

M1.(a) Multiply volume of propan-1-ol by density
Allow measure the mass of the volume added
Any reference to concentration of propan-1-ol CE = 0 1

Divide the mass by the M_r of propan-1-ol 1

(b) Titrate a measured volume of the concentrated HCl added initially to determine moles of HCl used in the experiment
Allow addition of AgNO_3 to form AgCl precipitate. Use mass of precipitate to calculate initial moles of HCl added. 1

Subtract this number of moles of HCl from the total moles of acid at equilibrium 1

(c) M1 ester will evaporate / escape
Allow reactants / products will evaporate 1

M2 incorrect values used (to determine K_c)
Allow the system will no longer be at equilibrium
Do not allow references to equilibrium position shifting alone 1

[6]

M2.(a) Bonds broken = $2(\text{C}=\text{O}) + 3(\text{H}-\text{H}) = 2 \times 743 + 3 \times \text{H}-\text{H}$
Bonds formed = $3(\text{C}-\text{H}) + (\text{C}-\text{O}) + 3(\text{O}-\text{H}) = 3 \times 412 + 360 + 3 \times 463$
Both required 1

$$-49 = [2 \times 743 + 3 \times (\text{H}-\text{H})] - [3 \times 412 + 360 + 3 \times 463]$$

$$3(\text{H}-\text{H}) = -49 - 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$$

Both required 1

H-H = 483 (kJ mol⁻¹)
Allow 483.3(3)

1

(b) Mean bond enthalpies are not the same as the actual bond enthalpies in CO₂
(and / or methanol and / or water)

1

(c) The carbon dioxide (produced on burning methanol) is used up in this reaction

1

(d) 4 mol of gas form 2 mol

1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

1

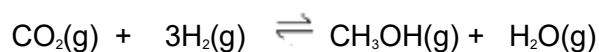
This increases the yield of methanol

1

(e) Impurities (or sulfur compounds) block the active sites
Allow catalyst poisoned

1

(f) Stage 1: moles of components in the equilibrium mixture
Extended response question



Initial moles	1.0	3.0	0	0
Eqm moles	(1-0.86) = 0.14	(3-3×0.86))	0.86	0.86

$$= 0.42$$

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction \times p_{total}

1

$$p_{\text{CO}_2} = \text{mol fraction} \times p_{\text{total}} = 0.14 \times 500 / 2.28 = 30.7 \text{ kPa}$$

$$p_{\text{H}_2} = \text{mol fraction} \times p_{\text{total}} = 0.42 \times 500 / 2.28 = 92.1 \text{ kPa}$$

M3 is for partial pressures of both reactants

Alternative M3 =

$$pp_{\text{CO}_2} = 0.0614 \times 500$$

$$pp_{\text{H}_2} = 0.1842 \times 500$$

1

$$p_{\text{CH}_3\text{OH}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

$$p_{\text{H}_2\text{O}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

M4 is for partial pressures of both products

Alternative M4 =

$$pp_{\text{CH}_3\text{OH}} = 0.3772 \times 500$$

$$pp_{\text{H}_2\text{O}} = 0.3772 \times 500$$

1

Stage 3: Equilibrium constant calculation

$$K_p = p_{\text{CH}_3\text{OH}} \times p_{\text{H}_2\text{O}} / p_{\text{CO}_2} \times (p_{\text{H}_2})^3$$

1

$$\text{Hence } K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$$

Answer must be to 2 significant figures

1

Units = kPa⁻²

1

[16]

M3.A

[1]

M4.B

[1]

M5.D

[1]

M6. (a) *(must state correct effect on yield or rate to score the reason mark)*

T effect: higher temp: yield greater or shifts equilibrium to right; 1

effect: higher temp: rate increased; 1

reason: endothermic

OR

more particles have $E > E_a$ 1

OR

more successful/productive collisions; 1

P effect: higher pressure: yield less or shifts equilibrium to left; 1

effect: higher pressure: rate increased;

reason: increase in gas moles L to R

OR

greater collision frequency;

(Q of L mark)

1

(b) M1 equilibrium moles of CO = 62.8 - 26.2 = 36.6

1

M2 equilibrium moles of H₂ = 146 - 2(26.2) = 93.6

1

M3 total no moles = 36.6 + 93.3 + 26.2 = 156.4

1

M4 partial pressure = mole fraction x total pressure

1

M5
$$K_p = \frac{P_{\text{CH}_3\text{OH}}}{P_{\text{CO}} \times P_{\text{H}_2}^2}$$

1

M6
$$= \frac{\left(\frac{26.2}{156.4} \times 9.50\right)}{\left(\frac{36.6}{156.4} \times 9.50\right) \times \left(\frac{93.6}{156.4} \times 9.50\right)^2}$$

$$\frac{(0.168 \times 9.5)}{(0.234 \times 9.50) \times (0.598 \times 9.5)^2}$$

$$\frac{(1.59)}{(2.22) \times (5.69)^2}$$

1

M7 0.022(1) 2.2(1) × 10⁻⁸ 2.2(1) × 10⁻¹⁴

1

M8 MPa⁻² kPa⁻² Pa⁻²

1

If no subtraction lose M1, M2 and M3)

(If ×2 missed in M2, lose both M2 and M3)

(If M1 gained but moles of H₂ = 73.2 (i.e. double CO), M2 and M3 lost)

(If M1 gained but mol H₂ = 2(146 - 26.2), M2 and M3 lost)

(If M1 and M2 correct but M3 lost for CE, penalise M6 also)

(M4 can be gained from the numbers in the expression for M6 even if these numbers are wrong)

(If K_p contains [] lose M5 but then mark on)

(If chemically wrong expression for K_p, lose M5, M6 and M7)

(allow M8 conseq on their K_p)

(If divided by 9.5, or not used 9.5 at all, lose M6 and M7 (and M4))

(If tried to convert to kPa and is factor(s) of 10 out, penalise

- M7.** (a) (i) $(K_p) = (p_z)^2 / (p_x)(p_y)^3$
(penalise use of square brackets, allow ()) 1
- (ii) **X** $(22-6)/4 = 4$ (MPa)
(mark is for value 4 only, ignore units) 1
- Y** obtained by multiplying value for **X** by 3
(allow conseq on wrong value for **X**) 1
- Y** $4.0 \times 3 = 12$ (MPa)
(mark is for value 12 only) 1
- (iii) $K_p = 6.0^2 / 4.0 \times 12.0^3 = 5.21 \times 10^{-3}$
(allow conseq on wrong values for **X** and **Y** e.g. $6^2/3 \times 9^3 = 0.165$)
- (if K_p wrong in (a)(i) CE) 1
- MPa^{-2}
(allow any unit of P^{-2} provided ties to P used for K_p value) 1
- (b) high pressure expensive (due to energy or plant costs) 1
- (Rate is) slow (at lower temperatures) 1

