**Q1.**

The equation for the complete combustion of butane is

$$C_4H_{10} + 6\frac{1}{2}\ O_2 \rightarrow 4\ CO_2 + 5\ H_2O$$

What is the mole fraction of butane in a mixture of butane and oxygen with the minimum amount of oxygen needed for complete combustion?

**A** 0.133 ○

**B** 0.153 ○

**C** 0.167 ○

**D** 0.200 ○

**(Total 1 mark)**

## Q2.

This question is about some gas mixtures at equilibrium.

This reaction can be used to make hydrogen.

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g) \qquad \Delta H = -41 \text{ kJ mol}^{-1}$$

(a) A mixture of 2.00 mol of $H_2O(g)$ and 2.00 mol of $CO(g)$ is allowed to reach equilibrium at a constant temperature in a 20 $dm^3$ container.
At equilibrium, there are 0.92 mol of $H_2(g)$.

Calculate the mole fraction of $H_2(g)$ in the equilibrium mixture.

Mole fraction of $H_2(g)$ ____________________

**(2)**

(b) State why the equilibrium constant ($K_p$) for this reaction has no units.

___________________________________________________________

___________________________________________________________

___________________________________________________________

**(1)**

(c) The temperature of the equilibrium mixture formed in part (a) is increased.

How does the amount of $H_2(g)$ change when the new position of equilibrium is reached?

Tick (✓) **one** box.

| | |
|---|---|
| The amount decreases. | ☐ |
| The amount does not change. | ☐ |
| The amount increases. | ☐ |

**(1)**

Ethanol can be made from ethene and steam.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \qquad \Delta H = -45 \text{ kJ mol}^{-1}$$

The table below shows the mole fractions of each of the gases in an equilibrium mixture at 6000 kPa

| **Gas** | **Mole fraction** |
|---|---|
| Ethene | 0.645 |
| Steam | 0.323 |
| Ethanol | 0.0321 |

(d) Give an expression for $K_p$ for this reaction.

Calculate the value of $K_p$ at 6000 kPa

State the units.

$K_p$

Units ____________________

**(4)**

(e) State the effect, if any, of an increase in volume of the container on the value of $K_p$ for this reaction at a constant temperature.

________________________________________

________________________________________

**(1)**

**(Total 9 marks)**

**Q3.**

Nitrogen dioxide decomposes at a high temperature.

$$2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g) \qquad \Delta H = +113\ kJ\ mol^{-1}$$

(a) A 0.317 mol sample of nitrogen dioxide is placed in a sealed flask and heated at a constant temperature until equilibrium is reached.

At equilibrium, the flask contains 0.120 mol of oxygen.

Calculate the mole fraction of each substance at equilibrium.

Mole fraction of $NO_2$ ____________________

Mole fraction of NO ____________________

Mole fraction of $O_2$ ____________________

**(3)**

(b) The total pressure in the flask in part (a) is 120 kPa at equilibrium.

Calculate the partial pressure, in kPa, of $NO_2$

If you were unable to answer part (a) you should assume that the mole fraction of $NO_2$ is 0.380. This is **not** the correct answer.

Partial pressure ____________________ kPa

**(1)**

(c) The table below shows the mole fractions of the three gases in a different equilibrium mixture.

$$2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g) \qquad \Delta H = +113\ kJ\ mol^{-1}$$

| Gas | Mole fraction |
|---|---|
| $NO_2$ | 0.310 |
| NO | 0.460 |
| $O_2$ | 0.230 |

For this equilibrium mixture, $K_p$ = 59.7 kPa

Give an expression for $K_p$ for this reaction.

Use your expression and the data in the table to calculate the total pressure, in kPa, in the flask.

$K_p$

Total pressure ____________________ kPa

**(3)**

(d) The equilibrium mixture in part (c) is compressed into a smaller volume.

Deduce the effect, if any, of this change on the equilibrium yield of oxygen and on the value of $K_p$

Effect on yield of oxygen ______________________________________

Effect on $K_p$ ______________________________________

**(2)**

(e) The equilibrium mixture in part (c) is allowed to reach equilibrium at a lower temperature.

Explain why the equilibrium yield of oxygen decreases.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**(2)**

**(Total 11 marks)**

## Q4.

This question is about equilibria.

(a) Give **two** features of a reaction in dynamic equilibrium.

Feature 1 ______________________________________________

______________________________________________

Feature 2 ______________________________________________

______________________________________________

**(2)**

(b) A gas-phase reaction is at equilibrium.
When the pressure is increased the yield of product decreases.

State what can be deduced about the chemical equation for this equilibrium.

______________________________________________

______________________________________________

**(1)**

(c) Carbon monoxide and hydrogen react to form methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

0.430 mol of carbon monoxide is mixed with 0.860 mol of hydrogen.
At equilibrium, the total pressure in the flask is 250 kPa and the mixture contains 0.110 mol of methanol.

Calculate the amount, in moles, of carbon monoxide present at equilibrium.

Calculate the partial pressure, in kPa, of carbon monoxide in this equilibrium mixture.

Amount of carbon monoxide ____________________ mol

Partial pressure ________________ kPa

**(3)**

(d) Give an expression for the equilibrium constant ($K_p$) for this reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

**(1)**

(e) A different mixture of carbon monoxide and hydrogen is left to reach equilibrium at a temperature *T*.

Some data for this equilibrium are shown in the table below.

| | |
|---|---|
| **Partial pressure of CO** | 125 kPa |
| **Partial pressure of $CH_3OH$** | 5.45 kPa |
| $K_p$ | $1.15 \times 10^{-6}$ $kPa^{-2}$ |

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Calculate the partial pressure, in kPa, of hydrogen in this equilibrium mixture.

Partial pressure ________________ kPa

**(3)**

(f) Use the $K_p$ value from the table above to calculate a value for $K_p$ for the following reaction at temperature $T$.

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

$K_p$ ________________

Units ________________

**(2)**

**(Total 12 marks)**