Solution Sheet

Question 1

The given equation can be rephrased as follows: one mole of A reacts to form two moles of B. This means that a decrease of x in $[A]$ corresponds to an increase of $2x$ in $[B]$.

$$-\frac{\Delta[A]}{\Delta t} = \frac{1}{2}\frac{\Delta[B]}{\Delta t}$$

The negative sign is included because $[A]$ decreases while $[B]$ increases.
Answer: C (1 point)

Question 2

The temperature of a gas is proportional to its average kinetic energy. Let the unknown gas be X. Then,

$$200 : 360 = \frac{m_{CO_2} v^2}{2} : \frac{m_X (6v)^2}{2}$$

Solving gives:

$$m_X = \frac{m_{CO_2}}{20}$$

Substituting $m_{CO_2} = 44\,\mathrm{g\,mol^{-1}}$:

$$m_X = 2.2\,\mathrm{g\,mol^{-1}}$$

Hence, the only valid option is H_2.
Answer: A (1 point)

Question 3

The reaction occurring is:

$$Ag^+ \text{ (aq)} + Br^- \text{ (aq)} \longrightarrow AgBr \text{ (s)}$$

Both $AgNO_3$ and KBr contain:

$$0.02 \times 1 = 0.02 \text{ mol}$$

Thus, 0.02 mol of AgBr is produced.
The heat released is:

$$Q = 40 \times 4.2 \times (35 - 25) = 1680\,\text{J} = 1.68\,\text{kJ}$$

The reaction enthalpy is:

$$\Delta H = \frac{1.68}{0.02} = 84\,\text{kJ}\,\text{mol}^{-1}$$

Since the reaction is exothermic:

$$\Delta H = -84\,\text{kJ}\,\text{mol}^{-1}$$

Answer: A (1 point)

Question 4

Consider each statement separately:

- **A:** If B is the limiting reactant, then $a > \frac{b}{3}$ or $3a > b$. This is false.
- **B:** The amount of C formed is $\frac{2}{3}b$. This is false.
- **C:** If A is the limiting reactant, then $a < \frac{b}{3}$. This is true.
- **D:** Since the reaction ratio is $1:3$, the amount of B remaining is $b - 3a$. This is false.

Answer: C (1 point)

Question 5

Since there are 100 C–H bonds, the molecule must contain at least 100 hydrogen atoms. The smallest hydrocarbon satisfying this is a saturated alkane.
For an alkane:

$$C_nH_{2n+2}$$

Setting $2n + 2 = 100$ gives $n = 49$, so the formula is $C_{49}H_{100}$.
The molar mass is:

$$49 \times 12 + 100 \times 1 = 688\,\text{g}\,\text{mol}^{-1}$$

Answer: D (1 point)

Question 6

The reaction is:

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2\,HI\,(g)$$

The equilibrium constant is:

$$K = \frac{[HI]^2}{[H_2][I_2]}$$

At equilibrium:

$$K = \frac{0.7^2}{0.1 \times 0.1} = 49$$

After adding 0.1 mol of both H_2 and I_2, let x mol react:

$$49 = \frac{(0.7 + 2x)^2}{(0.2 - x)^2}$$

Solving:

$$7(0.2 - x) = 0.7 + 2x$$

$$9x = 0.7$$

$$x = 0.077$$

Answer: A (1 point)

Question 7

Let the molar masses of X and Z be m_X and m_Z.

From compound A:

$$\frac{60}{100} = \frac{2m_X}{2m_X + m_Z} \quad \text{and} \quad \frac{40}{100} = \frac{m_Z}{2m_X + m_Z}$$

Solving gives:

$$3m_Z = 4m_X$$

Assume the empirical formula of B is X_cZ_d. Then:

$$\frac{1}{3} = \frac{cm_X}{cm_X + dm_Z} \quad \text{and} \quad \frac{2}{3} = \frac{dm_Z}{cm_X + dm_Z}$$

Thus:

$$\frac{d}{c} = 2\frac{m_X}{m_Z} = \frac{3}{2}$$

So:

$$c : d = 2 : 3$$

The empirical formula of B is X_2Z_3.
Answer: C (1 point)

Question 8

Compound A is a gas found in ordinary air and is important for photosynthesis. Hence, A must be carbon dioxide, CO_2.

When magnesium burns in A, a white substance B and a black substance C are formed. The white substance dissolves in dilute acids, which indicates that it is magnesium oxide, MgO.

The black substance is insoluble in dilute solutions of both acids and bases, which identifies it as carbon, C.

Complete combustion of substance C in oxygen gives substance A, confirming that C is carbon and A is carbon dioxide. Substance D is a common component of the atmosphere and must therefore be nitrogen, N_2.

When magnesium burns in D, substance E is formed, which is magnesium nitride, Mg_3N_2.

Substance E reacts with water to form magnesium hydroxide and a gas F with a characteristic foul smell. This gas is ammonia, NH_3.

(a)Answer: (1 point for 3 right answers, 2 points total)
$A : CO_2$
$B : MgO$
$C : C$
$D : N_2$
$E : Mg_3N_2$
$F : NH_3$

(b) Answer: (1 point for 2 right answers, 2 points total)
$2Mg_{(s)} + CO_{2(g)} -> 2MgO_{(s)} + C_{(s)}$
$C_{(s)} + O_{2(g)} -> CO_{2(g)}$
$3Mg_{(s)} + N_{2(g)} -> Mg_3N_{2(s)}$
$Mg_3N_{2(s)} + 6H_2O_{(l)} -> 3Mg(OH)_{2(s)} + 2NH_{3(g)}$

Question 9

(a) Answer: (1 point)
$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

(b) Answer: (1 point)
Assume that the reaction per mole of H_2:
$H_2(g) + \frac{1}{2}O_2(g) \rightarrow 2H_2O(g)\ \Delta H = -241 kJmol^{-1}$
Bonds broken:

- 1 H–H bond: 432 kJ/mol
- $\frac{1}{2}$ O=O bond: $\frac{1}{2}D_{O=O}$

Bonds formed:

- 2 O–H bonds: $2 \times 460 = 920$ kJ/mol

$\Delta H = 432 + \frac{1}{2}D_{O=O} - 920 = -241 kJmol^{-1}$

$D_{O=O} = 494 kJmol^{-1}$

(c) Answer: (1 point)
$CO_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O(g)$

(d) Answer: (1 point)
$\Delta H_{net} = -890.8 + 21.8 = -869.0 kJmol^{-1}$

(e) Answer: (1 point)
$\Delta H_{net} = -241 + 4.3 = -236.7 kJmol^{-1}$

(f) Answer: (1 point for each thing mentioned, 2 points total)

- Energy efficiency: Hydrogen releases more energy per unit mass than methane, making it advantageous for rocket performance
- Mars fuels: Methane is more practical because it can be produced locally on Mars via the Sabatier process and is easier to store than hydrogen

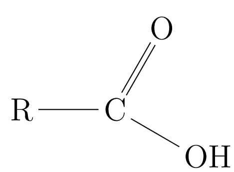
(g) Answer: (1 point)
No, the rocket does not "save" energy by using liquid fuels.

Question 10

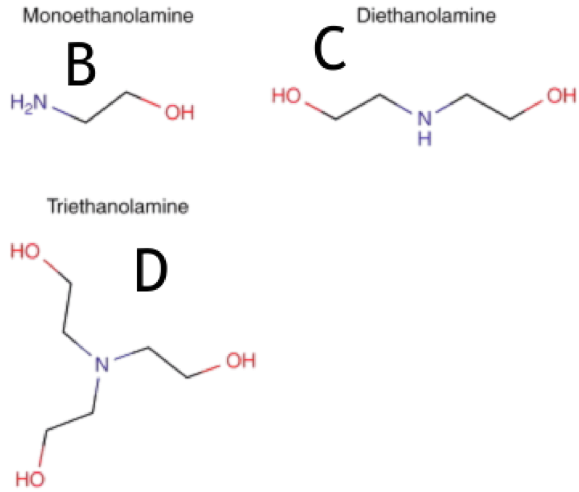
(a)Answer: (1 point)

An epoxied with n carbon atoms has the formula: $C_nH_{2n}O$

(b)Answer: (1 point)

The structure of compound **A** is: 

(c) Answer: (1 point for each compound, 3 points total)

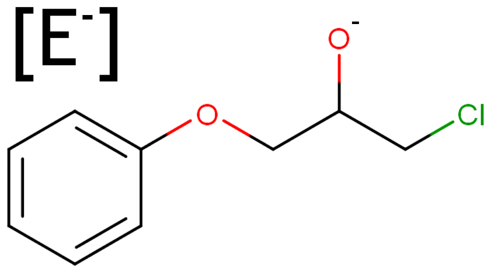


(d) Answer: (1 point for each thing mentioned, 2 points total)
The first reaction is faster then the third because:

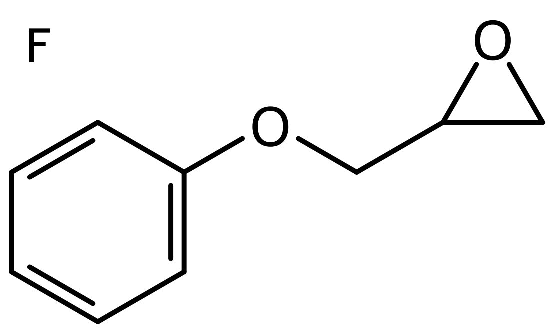
- NH_3 is more nucleophilic then compound **C**
- Compound **C** is bigger then NH_3, hence it causes more steric hindrance

(e) Answer: (1 point for each compound, 2 points total)

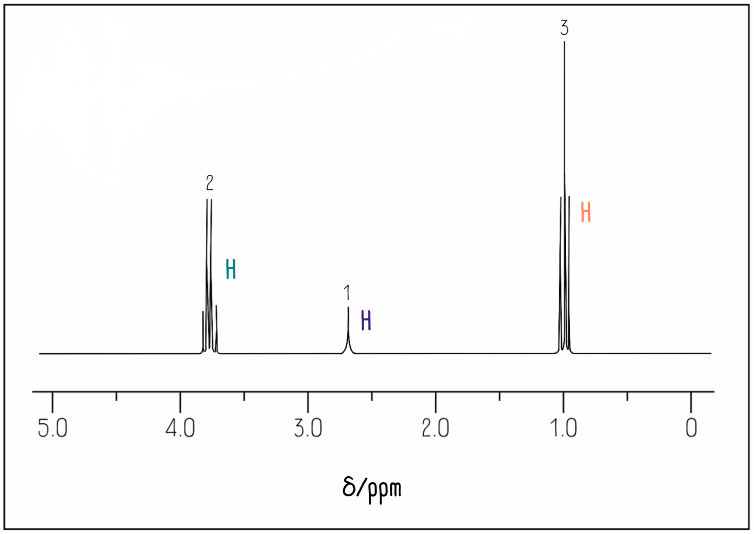
[E⁻]



F



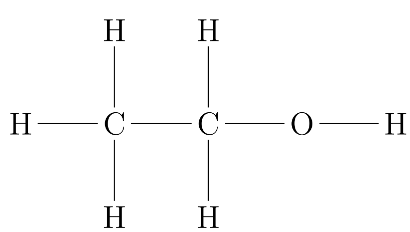
Question 11



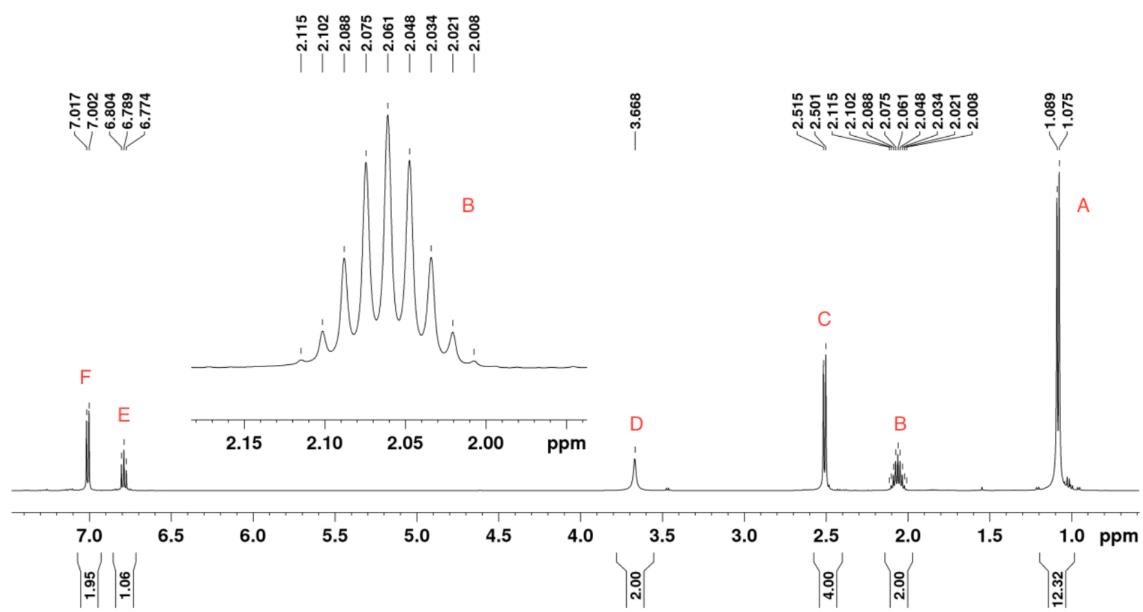
The spectrum shows three signals:

- 1.20 ppm, triplet, integration 3
- 3.60 ppm, quartet, integration 2
- 2.60 ppm, broad singlet, integration 1

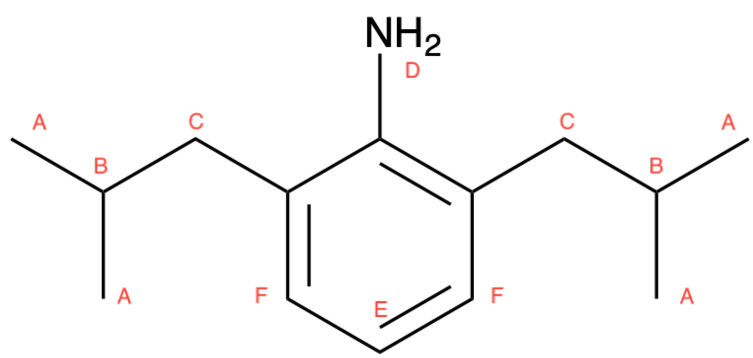
The signal at 1.20 ppm represents 3 hydrogen atoms and from the triplet multiplicity it can be deduced that it has 2 hydrogen atoms as neighbours. The signal therefore represents a methyl group.
This deduction is also supported by the signal at 3.60 ppm which represent two hydrogen atoms and has a multiplicity of a quartet, meaning it has four hydrogen atoms as neighbours, this signal is therefore the CH2 group that is attached to the -CH3 group.
The signal at 2.60 ppm represents 1 hydrogen atom and has a multiplicity of a broad singlet, this means it is easily exchangeable in deuterium solutions and based on the chemical formula given, it corresponds to a -OH group. The correct structure is therefore the structure that is shown below.
(a)Answer: (1 point)

The compound is Ethanol with this structure: 

^{1}H NMR spectrum (500 MHz, $CDCl_3$)



Apply the same logic used in part (a) of Question 11



(b) Answer: (1 point for each signal (letter), 6 points total)