

F325: Equilibria, Energetics and Elements

5.1.2 How Far?

1. (a) rate of forward reaction = rate of reverse reaction (1)
concentrations of reactants and products are constant but they are constantly interchanging (1) 2

 - (b) (i) $K_c = [\text{CH}_3\text{OH}] / [\text{CO}] [\text{H}_2]^2$ (1) 1
 (ii) use of $K_c = [\text{CH}_3\text{OH}] / [\text{CO}] [\text{H}_2]^2$ and moles to obtain a calculated value (1)
 convert moles to concentration by +2: $[\text{CO}] = 3.10 \times 10^{-3} \text{ mol dm}^{-3}$;
 $[\text{H}_2] = 2.60 \times 10^{-5} \text{ mol dm}^{-3}$; $[\text{CH}_3\text{OH}] = 2.40 \times 10^{-2} \text{ mol dm}^{-3}$ (1)
 $K_c = [2.60 \times 10^{-5}] / [3.10 \times 10^{-3}] [2.40 \times 10^{-2}]^2 = 14.6 / 14.56$ (1)
 If moles not converted to concentration, calculated K_c value = 3.64
 (scores 1st and 3rd marks)
 units: $\text{dm}^6 \text{ mol}^{-2}$ (1) 4

 - (c) (i) fewer moles of gas on right hand side (1) 1
 (ii) None (1) 1

 - (d) (i) moved to left hand side/reactants increase/less products (1) 1
 (ii) ΔH negative because high temperature favours the endothermic direction (1) 1

 - (e) (i) $\text{CH}_3\text{OH} + 1\frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$ (1) 1
 (ii) adds oxygen/oxygenated (1) 1
- [13]**
-
2. (a) $K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]}$ (1) 1

 - (b) (i) $\text{PCl}_5 > 0.3 \text{ mol dm}^{-3}$; PCl_3 and $\text{Cl}_2 < 0.3 \text{ mol dm}^{-3}$ (1) 1
 (ii) At start, system is out of equilibrium with too much PCl_3 and Cl_2 and not enough PCl_5 /
 $\frac{0.3 \times 0.3}{0.3} = 0.3$ is greater than $K_c = 0.245 \text{ mol dm}^{-3}$ (1) 1

 - (c) (i) K_c does not change as temperature is the same (1) 1
 (ii) Fewer moles on left hand side (1)

system moves to the left to compensate for increase in pressure by producing less molecules (1)

2

(d) (i) K_c decreases (as more reactants than products)(1)

1

(ii) Forward reaction is exothermic/
reverse reaction is endothermic (1)
equilibrium $\rightarrow$ left to oppose increase in energy/
because K_c decreases (1)

2

[9]

3. (a) $\text{CH}_4 + \text{H}_2\text{O} \rightarrow 3\text{H}_2 + \text{CO}$
 $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow 4\text{H}_2 + \text{CO}_2$
 $\text{CH}_4 + \text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{CH}_2\text{O}/\text{HCHO}$
 $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{CH}_2\text{O}_2/\text{HCOOH} \checkmark$
or $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CH}_3\text{OH} \checkmark$

1

(b) (i) $k_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \checkmark$
 $[\text{NH}_3]^2 = (K_c \times [\text{N}_2] \times [\text{H}_2]^3) \checkmark$
 $= 0.768 \checkmark$

1

(ii) $[\text{NH}_3] = \sqrt{0.78} = 0.876/0.88 \text{ (mol dm}^{-3}\text{)} \checkmark$
If no powers, then rearrangement mark only.

3

(c) **High pressure:**

adv: Fewer moles on r.h.s. $\rightarrow$ equilibrium moves to right $\checkmark$
Greater pressure $\rightarrow$ faster rate/more frequent collisions $\checkmark$

dis: Safety issues from (high) pressure
Expense of (high) pressure $\checkmark$

3

High temperature:

adv: more collisions exceed activation energy/
more successful collisions/more energetic
collisions/molecules have more energy $\checkmark$

dis: Equilibrium moves to left/reverse direction because
(forward) reaction is exothermic $\checkmark$

2

Catalyst:

lowers activation energy/

allows reaction to take place at a lower temperature ✓

1

QWC: Uses 2 words following list in the correct context:

1

exothermic/endothermic, activation energy, collisions,

equilibrium/Le Chatelier

[12]

4. (a) $K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$ (1) 1

(b) (i)

H_2	I_2	HI
0.30	0.20	0
0.14	0.04	0.32
(1)		(1)

 2

(ii) $K_c = \frac{0.32^2}{0.14 \times 0.04} = 18.28571429$ (1)
 = 18 (to 2 sig figs) (1)
 no units (1)
 (or ecf based on answers to (i) and/or (a)) 3

(c) K_c is constant (1)
 Composition of mixture is the same (1) 2

[8]

5. (a) (change in) concentration/mass/volume with time 1

(b) (i) O_2 :
 Exp 2 has $4 \times [\text{O}_2]$ as Exp. 1: rate increases by 4 (1),
 so order = 1 with respect to O_2 (1)
 NO:
 Exp 3 has $3 \times [\text{NO}]$ as Exp. 3: rate has increases by 9 (1),
 so order = 2 with respect to NO (1) 4

(ii) $\text{rate} = k[\text{O}_2][\text{NO}]^2$ (1) 1

$$(iii) \quad k = \frac{\text{rate}}{[\text{O}_2][\text{NO}]^2} = \frac{7.10}{0.0010 \times 0.0010^2} = 7.10 \times 10^9 \text{ (1)}$$

units: $\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$ (1)

2

[8]

6. (a) $K_p = \frac{p(\text{SO}_3)^2}{p(\text{SO}_2)^2 \times p(\text{O}_2)}$ (1)(1)

1 mark for correct powers but wrong way up.

1 mark for square brackets

2

(b) An increase in pressure moves equilibrium to the right because there are less gaseous moles on the right hand side (1)

Increased pressures are expensive to generate/safety problems with walls of containers/enables gases to flow (1)

K_p gets less with increasing temperature (1)

SO_2 and O_2 increase/ SO_3 decreases (1)

Equilibrium $\rightarrow$ left to oppose increase in temperature (1)

Forward reaction is exothermic or ΔH is $-ve$ /reverse

reaction is endothermic or ΔH is $+ve$ because K_p gets less with increasing temperature (1)

6

QoWC: organises relevant information clearly and

coherently, using specialist vocabulary where appropriate (1)

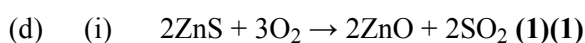
1

(c) $3.0 \times 10^2 = \frac{p(\text{SO}_3)^2}{10^2 \times 50}$ (1)

$$p(\text{SO}_3) = \sqrt{(3.0 \times 10^2 \times 10^2 \times 50)} = 1225 \text{ kPa (1)}$$

$$\%(\text{SO}_3) = 100 \times 1225 / (1225 + 10 + 50) = 95\% \text{ (1)}$$

3



ZnS , O_2 as reactants **and** SO_2 as a product: 1st mark.

ZnO **and** balance: 2nd mark

2

(ii) ZnS is more available than S . (1)

1

[15]

7. (a) (i) O_3 : 1
and C_2H_4 (1)

1

(ii) 2 (1)

1

(iii) $\text{rate} = k[\text{O}_3][\text{C}_2\text{H}_4]$ (1)

1

(b) (i) measure gradient/tangent (1)

	at t = 0/start of reaction (1)	2	
(ii)	$k = \frac{\text{rate}}{[\text{O}_2][\text{C}_2\text{H}_4]}$ (1)		
	$k = \frac{1.0 \times 10^{-12}}{0.5 \times 10^{-7} \times 1.0 \times 10^{-8}} = 2 \times 10^3$ (1) $\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$ (1)	3	
(iii)	2 mol CH ₂ O forms for every 0.5 mol O ₂ / stoichiometry of CH ₂ O : O ₂ is not 1:1 (1)	1	
(iv)	rate increases (1) k increases (1)	2	
			[11]
8.	(i) each atom has two unpaired electrons (1)	1	
	(ii) 2 oxygen atoms bonded by double bond (1) third oxygen bonded by a covalent bond and outer shells correct (1) For 2 nd mark, all O atoms must have an octet. A triangular molecule would have 3 single covalent bonds for 1 st mark but the origin of each electron must be clear for 2 nd mark	2	
	(iii) amount of O ₃ in 150 kg = $150 \times 10^3 / 48 = 3.13 \times 10^3$ mol (1) amount of Cl radicals in 1 g = $1 / 35.5 = 2.82 \times 10^{-2}$ mol (1) 1 mol Cl destroys $3.13 \times 10^3 / 2.82 \times 10^{-2} = 1.11 \times 10^5$ mol O ₃ 1 Cl radical destroys 1.11×10^5 O ₃ molecules (1) (calculator: 110937)	3	
			[6]
9.	(a) High Pressure Equilibrium → right as fewer moles on right hand side and the shift reduces number of molecules/compensates for increasing pressure (1) Rate increases/ more collisions (1)	2	
	High temperature Equilibrium → left as equilibrium goes to the left to compensate for increased temperature/absorbs the energy/in endothermic direction (ora) (1) Rate increases/ more successful collisions (1)	2	
	Other effect High pressures expensive/ high temperatures expensive /high pressures cause safety problems (1)	1	
	QWC: One correct statement followed by correct explanation (1)	1	

- (b) (i)
- | CO | H ₂ | CH ₃ OH | |
|--|--------------------------|---------------------|------------|
| 1.0 | 2.0 | 0.0 | |
| 0.9 | 1.8 (1) | 0.1 (1) | |
| 0.9/2.8 or 0.321 or 0.32/0.3 | | 1.8/2.8 or 0.643 or | |
| 0.64/0.6 | 0.1/2.8 or 0.036 or 0.04 | | (1) |
| 3.21 (MPa) | 6.43 (MPa) | 0.36 (MPa) | (1) |
| In 3 rd and 4 th rows, ecf from previous row | | | 4 |
- (ii) $K_p = \frac{p(\text{CH}_3\text{OH})}{p(\text{CO}) \times p(\text{H}_2)^2}$ **(1)(1)**
 1 mark for K_c / use of any [] /inverted/power missing. 2
- (iii) K_p stays the same **(1)**
 Equilibrium position moves to the right/yield increases **(1)**
 in response to increase in reactants **(1)**
 $K_p = \frac{0.261}{3.70 \times 5.10^2} = 2.71 \times 10^{-3}$ **(1)** MPa⁻² **(1)** 3
- (iv) calc value 2.7120546×10^{-3} ; answer and/or units ecf from (ii) 2
- (c) $\text{CH}_3\text{OH} + 1.5\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$ **(1)** 1

[18]