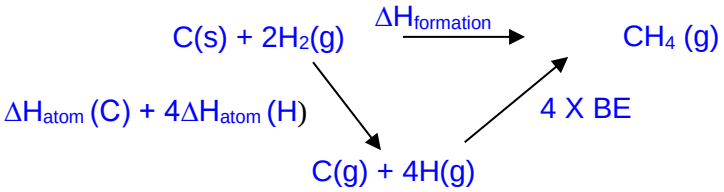
D The enthalpy change of reaction is reduced by using a catalyst.

False: Catalyst does not affect the overall enthalpy of the reaction

33 Ans: D

Hydration energy is for energy released for 1 mol of gaseous ions to be hydrated.

34 Ans: B



35 The enthalpy changes of formation of gaseous ethene and ethane are +52 kJ mol^{-1} and –85 kJ mol^{-1} respectively at 298 K.

Consider the following reaction:

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

Which statement is true?

A $\Delta S_{reaction}$ is positive. False: decrease in no of mol of gas

B The enthalpy change of the reaction is –137 kJ mol^{-1}.

$\Delta H_{rxn} = \sum n\ \Delta H_f^{\ominus}$ (products) – $\sum m\ \Delta H_f^{\ominus}$ (reactants) = (–85–52 = –137)

C If ethene is converted to ethane via four stages instead of one as shown above, the enthalpy change of the reaction will be less exothermic.

False: Hess law states that the overall enthalpy of reaction is unchanged regardless which route the reaction proceeds, so long the starting reactant and the final product is the same.

D The addition of a catalyst will cause the enthalpy change of reaction to be more exothermic.

False: Catalyst does not affect the overall enthalpy of the reaction

36 Ans: B

For phase change, $\Delta G = 0$,
$\Delta H = T\,\Delta S$
$51.6 = (100+273)\,\Delta S$
$\Delta S = 138\ J\ K^{-1}\ mol^{-1}$
54g of H_2O = 3mol of H_2O
$\Delta S = +415\ J\ K^{-1}$

37 Ans: C

$\Delta G = \Delta H - T\Delta S$,
for graph I: since gradient is zero, imply $\Delta S = 0$,
Hence change in no of mol of gas is negligible.
For graph II: reaction becomes less spontaneous at higher T => ΔS = negative
⇨ Decrease in number of mol of gas.

38 Ans: C

$Fe_2O_3(s) + 3/2\ C(s) \rightarrow 2Fe(s) + 3/2\ CO_2(g) \quad \Delta H = +234$ (1)

$2Fe(s) + 3CO_2(g) \rightarrow Fe_2O_3(s) + 3CO(g) \quad \Delta H = +24.8$ (−2)
(1) − (2): $3/2\ C(s) + 3/2\ CO_2(g) \rightarrow 3CO(g) \quad \Delta H = +258.8$ *(3)*
2/3 × (3) = $C(s) + CO_2(g) \rightarrow 2CO(g) \quad \Delta H = 172.5$

39 Ans: A

+ due to increase in amt of gas

40 Ans: B

A 200 K

B 400 K

C 600 K

D Cannot be determined from the above data

Amt of Q = 40/1000 × 1 = 0.04

ΔH = 1600/0.04 = 40 kJ mol^{-1}

For phase change, $\Delta G = 0$,

$\Delta H = T\,\Delta S$ => T = 40000/100 = 400K

41 Ans: D

$\Delta G = \Delta H - T\Delta S$, Since ΔH is positive and ΔS is negative, then $\Delta G > 0$ at all T.

42 Ans: C

For reaction to be thermodynamically feasible at all T, ΔS is positive and ΔH is negative. Reaction C has a positive ΔS due to increase in amount of gas.

43 Ans: A

Total vol = 100cm^3 => Vol of $KMnO_4$ for ΔT_{max} = 30cm^3

$6H^+ + 2MnO_4^- + 5H_2O_2 \rightarrow 2Mn^{2+} + 5O_2 + 8H_2O$

Amt of H_2O_2 = 5/2 Amount of MnO_4^- = 5/2 (0.03 x 0.5) = 0.0375 mol

$[H_2O_2]$ = 0.0375/ 0.07 = 0.536 mol dm^{-3}

$\Delta H = \frac{McT}{n_{H2O2}} = (100)(4.2)(13.5)/\ (0.0375)$ = 151.2 kJ mol^{-1}

45

Ans: A

(1) represents 2 x $\Delta H_f^{\ominus}$ ($NH_3(g)$)

(2) represents $\Delta H_f^{\ominus}$ ($H_2O(l)$)

ΔH_{rxn} = $\sum n\ \Delta H_f^{\ominus}$ (products) – $\sum m\ \Delta H_f^{\ominus}$ (reactants)

(3) : $-906 = 4x + 6(-242) - 2(-93)$ => $x = +90$

46 Ans: C

$\Delta H_3 = +1235 - 1368 = -133$

Amount of H_2O in 108g = 108/18 = 6 mol

For 6 $H_2O(l) \rightarrow 6\ H_2O(g)$, $\Delta H = +266$

$\Delta G = \Delta H - T\Delta S$, for phase change, $\Delta H = T\Delta S$

$+266000 = 373\Delta S$ => $\Delta S = +713\ J\ K^{-1}$

47 *Ans: B*

$q = mc\Delta T$

$q = (100)(4.18)(33) = 13800\ J$

48 Ans: B

1 **R** is equal to the 1st IE of Mg.

True: 1st IE is for X (g) □ X^+ (g) + e^-

2 magnitude of (**Q** - **S** – **R**) is greater than that of **P**.

$Mg^{2+}(g) + e \longrightarrow Mg^+(g)$ $\Delta H = -\mathbf{S}$
$Mg^+(g) + e \longrightarrow Mg(g)$ $\Delta H = -\mathbf{R}$
$Mg(s) \longrightarrow Mg^{2+}(g) + 2e$ $\Delta H = \mathbf{Q}$
Therefore, ΔH = **Q** - **S** – **R is for reaction** $Mg(s) \longrightarrow Mg(g)$, which has the same magnitude as **P**.

3 **T** is not equal to the sum of **R** and **S**.

$\Delta H = R + S$ is for $Mg(g) \longrightarrow Mg^{2+}(g) + 2e$ which has the $\Delta H = T$ too.

49 Ans: C

1 The C-H bond dissociation energy is 60 kJ mol^{-1}.

False: −120 kJ is for not just for forming 2 C-H bond, but for breaking a C−C pi bond and a H−H sigma bond too, so the C-H bond dissociation energy cannot be just half of the value.

2 Penta-1,4-diene has an enthalpy change of hydrogenation of −240 kJ mol^{-1}.

True: since hydrogenation of 1 C=C pi bond is −120 kJ mol^{-1} , hydrogenation of 2 C=C pi bonds is −240 kJ mol^{-1}

3 Ethene has a higher energy content than ethane.

True: Since $\Delta H_{hydrogenation}$ from ethane to ethane is a negative value, it suggests that ethene exist at a higher energy level.

50 Ans: B

1 The activation energy of the backward reaction is $x + y$.

True: it is the size of the hump from N to (L + M)

2 The backward reaction is endothermic.

True: Since (L + M) exist at a higher energy level than N.

3 The magnitude of the enthalpy change of the backward reaction is $x – y$.

False: it is equal to +y

51 Ans: A

1 The bond energy of the carbon–carbon bonds in graphite is greater than that in diamond.

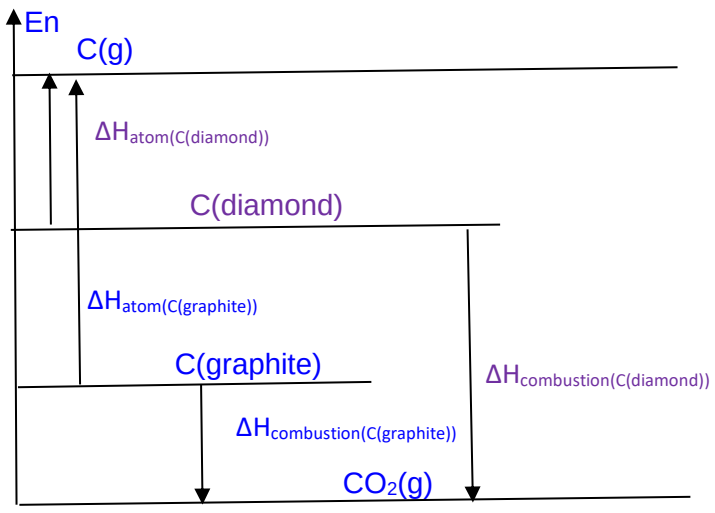
$\Delta H = (\Delta G + T\Delta S) = +2100$ kJ mol^{-1} , it means that graphite is at a lower energy level than diamond, and it is more stable (carbon-carbon bond in graphite is stronger)

2 The enthalpy change of atomisation of diamond is less positive than that of graphite.

See below (compare length of ΔH_{atom} for both graphite and diamond)

3 The enthalpy change of combustion of diamond is more negative than that of graphite.

See below (compare length of $\Delta H_{combustion}$ for both graphite and diamond)



52 Ans: C

1: vaporisation (bond breaking) 2: ΔH_{hyd}: forming ion-dipole interaction

3: electron affinity (forming bonds between atom and electron)

53 Ans: A

1: (− 1st IE). For 1st IE, Mg has a higher first IE than Ca since the most loosely held electrons are in an electron shell closer to the nucleus. Thus, the (− 1st IE) for Mg^{2+} is more exothermic as well.

2: |L.E| $\propto \frac{q_+ \times q_-}{r_+ + r_-}$

Since charge product is the same but interionic distance for magnesium oxide is shorter, the formation of ionic oxide lattice has higher |LE|

3. hydration of gaseous ions is formation of ion-dipole interaction, which is depdendent on charge/size of the ions. The higher the charge/size, the more exothermic the enthalpy change of hydration.

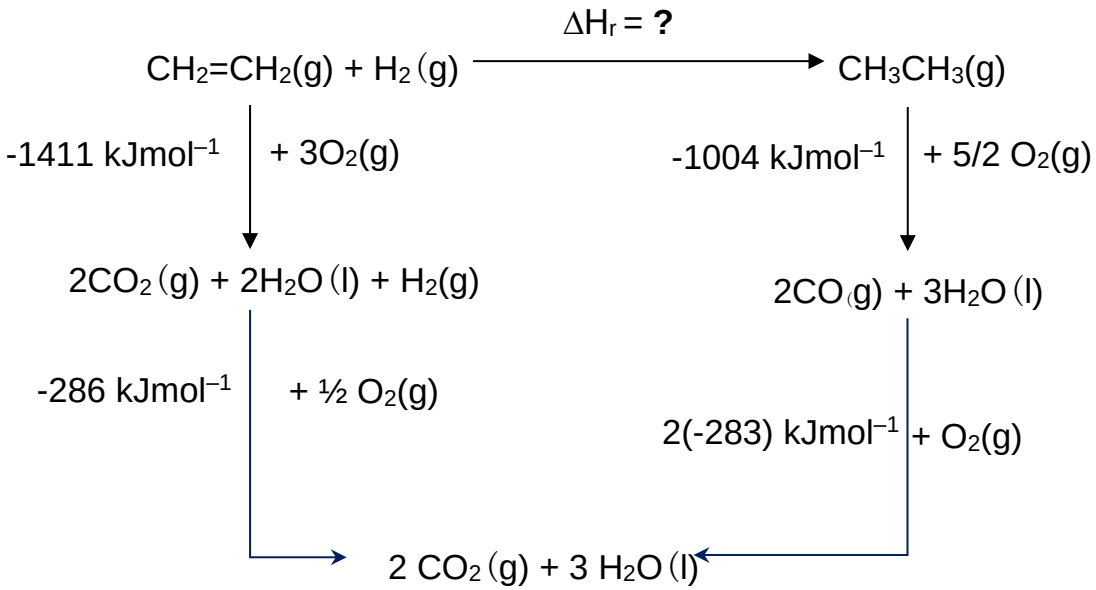
Structured and Essay:

1 (i) balanced equation: $C_2H_6(g) + 5/2\ O_2(g) \longrightarrow 2CO(g) + 3H_2O(l)$

Thermochemical equation:

$C_2H_6(g) + 5/2\ O_2(g) \longrightarrow 2CO(g) + 3H_2O(l)\ \Delta H_c = -1004\ kJ\ mol^{-1}$

(ii)



By Hess' Law,

ΔH_r = –1411 – 286 – 2(–283) –1004 = –127 kJ mol^{-1}

(i) Lattice energy of $MgCl_2$ is the heat evolved when one mole of ionic solid $MgCl_2$ is formed from gaseous Mg^{2+} and Cl^- ions.

$$Mg^{2+}(g) + 2Cl^-(g) \rightarrow MgCl_2(s) \quad L.E. < 0$$

(ii) By Hess' Law,

L.E. = –641 – [+147 + 244 +736+1450 + 2(–364)] = – 2490 kJ mol^{-1}

(iii) Magnitude of lattice energy of $BaCl_2$ < $MgCl_2$.

Product of charges are the same for both.

Ionic radius of Ba^{2+} > Mg^{2+}

Since LE $\langle \frac{q^+q^-}{r_+ + r_-}$, Ba^{2+} has a larger ionic radius than Mg^{2+}.

Hence inter-ionic distance in $BaCl_2$ is larger, leading to weaker electrostatic forces of attraction between Ba^{2+} and Cl^- ions.

$BaCl_2$ has less exothermic lattice energy.

(iv) $\Delta H^e_{rxn} = \sum m\Delta H^e_f$**(products)** $- \sum n\Delta H^e_f$**(reactants)**

- Applicable only when the **enthalpy changes of *formation*** of compounds are given.

- ΔH_f of an element is zero.

$\otimes H_{reaction}$ = –641–2(–125) = – 391 kJ mol^{-1}

Reaction is exothermic; $MgCl_2$(s) is more stable than MgCl(s).

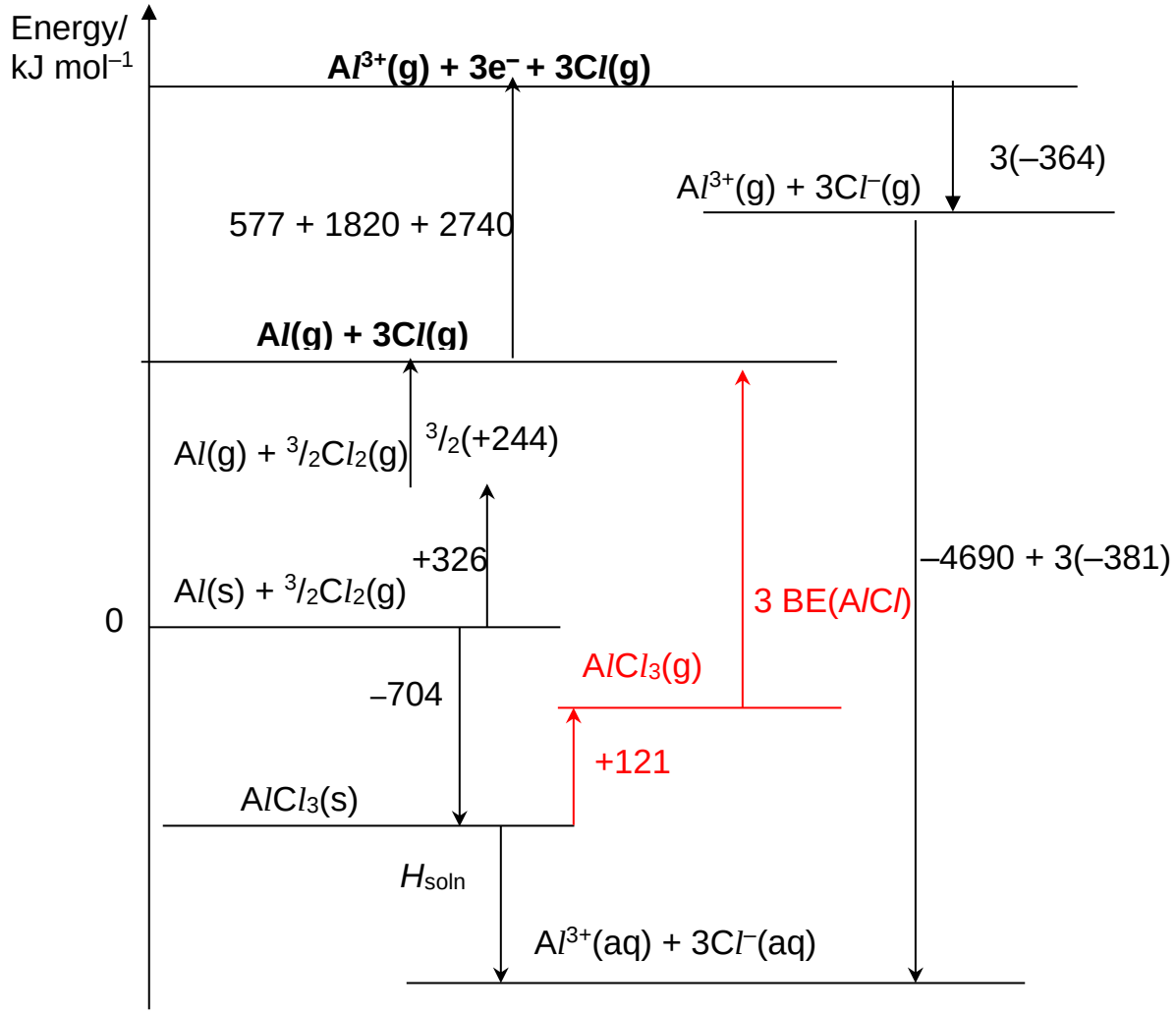
3 (a) $\otimes H_{hyd} \propto \frac{q^+}{r_+}$

Since Cr^{3+} has a larger ionic radius than Al^{3+} , Cr^{3+} has a smaller charge /size ratio than Al^{3+}.

Cr^{3+} forms weaker ion–dipole interactions with water molecules

Hydration of Cr^{3+} is less exothermic. / $\otimes H_{hyd}$ of Cr^{3+} has a smaller magnitude.

b (i)



By Hess' Law,

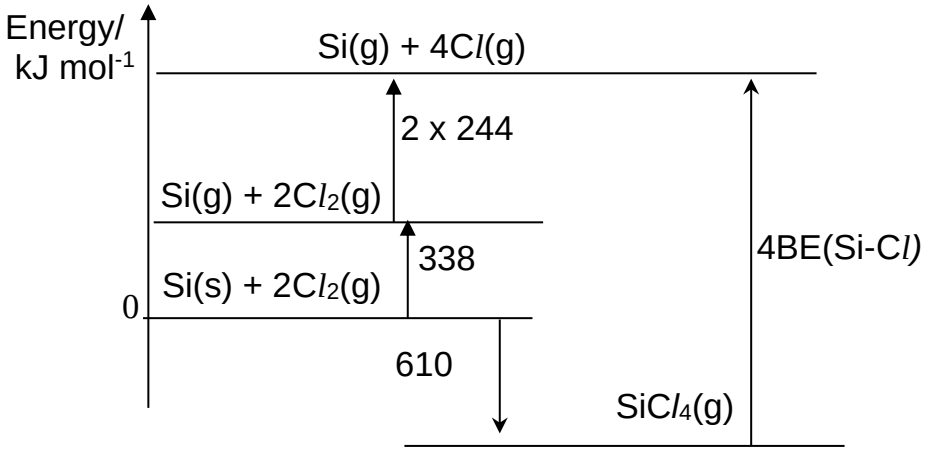
ΔH_{sol} = –(–704) + 326 + $^3/_2$(244) + 577 + 1820 + 2740 + 3(–364) – 4690 + 3(–381)

= –392 kJ mol^{-1}

(i) By Hess' Law, +121 + 3BE(Al–Cl) = –(–704) + 326

⇒ BE(Al–Cl) = <u>+425</u> kJ mol^{-1}

4(a)



By Hess' Law,

$4BE(Si\text{-}Cl) = -(-610) + (338) + 2(244)$

$BE(Si\text{-}Cl) = +359 \text{ kJ mol}^{-1}$

(b)(i) Energy required, $mc\Delta T = 125 \times 4.20 \times (75 - 15) = 3.15 \times 10^4$ J

Since the process is only 80% efficient,

energy from burning 1.50 g of cyclohexene $= 3.15 \times 10^4 \times \frac{100}{80}$

$= 3.94 \times 10^4$ J

Amt of cyclohexene used $= \frac{1.50}{82.0} = 0.0183$ mol

Enthalpy change of combustion of cyclohexene $= -\frac{3.94 \times 10^4}{0.0183} = -2150$ kJ mol^{-1}

(ii) Heat loss to surroundings / heat evolved to heat the container / Heat absorbed by container.

(c) Volume of air in the room = 5 x 5 x 3 = 75 m^3

600 ppm of CO_2 = 600 m^3 of CO_2 in 10^6 m^3 of air

Volume of CO_2 needed $= \frac{75 \times 600}{1 \times 10^6} = 0.45$ m^3 or 45 dm^3

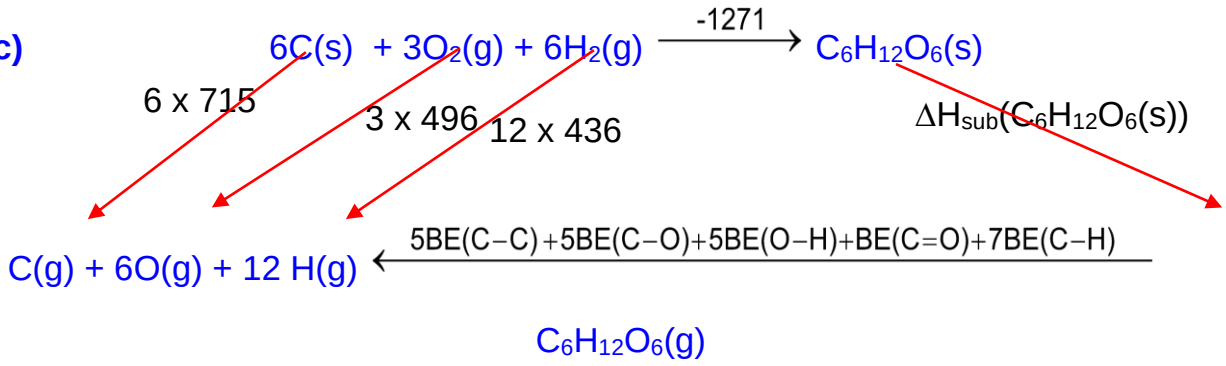
Amount of CO_2 required to reach the limit $= \frac{45}{24} =$ **1.88** mol

5(a) $6C(s) + 3O_2(g) + 6H_2(g) \rightarrow C_6H_{12}O_6(s)$ $\Delta H_f = -1271$ kJ mol^{-1}

(b) $\Delta H_1 = \sum\Delta H_{f(}$products) – $\sum\Delta H_{f(}$reactants)

$= -1085 + 2 \times -286 - (-1271) = -386$ kJ mol ^{1}

(c)

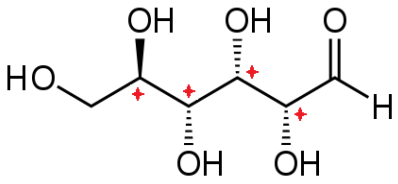


By Hess' law,

$-1271 + \Delta H_{sub}(C_6H_{12}O_6) + 5\,(350 + 360 + 460) + 8 \times 740 = 6 \times 715 + 12 \times 436 + 3 \times 496$

$\Delta H_{sub}(C_6H_{12}O_6) =$ **+205** kJ mol^{-1}

(d)



has 4 chiral carbons; no. of isomers = $\mathbf{2^4 = 16}$

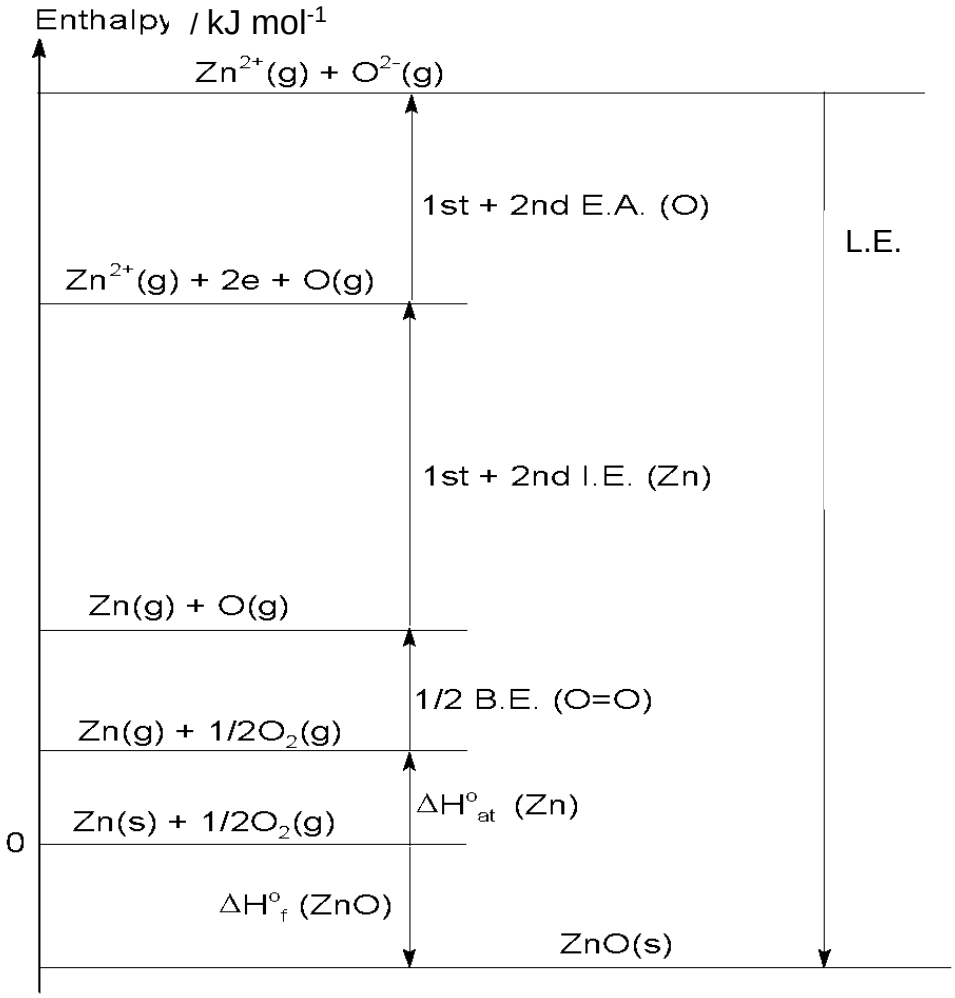
6(a)(i) At 298 K, $\Delta G^{\theta} = \Delta H^{\theta} - T\Delta S^{\theta}$

$= +71 - 298(174/1000) = +19.1 > 0$

The reaction is not energetically feasible is the ΔG^{θ} is positive.

(ii) Yes. Since $\Delta S > 0$ and $\Delta H > 0$, for reaction to be feasible, $\Delta G < 0$, this can only occur at a higher temperature.

(b)



By Hess Law,

L.E.(ZnO) = –657 – 908 – 1730 – ½(496) - 130 +(-348) = **–4021** kJ mol^{-1}

7 (a)(i) Heat evolved = $200 \times 4.18 \times 46.9 \times \frac{100}{80}$ = 49000 J or 49.0 kJ

Amount of cyclobutane used = $\frac{1.00}{12.0 \times 4 + 1.0 \times 8}$ = 0.0179 mol

$\otimes H_c$(cyclobutane) = $-\frac{49.0}{0.0179}$ = –2740 kJ mol^{-1}

(ii) ΔH_r = ΔH_c(cyclobutane) – $2\Delta H_c(CH_2{=}CH_2)$

= –2740 – 2(−1422) = **+104** kJ mol^{-1}

(b)(i) The heat **evolved** when one mole of ethanol is formed from its constituent elements in their standard states at 298 K and 1 bar.

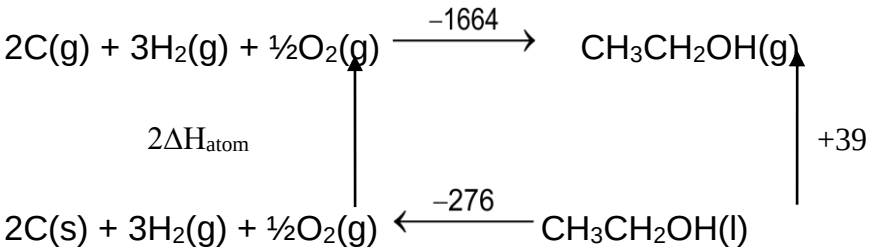
$2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow CH_3CH_2OH(l)$ ΔH_f = –276 kJ mol^{-1}

(ii) ΔH = ***∑mBE(bonds broken) – ∑nBE(bonds formed)***

= 3(436) + ½(496) – (350 + 5 x 410 + 360 + 460)

= **–1664** kJ mol^{-1}

(iii)



By Hess' Law,

$2\Delta H_{at}$ = –276 + 39 – (–1664) = +1427 kJ

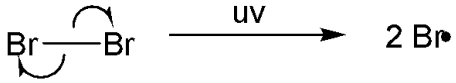
ΔH_{at} = +713.5 kJ mol^{-1}

(c)(i) Step 1: $K_2Cr_2O_7$, dil H_2SO_4, heat with immediate distillation (oxidation)

Step 2: KCN and HC*l*(aq) to generate HCN. With trace amt of KCN catalyst for nucleophilic addition

$CH_3CH_2OH \xrightarrow{\text{Step 1}} CH_3CHO \xrightarrow{\text{Step 2}} CH_3CH(OH)CN$

8(a)(i) Free radical substitution

initiation 

propagation $Br^{\bullet} + CH_3CH_2CH_3 \longrightarrow HBr + CH_3CH_2\dot{C}H_2$

$Br_2 + CH_3CH_2\dot{C}H_2 \longrightarrow Br^{\bullet} + CH_3CH_2CH_2Br$

termination $Br^{\bullet} + Br^{\bullet} \longrightarrow Br_2$

$2\ CH_3CH_2\dot{C}H_2 \longrightarrow CH_3CH_2CH_2CH_2CH_2CH_3$

(ii) $CH_3CH_2CH_2Br$ or $CH_3CHBrCH_3$

(iii) Condition of heat or uv light applies only in initiation step as Br• free radicals are regenerated in propagation stage to keep reaction going.

(iv) From Data booklet, F–F Bond energy = 158 kJ mol^{-1}

C*l*–C*l* Bond energy = 244 kJ mol^{-1}

Br–Br Bond energy = 193 kJ mol^{-1}

I–I Bond energy = 151 kJ mol^{-1}

If initiation stage is the rate-determining step, bond energies of the halogens are the activation energies for the initiation stage and hence rate of free radical substitution should be as follows:

$$I_2 > F_2 > Br_2 > Cl_2$$

Since rate of substitution of different halogens does not follow this trend, the rate determining step for free radical substitution cannot be the initiation stage

(b)(i) $\Delta H^{\theta} = \sum m\Delta H_f(\text{products}) - \sum n\Delta H_f(\text{reactants})$

$= -167 - 2(103) = -373$ kJ mol^{-1}

(ii) $\Delta G^{\theta} = \Delta H^{\theta} - T\,\Delta S^{\theta} = -373 - (298)(-190 \times 10^{-3}) = -316$ kJ mol^{-1}

(iii) $\Delta H^{\theta} < 0$ as propyl free radical reacts to form a C–C bond and thus it is an exothermic reaction.

$\Delta S^{\theta} < 0$ as $\Delta n = -1$; system gets less disordered after reaction.

® 2 gaseous particles react to give a single gaseous particle.

(iv) $\Delta G = -373 - 2000 \times (-190 \times 10^{-3}) = +7$ kJ mol^{-1} **> 0**; reaction is not feasible at 2000 K

(v) Since $\Delta G > 0$, 4 non-spontaneous. At higher temperature, the propyl free radical will undergo more free radical substitution in the propagation step to produce many by-products.

(c)(i) $C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(l)$ $\Delta H^{\theta}_c < 0$

(ii) Heat required to raise temperature of water = 1000 x 4.2 x 75

= 315000 J or 315 kJ

Amount of propane required= $\frac{315}{2220} = 0.1419$ mol

Vol of propane used = 0.01419 x 24 = 3.41dm^3

(iii) no heat loss to the surroundings

9 (a)(i) Standard enthalpy change of combustion of hydrazine is the energy **released** when one mole of hydrazine is completely burnt in excess oxygen at 298K and 1 bar.

(ii) Amount of heat absorbed by water = 200 x 4 x 4.18 = 3344 J

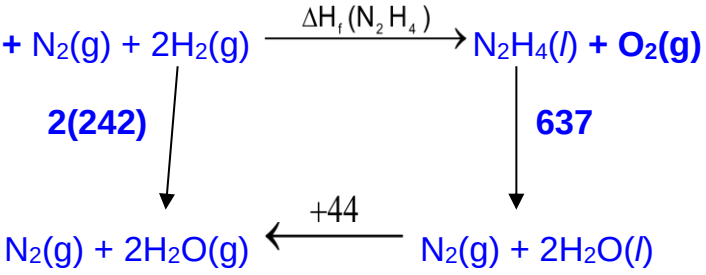
Amount of heat released by burning hydrazine = $3344 \times \frac{100}{80}$ = 4180 J

No of moles of N_2H_4 in 0.210 g = 6.56×10^{-3} mol

Standard enthalpy change of combustion of hydrazine = $-\frac{4180}{6.56 \times 10^{-3}}$

= −637 kJ mol^{-1}

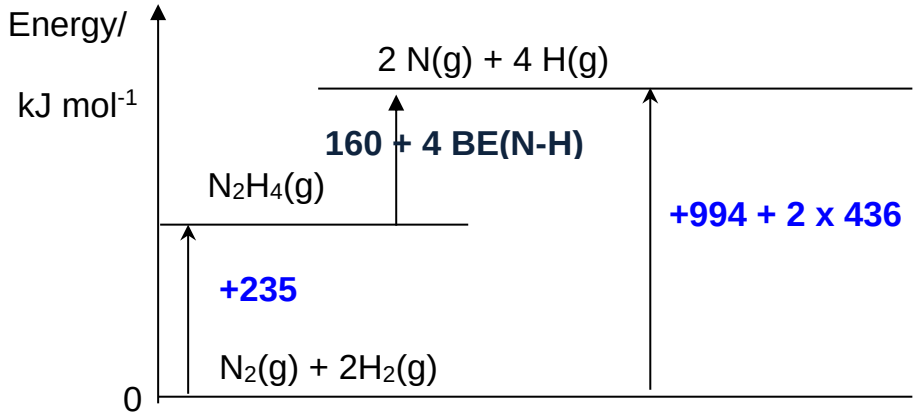
(iii)



By Hess' law,

$\Delta H_f(N_2H_4) = 2(-242) - (-637) - 2(+44) =$ **+65** kJ mol^{-1}

(b)(i)



By Hess Law,

235 + 160 + 4 BE(N–H) = 994 + 2 x 436

BE(N–H) = ¼{994 + 2 x 436 − (235 + 160)} = **368** kJ mol^{-1}

(ii) The bond energy values obtained from the *Data Booklet* are average values and would differ from the experimental values.

10 (a)(i) Let *x* be the fraction of trans-but-2-ene present at equilibrium.

$$K_p = \frac{P_{trans-but-2-ene}}{P_{cis-but-2-ene}} = \frac{x}{1-x} = 3.4$$

x = **0.773**

(ii) ΔH = − 120 − (−116) = **−4.00** kJ mol^{-1}

(iii) Assume ΔS to be a very small value, since there is no change in number of gaseous particles in the reaction,

Hence, ΔG = ΔH$^{\ominus}$ – T ΔS$^{\ominus}$

ΔH$^{\ominus}$ = **−4.00** kJ mol^{-1}

11(a)(i) $\log_{10}15 - \log_{10}0.05 = \frac{\Delta H\left(\frac{1}{300} - \frac{1}{400}\right)}{2.30(8.31)}$

ΔH = 56814 J mol^{-1} or 56.8 kJ mol^{-1}

Assumption is that ΔH remains constant at 300 K and 400 K

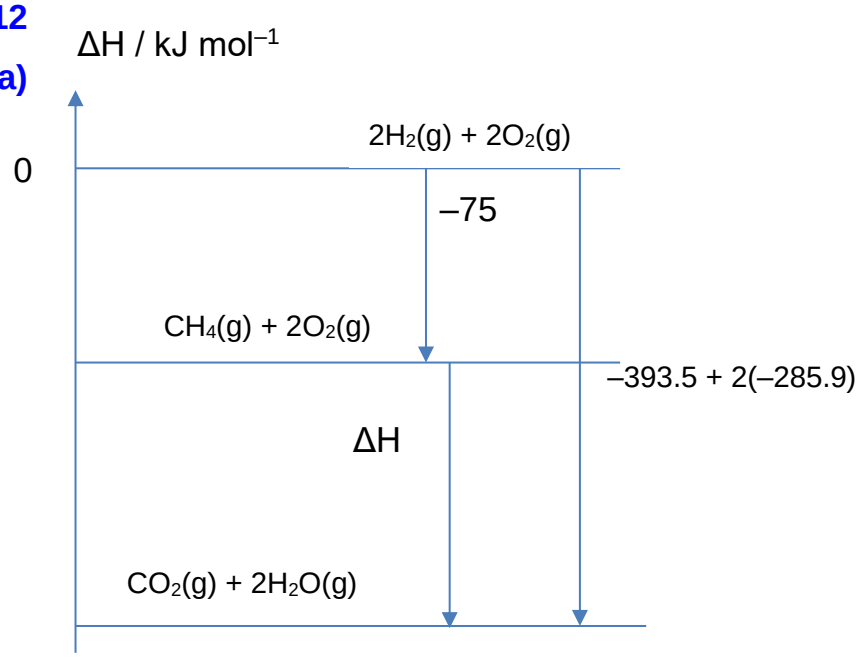
(ii) $\Delta S > 0$; There are more gaseous products than that of reactants. / There is an increase in number of gaseous particles (i.e. 1 mol − 2 mol). Since there is an increase in disorderness in the system, entropy increases.

(ii) $\Delta G = \Delta H - T\Delta S$

Since ΔH is positive and ΔS is positive ($-T\Delta S < 0$); ΔG will be positive at low temperatures, but negative at high temperatures.

Thus reaction is non-spontaneous at low temperatures, but spontaneous at high temperature. / Reaction becomes more spontaneous with increasing temperature.

12 (a)

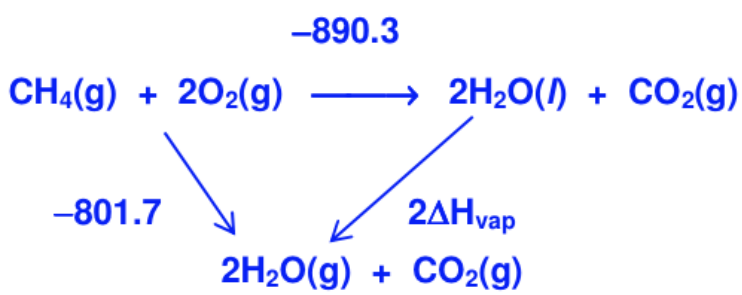


By Hess' Law:

$\Delta H = +75.0 + [2(-285.9) + (-393.5)]$

$= \underline{-890.3 \text{ kJ mol}^{-1}}$

(b) **(i)**



$2\Delta H_{vap} = +890.3 + (-801.7)$

$2\Delta H_{vap} = +88.6$

$\Delta H_{vap} = \underline{+44.3 \text{ kJ mol}^{-1}}$

(ii) $\Delta H = 4(410) + 2(496) - 4(460) - 2(805) = \underline{-818 \text{ kJ mol}^{-1}}$

The value obtained from bond energy calculations is different because bond energies are only average values obtained from different molecules. They may not be the actual values for the molecules used, except for the C=O bond in CO_2.

13 (i) Heat evolved, $Q = mc\Delta T$

$= (1)(4.18)(100 - 27)$

$= 305.14$ kJ (heat gained by water)

Since the process is only 65% efficient,

Total amount of heat released from combustion $= 305.14 \cdot \frac{100}{65}$

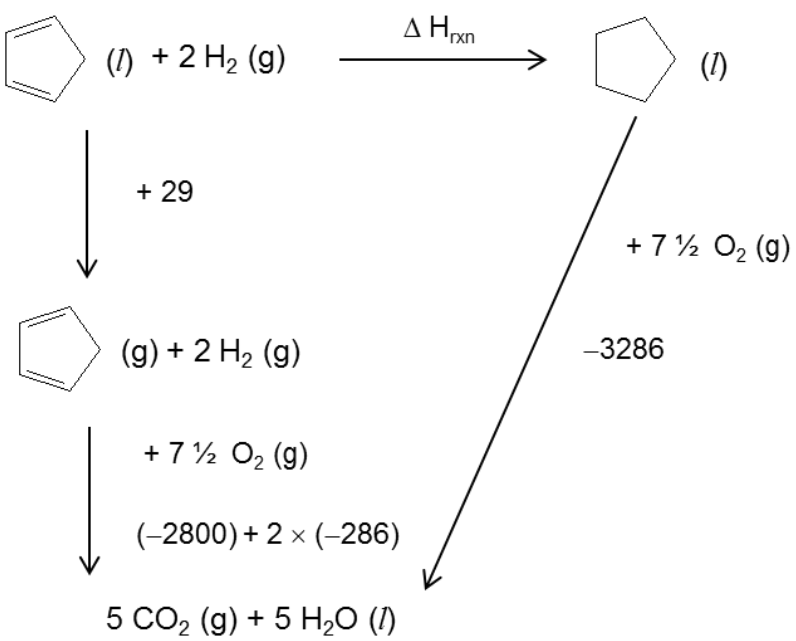
$= 469.4$ kJ

Amount of $C_5H_{10} = \frac{10}{70} = 0.1429$ mol

$\Delta H_c = -\frac{469.4}{0.1429} = -3286$

$= -3290 \text{ kJ mol}^{-1}$ (3 s.f)

(ii)



By Hess's Law,

ΔH_{rxn} = 29 + (−2800) + 2(−286) + 3286

= −57.0 kJ mol^{-1} (3 s.f.)

14 (i) The difference between the theoretical and experimental lattice energy values is larger for those of AgI than those of AgF.

When using the Kapustinskii equation, it is assumed that the cations and anions are spherical ions.

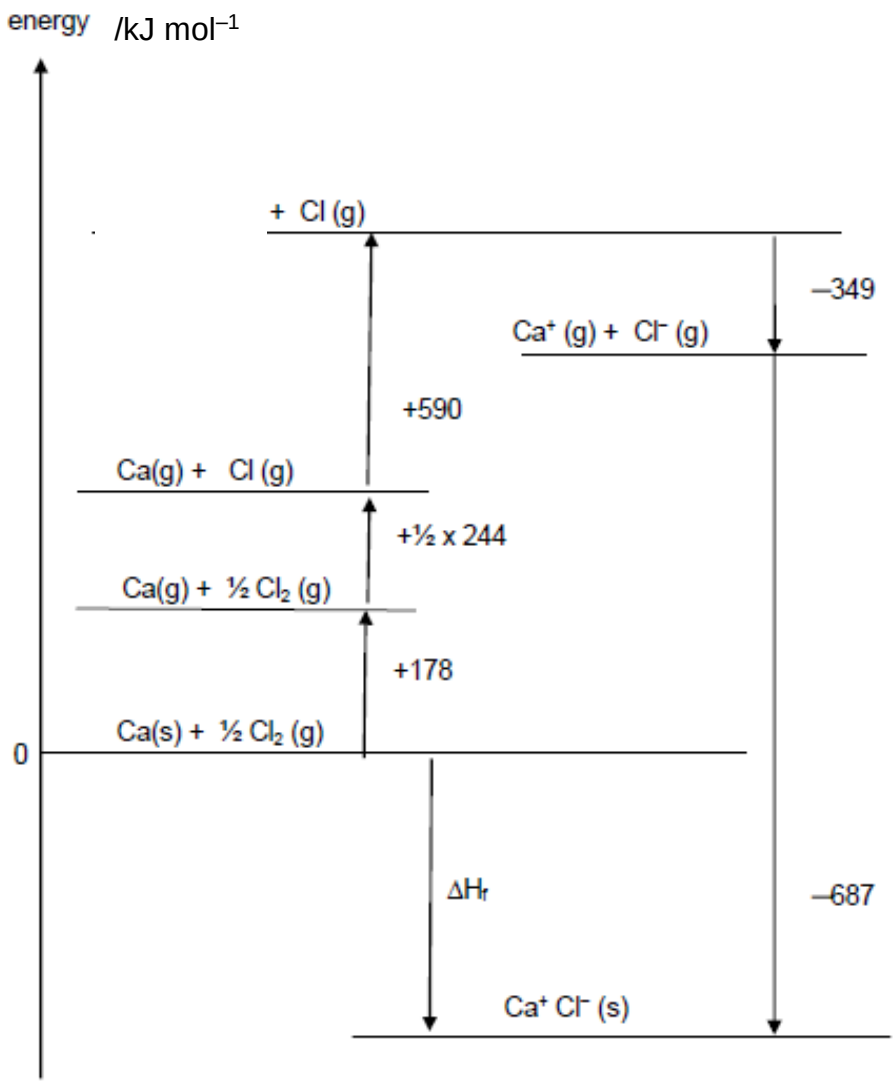
For a real ionic lattice, the high polarizing power of the silver ion distorts the large electron cloud of the iodide anion more.

Hence, the silver and iodide ions deviate more from the model of spherical ions, resulting in the larger difference.

(ii) $L.E.(CaCl) = \frac{107.9 \times 2 \times (+1) \times (-1)}{(0.133 + 0.181)} = -687\ kJ\ mol^{-1}$

$L.E.(CaCl_2) = \frac{107.9 \times 3 \times (+2) \times (-1)}{(0.099 + 0.181)} = -2312\ kJ\ mol^{-1}$

(iii)

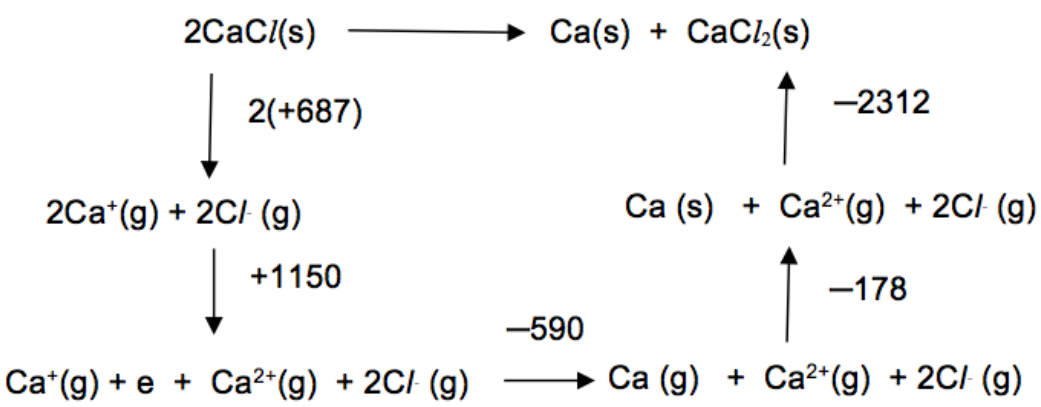


By Hess's Law,

ΔH_f = (+178) + (+½ x 244) + (+590) + (–349) + (–687)

= –146 kJ mol^{-1}

(iv)



ΔH_r = 2(+687) + (+1150) + (−590) + (−178) + (−2312)

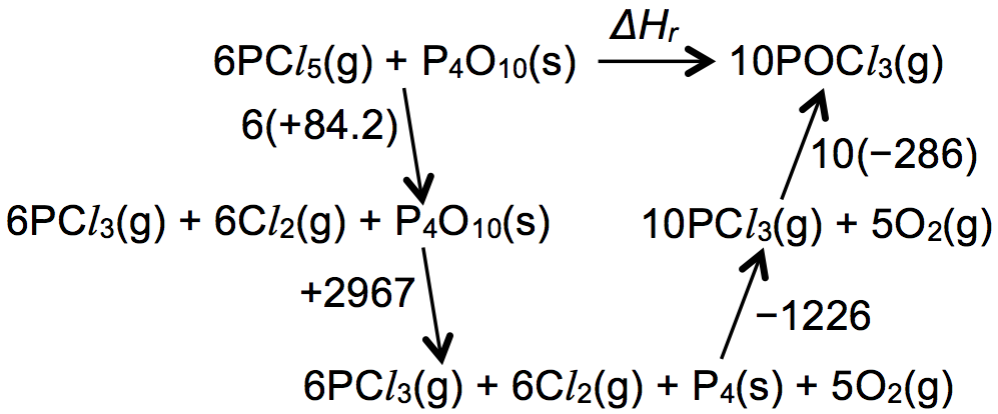
= −556 kJ mol^{-1}

(v) *Provides support :* **(b)(iv)**

Explanation :

Although a negative ΔH_f (= −146 kJ mol^{-1}) means that CaCl is stable with respect to its elements, CaCl is unstable with respect to its disproportionation products. So the reason for the non-existence of CaCl is because the ΔH_r of the disproportionation reaction is strongly exothermic (−556 kJ mol^{-1}).

15



Using Hess's law,

ΔH_r = 6(+84.2) +2967 + (−1226) + 10(−286)

= −614 kJ mol^{-1} (3sf)

16(i) The enthalpy change when **one mole** of a solute is **completely dissolved** in a solvent to form an infinitely dilute solution under **standard conditions / 298 K and 1 atm**.

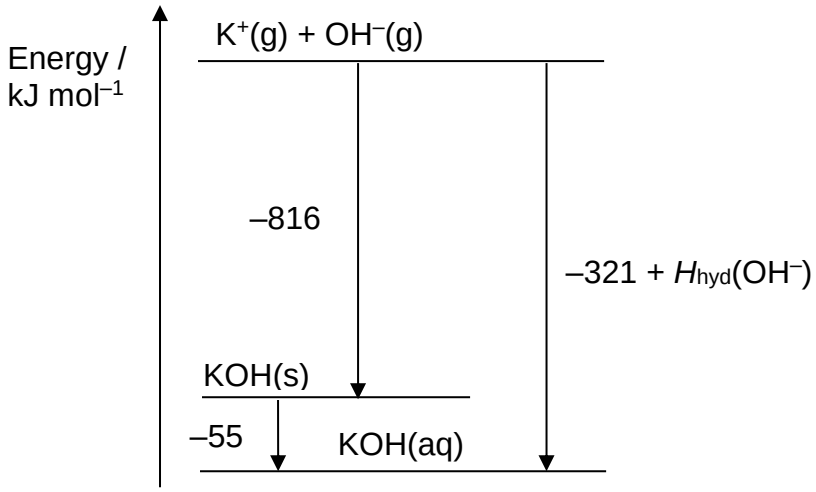
(ii) Temperature **increases** since enthalpy change of solution of KOH is **exothermic**.

(iii) $\Delta H_{hyd} \propto \frac{charge}{size}$

Ca^{2+} has a **higher ionic charge** and **smaller ionic size** than K^+.

Hence Ca^{2+} has a **higher charge/size ratio** than K^+, can form stronger ion-dipole interactions with water.

(iv)



By Hess' Law,

$-321 + \Delta H_{hyd}(OH^-) = -816 - 55$

$\Delta H_{hyd}(OH^-) = -550$ kJ mol^{-1}

(v) $-1650 + 2(-550) = -2580 + \mathbf{y}$

$\mathbf{y} = -170$ kJ mol^{-1}

(vi) There is a **decrease in entropy** (**or Δ*S* is negative)** as H_2O molecules are attached to the metal ion and lose their degree of freedom.

As **more H_2O molecules** are attached to the Ca^{2+} ion on average, the entropy change of solution of $Ca(OH)_2$ **decreases more** (**or Δ*S* is more negative)** than that of KOH.

(vii) $Ca(OH)_2$ dissolves with the formation of **more particles (aqueous ions)**.

Thus, the entropy change (of the system) **increases** (or Δ*S* is positive).