favours forward reaction produces fewer moles
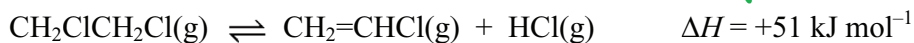
1. Chloroethene, $CH_2=CHCl$, is prepared in the presence of a solid catalyst using the equilibrium reaction below.

    heterogeneous

$$CH_2ClCH_2Cl(g) \rightleftharpoons CH_2=CHCl(g) + HCl(g) \qquad \Delta H = +51 \text{ kJ mol}^{-1}$$

Which change would result in an increased equilibrium yield of chloroethene?

Le Chatelier's principle)

A   increasing the pressure

B   increasing the surface area of the catalyst → ↑ ROR for forward + reverse reactions

C   increasing the temperature → as forward reaction is endothermic

D   use of a homogeneous catalyst → same effect on forward + reverse reaction

Your answer   [C]

[1]

2. Which statement(s) is/are correct when a catalyst is added to a system in dynamic equilibrium?

    1   The rates of the forward and reverse reactions increase by the same amount. ✓

    2   The concentrations of the reactants and products do not change. ✓

    3   The value of K_c increases. ✗

    A   1, 2 and 3

    B   Only 1 and 2

    C   Only 2 and 3

    D   Only 1

Your answer   B   [1]

$$2A + B \rightleftharpoons 3C + D$$

$$K_c = \frac{[C]^3[D]}{[A]^2[B]}$$
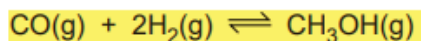
3.   Methanol, CH_3OH, can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \, kJ \, mol^{-1} \qquad \text{**Equilibrium 1**}$$

(a) Predict the conditions of pressure and temperature that would give the maximum equilibrium yield of CH_3OH in **equilibrium 1**.

want to favour forwards reaction

Explain your answer.

Right hand side has fewer gaseous moles
so high pressure
Forwards reaction was exothermic so low temperature

.... **[3]**

(b) A catalyst is used in the production of methanol in **equilibrium 1**.

State **two** ways that the use of catalysts helps chemical companies to make their processes more sustainable and less harmful to the environment.

1 lower energy demand

2 less CO_2 emission

[2]

(c) Standard entropy values are given below.

Substance	CO(g)	H_2(g)	CH_3OH(g)
$S^⦵$/$J\,K^{-1}\,mol^{-1}$	198	131	238

A chemist proposed producing methanol at 525 K using **equilibrium 1**.

Explain, with a calculation, whether the production of methanol is feasible at 525 K.

$\Delta S = 238 - (198 + (2 \times 131)) = -222\ JK^{-1}mol^{-1}$

$= -0.222\ kJK^{-1}mol^{-1}$

$\Delta G = \Delta H - T\Delta S$

$\Delta G = -91 - (525 \times -0.222) = 25.55\ kJmol^{-1}$

not feasible as $\Delta G > 0$

[5]

(d) At 298 K, the free energy change, ΔG, for the production of methanol in **equilibrium 1** is $-2.48 \times 10^4\ J\,mol^{-1}$.

ΔG is linked to K_p by the relationship: $\Delta G = -RT\ lnK_p$.

$lnkp = \dfrac{\Delta G}{-RT}$

R = gas constant
T = temperature in K.

$lnkp = \dfrac{-2.48 \times 10^4}{-8.314 \times 298}$

Calculate K_p for **equilibrium 1** at 298 K.

Give your answer to **3 significant figures.**

$= 10.01$

$kp = \dfrac{p(CH_3OH)}{p(CO) \times p(H_2)^2}$

$kp = e^{-10.01} = 2.22 \times 10^4$

$K_p =$ ..2.22×10^4.. units ..atm^{-2}.. **[3]**

4. The equilibrium constant K_p and temperature T (in K) are linked by the mathematical relationship shown in **equation 5.1** (R = Gas constant in $J\,mol^{-1}K^{-1}$ and ΔH is enthalpy change in $J\,mol^{-1}$).

$$\ln K_p = -\frac{\Delta H}{R} \times \frac{1}{T} + \frac{\Delta S}{R} \qquad \textbf{Equation 5.1}$$

$$y = m \times x + c$$

(a) The table shows the values of K_p at different temperatures for an equilibrium.

Complete the table by adding the missing values of $\frac{1}{T}$ and $\ln K_p$.

$$K_p = \frac{P\,(products)}{P\,(reactants)}$$

Temperature, T/K	400	500	600	700	800
K_p ~~decreased~~	3.00×10^{58}	5.86×10^{45}	1.83×10^{37}	1.46×10^{31}	1.14×10^{26}
$\frac{1}{T}/K^{-1}$	2.50×10^{-3}	2.00×10^{-3}	1.67×10^{-3}	1.43×10^{-3}	1.25×10^{-3}	3sf.
$\ln K_p$	135	105	86	72	60	whole numbers

[2]

(b) State and explain how increasing the temperature affects the position of this equilibrium and whether the forward reaction is exothermic or endothermic. *denominator higher as kp decreases so equilibrium favours reactants*

Equilibrium position shifts to the left.

Forwards direction is exothermic.

As temperature increases the equilibrium position moves in the endothermic direction which in this case is the backwards reaction. [1]

(c) Plot a graph of $\ln K_p$ against $\frac{1}{T}$ using the axes provided on the opposite page.

Use your graph and **equation 5.1** to determine ΔH, in $kJ\,mol^{-1}$, for this equilibrium.

Give your answer to **3 significant figures**.

$$\frac{\Delta y}{\Delta x} = 57142.85714 \qquad \frac{\Delta y}{\Delta x} = \frac{-\Delta H}{R}$$

$$-\Delta H = 475085.7143 \; J\,mol^{-1}$$

$$\Delta H = -475.085 \; kJ\,mol^{-1}$$

$\Delta H = $ _____ −475 _____ $kJ\,mol^{-1}$ [4]

(d) Explain how ΔS could be calculated from a graph of $\ln K_p$ against $\frac{1}{T}$.

use y intercept = $\frac{\Delta S}{R}$

$\Delta S = R \times y$ intercept

[2]

Graph of $\ln K_p$ against $\frac{1}{T}/K^{-1}$.

$$\frac{\Delta y}{\Delta x} = \frac{99-79}{1.90\times10^{-3}-1.55\times10^{-3}}$$

$$= 57142.85714$$