Equilibria, Energetics and Elements
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) $K_c = [CH_3OH] / [CO] [H_2]^2$ **(1)** 1

(ii) use of $K_c = [CH_3OH] / [CO] [H_2]^2$ and moles to obtain a calculated value **(1)**

convert moles to concentration by +2: $[CO] = 3.10 \times 10^{-3}$ mol dm^{-3}; $[H_2] = 2.60 \times 10^{-5}$ mol dm^{-3}; $[CH_3OH] = 2.40 \times 10^{-2}$ 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: dm^6 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) $CH_3OH + 1½\ O_2 \rightarrow CO_2 + 2H_2O$**(1)** 1

(ii) adds oxygen/oxygenated **(1)** 1

[13]

2. (a) $K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$ **(1)** 1

(b) (i) $PCl_5 > 0.3$ mol dm^{-3} ; PCl_3 and $Cl_2 < 0.3$ 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 $K_c = 0.245$ 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 → left to oppose increase in energy/
because K_c decreases **(1)** 2

[9]

3. (a) $CH_4 + H_2O \rightarrow 3H_2 + CO$ 1
$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$
$CH_4 + H_2O \rightarrow 2H_2 + CH_2O$/HCHO
$CH_4 + 2H_2O \rightarrow 2H_2 + CH_2O_2$/HCOOH ✓
or $CH_4 + H_2O \rightarrow H_2 + CH_3OH$ ✓

(b) (i) $k_c = \dfrac{[NH_3]^2}{[N_2][H_2]^3}$ ✓ 1

$[NH_3]^2 = (K_c \times [N_2] \times [H_2]^3)$ ✓
$= 0.768$ ✓

(ii) $[NH_3] = \sqrt{0.78} = 0.876/0.88$ (mol dm^{-3}) ✓ 3
If no powers, then rearrangement mark only.

(c) **High pressure:**

adv: Fewer moles on r.h.s. → equilibrium moves to right ✓
Greater pressure → faster rate/more frequent collisions ✓

dis: Safety issues from (high) pressure
Expense of (high) pressure ✓ 3

High temperature:

adv: more collisions exceed activation energy/
more successful collisions/more energetic
collisions/molecules have more energy ✓
dis: Equilibrium moves to left/reverse direction because
(forward) reaction is exothermic ✓ 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) $K_c = \dfrac{[HI]^2}{[H_2][I_2]}$ **(1)** 1

(b) (i)

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

2

(ii) $K_c = \dfrac{0.32^2}{0.14 \times 0.04}$ = 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 × $[O_2]$ as Exp. 1: rate increases by 4 **(1)**,
so order = 1 with respect to O_2 **(1)**

NO:
Exp 3 has 3 × [NO] as Exp. 3: rate has increases by 9 **(1)**,
so order = 2 with respect to NO **(1)** 4

(ii) rate = $k[O_2]\,[NO]^2$ **(1)** 1

(iii) $k = \frac{\text{rate}}{[O_2][NO]^2} = \frac{7.10}{0.0010 \times 0.0010^2} = 7.10 \times 10^9$ **(1)**

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

[8]

6. (a) $K_p = \frac{p(SO_3)^2}{p(SO_2)^2 \times p(O_2)}$ **(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 → 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) $3.0 \times 10^2 = \frac{p(SO_3)^2}{10^2 \times 50}$ **(1)**

$p(SO_3) = \sqrt{(3.0 \times 10^2 \times 10^2 \times 50)} = 1225$ kPa **(1)**
$\%(SO_3) = 100 \times 1225 / (1225 + 10 + 50) = 95\%$ **(1)** 3

(d) (i) $2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$ **(1)(1)**
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) rate = $k[O_3]\ [C_2H_4]$ **(1)** 1

(b) (i) measure gradient/tangent **(1)** at t = 0/start of reaction **(1)** 2

(ii) $k = \frac{\text{rate}}{[O_2][C_2H_4]}$ **(1)**

$k = \frac{1.0 \times 10^{-12}}{0.5 \times 10^{-7} \times 1.0 \times 10^{-8}}$ $= 2 \times 10^3$ **(1)** $dm^3\ mol^{-1}\ s^{-1}$ **(1)** 3

(iii) 2 mol CH_2O forms for every 0.5 mol O_2 /
stoichiometry of $CH_2O : O_2$ 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 2nd mark, all O atoms must have an octet.

A triangular molecule would have 3 single covalent bonds
for 1st mark but the origin of each electron must be clear for 2nd mark 2

(iii) amount of O_3 in 150 kg = $150 \times 10^3/48 = 3.13 \times 10^3$ mol **(1)**
amount of C*l* radicals in 1 g = 1 /35.5 = 2.82×10^{-2} mol **(1)**
1 mol C*l* destroys $3.13 \times 10^3/2.82 \times 10^{-2} = 1.11 \times 10^5$ mol O_3
1 C*l* 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_3OH	
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 3rd and 4th rows, ecf from previous row 4

(ii) $K_p = \dfrac{p(CH_3OH)}{p(CO) \times p(H_2)^2}$ **(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)**

$K_p = \dfrac{0.261}{3.70 \times 5.10^2}$ = 2.71×10^{-3} **(1)** MPa^{-2} **(1)** 3

(iv) calc value 2.7120546×10^{-3}; answer and/or units ecf from (ii) 2

(c) $CH_3OH + 1.5O_2 \rightarrow CO_2 + 2H_2O$ **(1)** 1

[18]