AQA A-LEVEL CHEMISTRY · 7405

CHEMISTRY



MARK SCHEME

3.1.6 CHEMICAL EQUILIBRIA, LE CHATELIER'S PRINCIPLE AND KC

SCORE	PERCENTAGE
/552	%

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Q1.

(a) 3 minutes

M2 dependent on M1 or near miss

1

(At equilibrium, $rate_{fwd}$ = $rate_{back}$ so) concentrations (of O_2 and SO_3) remain constant

Not concentrations are the same/equal

Allow (after this point) gradient is zero / curve flattens out

1

(b) Sketch begins at origin <u>and</u> goes up until 3 mins

1

Levels off at 0.3 mol dm^{-3}

Mark Independently

1

(c) T_2 (Not worth a mark alone)

T_1, CE=0

Equilibrium has <u>moved / shifted</u> to <u>RHS/forward</u> in <u>endothermic</u> direction

Both RHS / forward and endothermic needed

1

Equilibrium has opposed the increase in T / Equilibrium moves to decrease the T

Not just to oppose the change

1

[6]

Q2.

(a) **M1** no effect (on yield)

CE = 0 if yield changes

1

M2 increases rate / speed of both / forward and reverse reactions <u>equally / by the same amount</u>

*If no reference to effect on yield, could still score **M2***

Ignore reference to no change in position of equilibrium, and reference to lowering activation energies

***M2** allow changes rate of both / forward and reverse reactions <u>equally / by the same amount</u>*

1

(b) $(K_c =) \frac{[CH_3OH]}{[CO][H_2]^2}$

Must be square brackets

Ignore state symbols

Ignore units

1

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(c) **M1** divides moles by volume (0.250 or $\frac{250}{1000}$)

M2 $K_c = \frac{\frac{0.0610}{0.250}}{\left[\frac{0.340}{0.250}\right]\left[\frac{0.190}{0.250}\right]^2} \left(= \frac{0.244}{1.36 \times 0.76^2}\right)$

1

M3 0.311

1

*Correct answer scores 3; **M3** to at least 2sf (0.3106159 …); ignore units*

*Allow ECF from **M1** to **M2** if an attempt to calculate concentration has been made by dividing by some factor of 250 cm³*

*Allow ECF from **M2** to M3 for use of an expression containing each reagent in a correctly substituted K_c expression*

If volume not used, then allow M3 only for 4.97 (4.96985 … to at least 2sf)

1

(d) **M1** $\frac{1}{\text{Answer to (c)}}$ = 3.22

***M1** to at least 2sf (0.31 gives 3.2(258))*

***M1** = 1.21 if alternative answer to 8.3 used*

*If an error was made in 8.3, but the candidate produced an answer in 8.4 that did fit the inverted calculation from 8.3, then candidate could score **M1***

1

M2 $mol^2\ dm^{-6}$

(if volumes are not used, then candidate would get 0.20(12.)

1

[8]

Q3.

C

[1]

Q4.

(a) Initial amount of A = 6.4×10^{-3}

If M1 wrong can score max 3

M1

Equ A = $6.4 \times 10^{-3} - 2x \therefore x = 1.25 \times 10^{-3}$

If incorrect x can score max 3

M2

B = $9.5 \times 10^{-3} - x = 8.25 \times 10^{-3}$

Allow 2 or more sig figs

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M3

$C = 2.8 \times 10^{-2} + 3x = 0.0318$

M4

$D = x = 1.25 \times 10^{-3}$

M5

(b) $K_c = \frac{[C]^3[D]}{[A]^2[B]}$

Penalise ( ) but mark on in (b) & (c)

1

Units = mol dm^{-3}

If K_c wrong no mark for units

1

(c) M1 for correct rearrangement $[A]^2 = \frac{[C]^3[D]}{K_c[B]}$ or $[A] = \sqrt{\frac{[C]^3[D]}{K_c[B]}}$

If K_c wrong in (b) can score 1 for dividing by correct volume

M1

M2 for division of mol of B, C and D by correct volume

If K_c correct but incorrect rearrangement can score 1 for dividing by correct volume

M2

$$[A]^2 = \frac{[1.05/0.5]^3[0.076/0.5]}{116 \times [0.21/0.5]}$$

M3 for final answer: [A] = 0.17 (must be 2 sfs)

M3

(d) (All) conc fall: (ignore dilution)

OR K_c = mole ratio × 1/V

1

Equm moves to side with more moles

If vol increases, mole ratio must increase

1

To oppose the decrease in conc

To keep K_c constant

If only conc of A falls CE=0

If pressure falls CE=0

1

[13]

Q5.

C

[1]

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Q6.

D

[1]

Q7.

(a) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

Level 3 (5 – 6 marks)
All stages are covered and the explanation of each stage is generally correct and virtually complete. To access Level 3, statement 3a must be considered.
Answer is communicated coherently and shows a logical progression from stage 1 (including 1b) to stage 2 and stage 3

Level 2 (3 – 4 marks)
All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.
Answer is mainly coherent and shows progression from stage 1 to stage 2 and/or stage 3.

Level 1 (1 – 2 marks)
Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.
Answer includes isolated statements but these are presented in a logical order, with sensible reasoning.

Level 0 (0 marks)
Insufficient correct chemistry to gain a mark.

Indicative chemistry content

Stage 1 – Deductions from graph
1a Yield increases as temperature increases (or converse)
1b After a certain temperature yield no longer increases
1c Yield decreases as pressure increases (or converse)

Stage 2 – Optimum temperature and explanation
2a High temperature results in high energy costs/expensive
2b (After a certain temperature) yield no longer increases therefore there is no gain in using a higher temperature
2c Optimum temperature is between 780-880oC

Stage 3 – Optimum pressure and explanation
3a Low pressure may be too slow
3b So compromise pressure required
3c Optimum pressure is 1000-2000kPa or moderate pressure used

6

(b) Moles of carbon monoxide 17.9

Allow 17.94

1

Moles of hydrogen 19.9

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Allow 19.88

1

(c) $K_p = \frac{pp(CH_3OH)}{pp(CO) \times pp(H_2)2}$

ignore brackets
If K_p expression incorrect can only score M2 & M3 & M4

1

Total moles of gas = (2.76 + 4.51 + 0.36) = 7.63
If CE in M2 allow ecf for M3, M4 and M6
If no total moles calculated then can only score M1 and M6

1

$pp(CO) = \frac{2.76}{7.63} \times 630$ (kPa) (= 228 (kPa))

$pp(H_2) = \frac{4.51}{7.63} \times 630$ (kPa) (= 372 (kPa))

$pp(CH_3OH) = \frac{0.36}{7.63} \times 630$ (kPa) (= 29.7 (kPa))

All 3 pp of CO, H_2 and CH_3OH = 2 marks
2 pp correct = 1 mark

2

$Kp = \frac{29.7}{228 \times (372)2} = 9.4(1) \times 10^{-7}$ or $9.4(1) \times 10^{-13}$ if *pp* in Pa

can also score M1 from this expression
Allow 9.39 to 9.50 × 10^{-7} (kPa^{-2})

1

kPa^{-2} or **Pa^{-2}** (if converted to 630 000)
*If no marks awarded allow M6 only for **kPa^{-2}** or **Pa^{-2}***

1

[14]

Q8.

C

[1]

Q9.

(a) Decrease

1

Increasing pressure moves equilibrium to the side of least moles i.e. backward reaction

1

To oppose the increase in pressure or to decrease the pressure

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1

(b) A catalyst speeds up the rate of the forward and backward reaction

1

By the same amount

1

(c) ΔH = −111 − (−75 − 242)

1

206 (kJ mol^{-1})

1

(d) $\Delta S = 3 \times 131 + 198 - (186 + 189) = 216$ J K^{-1} mol^{-1}

1

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

1

$0 = 206 - T\frac{216}{1000}$

1

T = 953.7 or 954 K

1

T = 681 (°C)

If the value given in the question is used then the answer is 283 (°C)

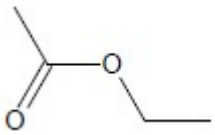
1

[12]

Q10.

(a) $CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$

1

(b) 

1

(c) A catalyst provides an alternative mechanism for reaction.

1

That has a lower activation energy.

1

(d) K_c expression shown correctly e.g. $K_c = \frac{[ester][water]}{[acid][alcohol]}$

1

Hence $K_c = 4.07 = x^2 / (0.0435 - x)^2$ (if x = amount of ester/water produced and therefore = amount by which amounts of acid and alcohol decreased).

1

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So $\sqrt{4.07} = x^2/(0.0435 - x)^2$
So x = 0.0291 mol.

1

Acid left at equilibrium = 0.0435 − 0.0291 = 0.0144 mol.

1

Adding acid catalyst = 0.0144 + 2(0.0005) = 0.0154 mol (adding 2 × 0.0005 as 0.0005 mol of H_2SO_4 added and catalyst so not used up and dibasic).

1

Volume of alkali needed = 1000 × 0.0154/0.400 = 38.5 cm^3.

1

(e) Test several samples − at least one tested after a week.

1

Check that the result has not changed.

1

[12]

Q11.

(a) amount of X = 0.50 – 0.20 = 0.30 (mol)

1

amount of Y = 0.50 – 2 × 0.20 = 0.10 (mol)

1

(b) Axes labelled with values, units and scales that use over half of each axis
All three of values, units and scales are required for the mark

1

Curve starts at origin

1

Then flattens at 30 seconds at 0.20 mol

1

(c) Expression = $K_c = \frac{[Z]}{[X][Y]^2}$

1

$[Y]^2 = \frac{[Z]}{[X]\,K_c}$

1

$[Y] = (0.35 / 0.40 \times 2.9)^{0.5} = 0.5493 = 0.55$ (mol dm^{-3})
Answer must be to 2 significant figures

1

(d) Darkened / went more orange

1

The equilibrium moved to the right

1

To oppose the increased concentration of Y

1

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(e) The orange colour would fade

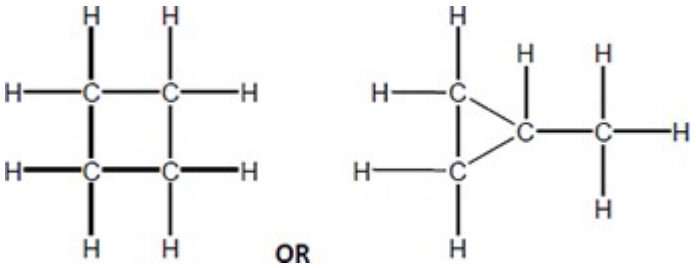
1

[12]

Q12.

(a) Alkenes

1



OR

Correctly drawn molecule of cyclobutane or methyl cyclopropane, need not be displayed formula

1

(b) C_6H_{14} (or correct alkane structure with 6 carbons)

Allow hexane or any other correctly named alkane with 6 carbons

1

(c) Poly(but-2-ene)

1

(d) High pressure

Allow pressure ≥ MPa

Mention of catalyst loses the mark

1

(e) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

Level 3

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer communicates the whole process coherently and shows a logical progression from stage 1 and stage 2 (in either order) to stage 3.

5–6 marks

Level 2

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression. Some steps in each stage may be out of order and incomplete.

3–4 marks

Level 1

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Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

1–2 marks

Level 0

Insufficient correct chemistry to gain a mark.

0 marks

Indicative chemistry content

Stage 1*: consider effect of higher temperature on yield*

(Or vice versa for lower temperature)

- *Le Chatelier's principle predicts that equilibrium shifts to oppose any increase in temperature*
- *Exothermic reaction, so equilibrium shifts in endothermic direction / to the left*
- *So a Higher T will reduce yield*

Stage 2*: consider effect of higher temperature on rate*

(Or vice versa for lower temperature)

- *At higher temperature, more high energy molecules*
- *more collisions have E>Ea*
- *So rate of reaction increases / time to reach equilibrium decreases*

Stage 3*: conclusion*

Industrial conditions chosen to achieve (cost-effective) balance of suitable yield at reasonable rate

[11]

Q13.

(a) Bonds broken = 2(C=O) + 3(H–H) = 2 × 743 + 3 × H–H

Bonds formed = 3(C–H) +(C–O) + 3(O–H) = 3 × 412 + 360 + 3 × 463

Both required

1

–49 = [2 × 743 + 3 × (H–H)] – [3 × 412 + 360 + 3 × 463]

3(H–H) = –49 – 2 × 743 + [3 × 412 + 360 + 3 × 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 CO_2 (and / or methanol and / or water)

1

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

1

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(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

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Initial moles	1.0	3.0	0	0
Eqm moles	(1–0.86) = 0.14	(3–3×0.86) = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

p_{CO2} = mol fraction × p_{total} = 0.14 × 500 / 2.28 = 30.7 kPa

p_{H2} = mol fraction × p_{total} = 0.42 × 500 / 2.28 = 92.1 kPa

M3 is for partial pressures of both reactants

Alternative M3 =

pp_{CO2} = 0.0614 × 500

pp_{H2} = 0.1842 × 500

1

p_{CH3OH} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

p_{H2O} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

M4 is for partial pressures of both products

Alternative M4 =

pp_{CH3OH} = 0.3772 × 500

pp_{H2O} = 0.3772 × 500

1

Stage 3: Equilibrium constant calculation

$K_p = p_{CH3OH} \times p_{H2O} / p_{CO2} \times (p_{H2})^3$

1

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

Answer must be to 2 significant figures

1

Units = $\underline{kPa^{-2}}$

1

[16]

Q14.

C

[1]

Q15.

A

[1]

Q16.

(a) (i) Curve drawn from origin with peak clearly lower and to right.

*New curve crosses original once only, finishes above original and does **not** clearly curve up*

***IGNORE** relative areas*

1

(ii) (Relative areas under curves indicate) <u>many</u> (owtte)
more molecules with E greater than or equal to Ea (at higher T)
or reverse argument

***ALLOW** 'particles'*

***IGNORE** 'atoms'*

1

(Large) increase in (number of) <u>successful</u> (owtte) <u>collisions per unit</u> time

OR '<u>frequency</u> of successful <u>collisions</u>'

1

(b) (i) Yield increases

Yield decreases/stays the same CE = 0

If not answered mark on

1

More moles/molecules (of gas) on left/fewer on right/3 on left 1 on right

1

<u>Equilibrium shifts/moves</u> (to right) to reduce pressure/oppose higher pressure

No M3 if 'more moles on right' in M2

***IGNORE** 'favours'*

***NOT** just 'oppose the change'*

QoL means that M3 is only awarded if these ideas are clearly linked in one statement

1

(ii) Higher T would increase rate but decrease yield/make less methanol
OR

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Lower T decreases rate but increases yield;

*If no mention of both rate **AND** (idea of) yield max 1*

1

Chosen T is a compromise/balance (between rate and yield) owtte

1

[8]

Q17.

(a) (i) **M1**

High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2

The (forward) reaction / to the right is endothermic or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M3 depends on correct M2 and must refer to temperature / heat

M3** depends on a correct statement for **M2

At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

to absorb heat OR

to lower the temperature OR

to cool down the reaction

3

(ii) **M1**

The reaction gets to equilibrium faster / in less time

OR

Produces a small yield faster / in less time

OR

Increases the rate (of reaction / of attainment of equilibrium)

Mark independently

M2

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

AND

- more collisions in a given time / increased collision frequency

*Penalise **M2** for reference to increased energy of the particles*

2

(iii) **M1** Increase in / more / large(r) / big(ger) surface area / surface sites

Mark independently

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*For **M1** accept Éan increase in surface"*

M2 increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)

*For **M2** not simply "more collisions"*

Ignore "the chance or likelihood" of collisions

2

(b) **M1**

No effect / None

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2 requires a correct M1

Equal / same number / amount of moles / molecules / particles on either side of the equation

OR

2 moles / molecules / particles on the left and 2 moles / molecules / particles on the right

M2** depends on a correct statement for **M1

*In **M2 not** "atoms"*

2

[9]

Q18.

(a) $MgCl_2(s) \longrightarrow Mg^{2+}(aq) + 2Cl^-(aq)$

State symbols essential

Do not allow this equation with H_2O on the LHS

Ignore + aq on the LHS

Allow H_2O written over the arrow / allow equation written as an equilibrium

Allow correct equations to form $[Mg(H_2O)_6]^{2+}$ ions

1

(b) $\Delta H_{soln}\ MgCl_2 = LE + (\Delta H_{hyd}Mg^{2+}) + 2(\Delta H_{hyd}Cl^-)$

$\Delta H_{soln}\ MgCl_2 = 2493 - 1920 + (2 \times -364)$

$= -155$ (kJ mol-1)

M1 for expression in words or with correct numbers

Ignore units, but penalise incorrect units

1

1

(c) M1: Solubility decreases (as temp increases)

M2: the enthalpy of solution is exothermic / reaction is exothermic / backwards reaction is endothermic

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce temperature/oppose the increase in temperature (in the endothermic direction)

If M1 is incorrect then CE=0/3

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If answer to (b) is a +ve value, allow:

M1: Solubility increases (as temp increases)

M2: Enthalpy of solution is endothermic etc

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce the temperature/oppose the increase in temperature (in the endothermic direction)

1
1
1

[6]

Q19.

(a) Mol of **E** 1.6(00)

Ignore extra zeros.

1

Mol of **F** 0.2(00)

1

(b) $K_c = \dfrac{[G]^2}{[E][F]^2}$

Penalise expression containing V.

Penalise missing brackets or ( ).

1

$mol^{-1}\ dm^3$

If K_c wrong, allow units consequential to their K_c, but no marks in (c) unless correct K_c used in (c).

1

(c) $K_c = \dfrac{(0.85/1.5)^2}{(2.50/1.5)(1.20/1.5)^2}$

Vol missed or used wrongly – no marks.

If K_c correct in (b) but squared term missed here, no further marks.

1

= 0.3(01) Allow 0.299−0.304

Ignore units.

1

(d) M1 Decrease

If M1 is incorrect CE=0 for the clip.

If M1 is blank, mark on and seek to credit the correct information in the explanation.

1

M2 More moles on LHS / reactants or fewer / less moles on RHS / products (allow correct ratio 3:2)

M2 not just a generic statement 'shifts to more moles'.

1

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M3 (Equilibrium) <u>shifts / moves</u> either to oppose reduction in pressure / or to increase the pressure

M3 depends on a correct statement for M2.

Not 'favours'.

Allow 'to oppose change' only if reduction in pressure noted.

1

(e) M1 T_1

If M1 is incorrect, CE=0 for the clip.

If M1 is blank, mark on and seek to credit the correct information in the explanation.

1

M2 (Forward*) reaction is <u>exothermic</u>
OR <u>Backward</u> reaction is <u>endothermic</u>

**Assume answer refers to forward reaction unless otherwise stated.*

1

M3 (at T_2 or lower temperature)

(Equilibrium) <u>shifted / moved</u> to oppose reduction in temp

OR

at T_1 or higher temp, (Equilibrium) <u>shifted / moved</u> to oppose (increase in temp)

M3 depends on a correct statement for M2

Allow "to oppose change" only if change in temperature is stated.

Not 'favours'.

1

[12]

Q20.

(a) (i) M1 <u>c(oncentrated) phosphoric acid / c(onc.) H_3PO_4</u>
OR <u>c(oncentrated) sulfuric acid / c(onc.) H_2SO_4</u>

*In **M1**, the acid must be concentrated.*
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
OR pass the gases over the catalyst several / many times

*In **M2**, ignore "remove the ethanol".*
Credit "re-use".

2

(ii) M1
(By Le Chatelier's principle) the equilibrium is <u>driven / shifts / moves to the right / L to R / forwards / in the forward direction</u>

M2 depends on a correct statement of M1
The <u>equilibrium moves / shifts to</u>

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- oppose the addition of / increased concentration of / increased moles / increased amount of water / steam
- to decrease the amount of steam / water

Mark M3 independently
M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

3

(iii) M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

M2 At higher pressures
More / higher cost of electrical energy to pump / pumping cost
OR
Cost of higher pressure equipment / valves / gaskets / piping etc.
OR expensive equipment

*Credit all converse arguments for **M2***

2

(b) M1 for balanced equation

M2 for state symbols in a correctly balanced equation

$2C(s / graphite) + 3H_2(g) + ½O_2(g) \longrightarrow CH_3CH_2OH(l)$ (C_2H_5OH)

Not multiples but credit correct state symbols in a correctly balanced equation.

Penalise C_2H_6O but credit correct state symbols in a correctly balanced equation.

2

(c) (i) M1 The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

*If standard enthalpy of formation **CE=0***

M2 is burned / combusts / reacts completely in oxygen
OR burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states
OR (all) reactants and products / (all) substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K

*For **M3***
Ignore reference to 1 atmosphere

3

(ii) M1

Correct answer gains full marks

ΣB(**reactants**) − ΣB(**products**) = *ΔH*

Credit 1 mark for (+) 1279 (kJ mol^{-1})

OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR

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B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = <u>*ΔH*</u>

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
(2060) (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*
(3220) (2778)
OR using only bonds broken and formed (**4256 − 5535**)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of **M1** which could be in words and scores **only M1***

M3
ΔH= **− 1279** (kJ mol^{-1})

*Allow a maximum of one mark if the only scoring point is LHS = 4719 **OR** RHS = 5998*

Award 1 mark for +1279

Candidates may use a cycle and gain full marks

3

(d) (i) Reducing agent ***OR*** reductant ***OR*** electron donor ***OR*** to reduce the copper oxide

Not "reduction".

Not "oxidation".

Not "electron pair donor".

1

(ii) CH_3COOH

1

[17]

Q21.

(a) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase

OR

(When a system / reaction in equilibrium is disturbed), the (position of) equilibrium shifts / moves in a direction which tends to reduce the disturbance

An alternative to shift / move would be the idea of changing / altering the position of equilibrium

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1

(b) (i) M1
A substance that <u>speeds up the reaction / alters the rate</u> but is <u>chemically unchanged at the end / not used up</u>

*Both ideas needed for **M1***

*Credit can score for **M1**, **M2** and **M3** from anywhere within the answer*

M2
Catalysts provide an alternative route / alternative pathway / different mechanism

M3
that has a <u>lower activation energy / E_a</u>

OR
<u>lowers the activation energy / E_a</u>

3

(ii) (Time is) less / shorter / decreases / reduces

Credit "faster", "speeds up", "quicker" or words to this effect

1

(iii) None

1

(c) (i) R

1

(ii) T

1

(iii) R

1

(iv) P

1

(v) Q

1

[11]

Q22.

(a) (i) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> ΔH symbols and the $\sum$ or SUM)**

M1 $\underline{\Delta H_r}$ = $\Sigma\Delta H_f$ **(products)** - $\Sigma\Delta H_f$ **(reactants)**

OR a <u>correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$</u>

M2 $\underline{\Delta H_r}$ = – 201 + (– 242) – (– 394)
$\underline{\Delta H_r}$ = – 201 – 242 + 394
$\underline{\Delta H_r}$ = – 443 + 394
(This also scores M1)

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M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (kJ mol^{-1})
For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either*
  correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$
  *OR a clear statement of **M1** which could be in words and*
  *scores <u>only **M1**</u>*

3

(ii) It is an element / elemental
Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more
*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are <u>more moles / molecules</u> (of gas) on the left / of reactants
OR <u>fewer moles / molecules</u> (of gas) on the right / products
OR there are <u>4 moles /molecules</u> (of gas) on the left <u>and 2 moles / molecules</u> on the right.
OR (equilibrium) shifts / moves <u>to the side with less moles / molecules</u>
*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if <u>M2 is correct</u>

The (position of) <u>equilibrium shifts / moves</u> (from left to right) to <u>oppose the increase in pressure</u>
*For **M3**, <u>not</u> simply "to oppose the change"*
*For **M3** credit the <u>equilibrium shifts / moves</u> (to right) to <u>lower / decrease the pressure</u>*
(There must be a <u>specific</u> reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

M2 The (forward) reaction / to the right is <u>endothermic</u> OR <u>takes in/ absorbs heat</u>

OR

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The reverse reaction / to the left is exothermic OR gives out / releases heat

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 if M2 is correct

M3 The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in temperature **(QoL)**

*For **M3**, not simply "to oppose the change"*

*For **M3**, credit the (position of) equilibrium shifts / moves **(QoL)***

*to absorb the heat **OR***

*to cool the reaction **OR***

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount / level of carbon dioxide /CO_2 carbon /greenhouse gas present in the atmosphere.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from the atmosphere

1

(ii) $CH_3OH + \mathbf{1}½\ O_2 \rightarrow CO_2 + \mathbf{2}H_2O$

Ignore state symbols

Accept multiples

1

(iii) $\mathbf{3}H_2 + \mathbf{1}½\ O_2 \rightarrow \mathbf{3}H_2O$

Ignore state symbols

OR

Accept multiples

$\mathbf{2}H_2 + O_2 \rightarrow \mathbf{2}H_2O$

Extra species must be crossed through

1

(e) **M1** $q = m\ c\ \Delta T$

Award full marks for correct answer

Ignore the case for each letter

OR $q = 140 \times 4.18 \times 7.5$

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol

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therefore ΔH = **– 399** (kJmol^{-1})
OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

*In **M1**, do not penalise incorrect cases in the formula*

If ΔT = 280.5; score q = m c ΔT only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]

Q23.

(a) (i) mol H_2 = 0.47

1

mol I_2 = 0.17

If answers reversed, ie

mol H_2 = 0.17

mol I_2 = 0.47

then allow one mark (for second answer).

1

(ii) $\frac{[HI]^2}{[H_2][I_2]}$

Penalise expression containing V
But mark on in (a)(iv)

***Penalise missing square brackets** in this part (and not elsewhere in paper) but mark on in (a)(iv)*

1

(iii) equal number of moles (on each side of equation)

OR

equal moles (top and bottom of *K*c expression)

1

(iv) $\frac{[1.94]^2}{[0.38][0,19]}$

Ignore V

If Kc wrong in (a)(ii) (wrong powers or upside down etc) no marks here

1

= 52(.1)

1

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(b) (i) **D**

1

(ii) **B**

1

(iii) **A**

1

(iv) **C**

1

[10]

Q24.

(a) **In either order**

For M1 accept [ ] for concentration

M1 Concentrations (of reactants and products) remain or stay constant / the same

NOT "equal concentrations" and NOT "concentration(s) is / are the same"

M2 Forward rate = Reverse / backward rate

NOT "amount"

Ignore "dynamic" and ignore "speed"

Ignore "closed system"

It is possible to score both marks under the heading of a single feature

2

(b) **M1** Catalysts increase rate of / speed up both forward and reverse / backward reactions

If M1 is given as "no effect" / "no change" then CE= 0 for clip

M2 increase in rate / affect on rate / speed is equal / the same

Ignore references to "decrease in rate"

2

(c) (i) **M1** (The yield) increases / goes up / gets more

If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank.

M2 There are more moles / molecules (of gas) on the left / of reactants

Ignore "volumes", "articles" "atoms" and "species" for M2

OR fewer moles / molecules (of gas) on the right / products

OR there are 4 moles / molecules (of gas) on the left and 2 moles / molecules on the right.

OR (equilibrium) shifts / moves to the side with less moles / molecules

M3 Can only score M3 if M2 is correct

The equilibrium shifts / moves (from left to right) to oppose the increase in pressure

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For M3, <u>not</u> simply "to oppose the change"

For M3 credit the <u>equilibrium</u> <u>shifts / moves</u> to <u>lower / decrease</u> the <u>pressure</u>

(There must be a <u>specific</u> reference to the change that is opposed)

3

(ii) **M1** The yield decreases / goes down / gets less

If M1 is given as "increase" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank.

M2 (Forward) reaction is <u>exothermic</u> ***OR*** <u>gives out / releases heat</u>

OR

reverse reaction is <u>endothermic</u> ***OR*** <u>takes in / absorbs heat</u>

Can only score M3 <u>if M2 is correct</u>

The <u>equilibrium shifts / moves</u> (from right to left) to <u>oppose the increase in temperature</u>

For M3, <u>not</u> simply "to oppose the change"

For M3 credit the <u>equilibrium shifts / moves</u>

to <u>absorb the heat</u> OR

to <u>cool the reaction</u> OR

to <u>lower the temperature</u>

(There must be a <u>specific</u> reference to the change that is opposed)

3

(d) (i) Must be comparative

Credit correct reference to rate being <u>too (s)low / (s)lower</u> at temperatures less than 600 K

<u>Higher rate</u> of reaction

OR <u>increase / speed up the rate</u> (of reaction)

Ignore statements about the "yield of ammonia"

OR Gets to equilibrium <u>faster/ quicker</u>

OR <u>faster or quicker rate / speed</u> of attainment of equilibrium

1

(ii) <u>Less</u> electrical <u>pumping cost</u>

Not just "less expensive" alone

OR

Not just "less energy or saves energy" alone

Use lower pressure <u>equipment / valves / gaskets / piping</u> etc.

Credit correct <u>qualified</u> references to higher pressures

OR

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Uses less expensive <u>equipment</u>

Ignore references to safety

1

[12]

Q25.

(a) (i) $Cu + \mathbf{4}HNO_3 \longrightarrow Cu(NO_3)_2 + \mathbf{2}NO_2 + \mathbf{2}H_2O$

Or multiples

Ignore state symbols

1

(ii) **M1** HNO_3 (+) **5**

M2 NO_2 (+) **4**

Ignore working out

M1 Credit (V)

M2 Credit (IV)

2

(iii) $HNO_3 + H^+ + e^- \longrightarrow NO_2 + H_2O$

OR

$NO_3^- + 2H^+ + e^- \longrightarrow NO_2 + H_2O$

Or multiples

Ignore state symbols

Ignore charge on the electron unless incorrect and accept loss of electron on the RHS

1

(b) (i) **In either order**

M1 <u>Concentration(s)</u> (of reactants and products) <u>remain(s) constant / stay(s) the same / remain(s) the same / do(es) not change</u>

M2 <u>Forward rate = Reverse / backward rate</u>

For M1 accept [ ] for concentration

NOT "equal concentrations" and NOT "concentration(s) <u>is/are</u> the same"

NOT "amount"

Ignore "dynamic" and ignore "speed"

Ignore "closed system"

It is possible to score both marks under the heading of a single feature

2

(ii) **M1**

The (forward) reaction / to the right is <u>endothermic</u> or <u>takes in / absorbs heat</u>

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OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M2 depends on correct M1 and must refer to temperature/heat

The equilibrium shifts / moves left to right to oppose the increase in temperature

M2 depends on a correct statement for M1

For M2, the equilibrium shifts/moves

to absorb the heat OR

to lower the temperature OR

to cool the reaction

2

(iii) **M1 refers to number of moles**

There are fewer moles (of gas) on the left OR more moles (of gas) on the right.
OR there is one mole (of gas) on the left and 2 moles on the right.

M2 depends on correct M1 and must refer to pressure
The equilibrium shifts / moves right to left to oppose the increase in pressure

M2 depends on a correct statement for M1

For M2, the equilibrium shifts/moves to lower the pressure.

2

[10]

Q26.

(a) (i) Mol SO_3 = 5.2

1

Mol SO_2 = 2.8

1

(ii)

$$\frac{[SO_2]^2[O_2]}{[SO_3]^2}$$

Penalise expression containing numbers or V

Allow ( ) but must have all brackets. If brackets missing but otherwise correct, penalise here but mark on

Ignore subsequent correct working

If Kc wrong (wrong powers or upside down etc) can only score M1 in (a)(iv)

1

(iii) mol dm^{-3}

Allow conseq to their wrong Kc

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1

(iv) *If Kc wrong in (a)(iv) (wrong powers or upside down etc) can only score M1*

Values from (a)(i)

$$\frac{[2.8/12]^2[1.4/12]}{[5.2/12]^2} \quad \text{or} \quad \frac{[0.233]^2[0.117]}{[0.433]^2}$$

Alternative values

$$\frac{[2.1/12]^2[1.4/12]}{[5.8/12]^2}$$

1

M1 *For dividing all three by volume – if volume missed or used wrongly, lose M1 & M2 but can score M3 conseq*

M2 *insertion of values (allow conseq use of their wrong values from (a)(i))*
AE (–1) for copying numbers wrongly or swapping two numbers

1

Values from (a)(i)
M3 = 0.0338 or 0.034
(allow 0.03376 to 0.035)
Min 2 sfs
Ignore units in (a)(iv)
If vol missed score only M3
Values from (a)(i)
0.406 - allow values between 0.40 (if correctly rounded) and 0.41

Alternative values
M3 0.0153 or 0.015
(allow 0.015 to 0.017)
Min 2 sfs
Ignore units in (a)(iv)
from alternative values allow 0.18 to 0.184

1

(b) (i) Increase or more moles (of oxygen) or higher

1

(ii) No change or no effect or none or (remains) same

1

(c) **M1** T_1

If T_2 CE = 0

1

M2 (At Temp,T2, when Kc is lower) Equm/reaction moves to left or towards reagent or towards SO_3 OR moles SO_3 increases

1

M3 This reverse reaction is exothermic,

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OR

M3 (forward) reaction is endothermic

M2 if Temp is increased Equm/reaction moves to right or towards product or towards SO_2 OR moles SO_2 increases

OR

M3 (forward) reaction is endothermic

M2 if Temp is decreased Equm/reaction moves to left or towards reagent or towards SO_3 OR moles SO_3 increases

1

[12]

Q27.

(a) Forward and backward reactions proceeding at equal rate

1

Amount (Conc or moles or proportion) of reactants and products remain constant

Not ''reactants and products have equal conc''

1

(b) **M1** $\frac{[R]^2}{[P][Q]^2}$

Allow ( ) but must have all brackets

*If Kc wrong can only score **M3** (process mark) for dividing both R and P by volume)*

1

(c) **M2** $[Q]^2 = \frac{[R]^2}{k_c[P]}$

Rearrangement of correct Kc expression

*If wrong Kc used can only score **M3** for correct use of vol*

*If wrong rearrangement can only score max 2 for **M3** and **M5** for correct √*

1

M3 $[Q]^2 = \frac{(5.24/10)^2}{68.0 \times (3.82/10)}$

Process mark for dividing both R and P by volume even in incorrect expression

*If vol missed can only score max 2 for **M2** and M5 for correct √*

*If vol used but then wrong maths can score **M2 M3** and **M5** for correct √*

*If moles used wrongly, eg (2 × 5.24) or (5.24 × 10/10^3) can only score **M2** and **M5***

1

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M4 $[Q]^2 = 0.0106$

Correct calculation of Q^2

1

M5 $[Q] = 0.10(3)$

Correct taking of √

1

(c) cont.

Wrong rearrangement and no use of volume

0

Wrong rearrangement

*For Correct use of volume **M3** and Correct taking of square root **M5***

2 max

No use of volume

2 max

answer = 0.325

Ignore subsequent multiplying or dividing by 10.

***0.0325 or 3.25** still score max 2*

*For Correct rearrangement **M2** and*

*Correct taking of square root **M5***

2 max

Use of volume but maths error e.g. using $(5.24)^2/10$
when should be $(5.24/10)^2$

Scores 3

also giving answer 0.325

*for **M2**, **M3** and **M5***

3

Use of volume but Q/10 also used
or Q multiplied by 10 at end
(i.e.muddling moles with concentration)

Gives answer 1.03

*For Correct rearrangement **M2** and*

*Correct taking of square root **M5***

2 max

Wrong use of moles, e.g (5.24×2) or $(5.24 \times 10/10^3)$

*For Correct rearrangement **M2** and*

*Correct taking of square root **M5***

2 max

Wrong Kc used, e.g. missing powers

*For Correct use of volume **M3***

1 max

(d) Increase or more or larger

Allow moves to left

1

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(e) Increase or more or larger

Allow moves to left

1

(f) Decrease or less or smaller

NOT allow moves left

1

(g) No effect or unchanged or none

1

(h) 0.0147 or 0.0148 or 1.47×10^{-2} or 1.48×10^{-2}

Allow 0.015 or 1.5×10^{-2}

If not 0.0147, look at (c) for conseq correct use of their [Q] in new Kc = $1.39 \times [Q]^2$

Not allow just 1/68.0

ignore units

1

[24]

Q28.

(a) (i) chlorotrifluoromethane

Spelling must be correct but do not penalise "flouro"

Ignore use of 1–

1

(ii) CF_3•

May be drawn out with dot on C

OR if as shown dot may be anywhere

1

(iii) An unpaired/non-bonded/unbonded/free/a single/one/lone <u>electron</u>

NOT "bonded electron" and NOT "paired electron"

NOT "pair of electrons"

NOT "electron<u>s</u>"

Ignore "(free) radical"

1

(b) **M1** Cl• + $O_3 \rightarrow$ ClO• + O_2

M2 ClO• + $O_3 \rightarrow$ **2**O_2 + Cl•

Mark independently

Equations could gain credit in either position

The dot can be anywhere on either radical

Penalise the absence of a dot on the first occasion that it is seen and then mark on. Do <u>not</u> make the same penalty in the next equation, but penalise the absence of a dot on the other radical.

Apply the list principle for additional equations

2

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(c) (i) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift/move so as to oppose the change.

OR

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase.

An alternative to shift/move would be the idea of changing/altering the position of equilibrium

1

(ii) **M1** The (forward) reaction/to the right is endothermic or takes in heat

OR The reverse reaction/to the left is exothermic or gives out heat

M2 The equilibrium moves/shifts to oppose the increase in temperature

M2 depends on a correct statement for M1

For M2 accept

The equilibrium moves/shifts

- *to take in heat/lower the temperature*
- *to promote the endothermic reaction and take in heat/ lower the temperature*
- *to oppose the change and take in heat/lower the temperature*

(leading to the formation of more ozone)

2

(d) Any one of

- Pentane does not contain chlorine OR C–Cl (bond)
- Pentane is chlorine-free
- Pentane does not release chlorine (atoms/radicals)

Ignore reference to F OR C–F OR halogen

Ignore "Pentane is not a CFC"

Ignore "Pentane is a hydrocarbon"

Ignore "Pentane only contains C and H"

Ignore "Pentane is C_5H_{12}"

1

[9]

Q29.

(a) (i) $\mathbf{4}FeS_2 + \mathbf{11}O_2 \longrightarrow \mathbf{2}Fe_2O_3 + \mathbf{8}SO_2$

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2 **5½** **(1)** **4**

Or multiples of this equation

1

(ii) **M1** **(+) 4**

M2 **– 1**

Ignore working

M1, credit (+) IV

M2, credit – I

2

(b) **M1** Lower/smaller/decreases/reduced yield
OR <u>equilibrium</u> shifts (right) <u>to left</u>

M2 (Forward) reaction is <u>exothermic</u> OR reverse reaction is <u>endothermic</u>

M3 (By Le Chatelier's principle) equilibrium responds/shifts/moves (R to L)
to lower the temperature
OR <u>to absorb the heat</u>
OR <u>to cool the reaction</u>

If M1 is blank, mark on and credit M1 in the text.

If M1 is incorrect, only credit correct M2

Mark M2 independently – it may be <u>above</u> the arrow in the equation

For M3, not simply "to oppose the change/temperature"

3

(c) **M1** $Fe_2O_3 + 3CO \longrightarrow \mathbf{2}Fe + \mathbf{3}CO_2$

Or multiples

Ignore state symbols

M2 Reducing agent
OR Reduce(s) (Fe_2O_3/iron(III) oxide)
OR Electron donor
OR to remove the oxygen (from iron(III) oxide to form CO_2)
OR reductant

For M2, credit "reduction"

2

[8]

Q30.

(a) **M1** The yield of zinc oxide <u>increases/greater</u>

If M1 is given as "decrease" OR "no effect" then CE= 0

M2 Removal of the carbon dioxide results in the **<u>equilibrium</u>**
Either
Shifting/moving/goes to the right
shifting/moving/goes L to R
favours the forward reaction/towards the products

M3 (By Le Chatelier's principle) the reaction/equilibrium will respond so as <u>to replace the CO_2/lost product</u>

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OR <u>to make more CO_2</u>
OR <u>to increase concentration of CO_2</u>

For M3, not simply "to oppose the change/to oppose the loss of CO_2/to oppose the removal of carbon dioxide."

3

(b) **M1** Process 2 produces/releases SO_2
OR Process 2 produces/releases CO

M2 It/Process 3 avoids the release of SO_2 OR CO
OR It/Process 3 (captures and) converts SO_2 to H_2SO_4

M3 SO_2 causes acid rain OR is toxic/poisonous
OR CO is toxic/poisonous

3

Ignore "global warming" and "greenhouse gases" and "the ozone layer"

If both CO and SO_2 claimed to form acid rain, treat as contradiction

(c) **M1** Process 3 (is expensive because it) uses <u>electrolysis</u>
OR due to high <u>electricity/electrical</u> consumption

M2 this is justified because the product/zinc is pure

Ignore "energy"

Penalise "pur<u>er</u>"

2

(d) **M1** $Zn^{2+} + 2e^- \longrightarrow Zn$

Ignore state symbols

M2 the negative electrode OR the cathode

Ignore absence of negative charge on electron

Accept electrons subtracted from RHS

2

(e) **M1** The reaction of ZnO with sulfuric acid
OR the second reaction in Extraction process 3

M2 neutralisation or acid-base

OR alternatively

M1 The reaction of zinc carbonate in Extraction process 1

M1 could be the equation written out in both cases

M2 (thermal) decomposition

M2 depends on correct M1

M3 It/carbon is <u>oxidised/gains oxygen/changes oxidation state/number from 0 to +2/increase in oxidation state/number</u> in Process 2

Do not forget to award this mark

Ignore reference to electron loss but penalise electron gain

Ignore "carbon is a reducing agent"

3

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(f) **M1** $Zn + H_2O \longrightarrow ZnO + H_2$

M2 Zinc oxide and hydrogen

OR as an alternative

M1 $Zn + 2H_2O \longrightarrow Zn(OH)_2 + H_2$

M2 Zinc hydroxide and hydrogen

Mark independently

If ZnO_2 is given for zinc oxide in the equation, penalise M1 and mark on

If ZnOH is given for zinc hydroxide in the equation, penalise M1 and mark on

Ignore state symbols

Credit multiples of the equation

If M1 is blank, either of the M2 answers could score

To gain both marks, the names must match the correct equation given.

2

[15]

Q31.

(a) (i) mol CH_4 = 0.75

1

mol H_2O = 1.5

1

mol H_2 = 1(.0)

1

(ii) 0.15 (mol dm^{-3})

conseq = (mol CH_4)/5

1

(b) (i) $\frac{[CO_2][H_2]^4}{[CH_4][H_2O]^2}$

not just numbers

do not penalise ( )

If wrong Kc no marks for calc but allow units conseq to their Kc

1

(ii) $\frac{(0.15)(0.25)^4}{(0.10)(0.48)^2}$

No marks for calc if concs used wrongly or wrong values inserted

1

0.025(4)

1

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$mol^2\ dm^{-6}$

allow 1 here for correct units from wrong Kc

1

(c) increase

if wrong, no further marks in (c)

1

M1 lower P

1

M2 eqm shifts to side with more moles (Le Chatelier)

not "greater volume" for M1 but allow "moves to form a greater volume" for M2

1

(d) (forward reaction is) endothermic or backward reaction is exothermic

1

eqm shifts in exothermic direction or to oppose reduction of or change in temp

This mark must have reference to temp change or exothermic reaction

1

[13]

Q32.

(a) (i) Reducing agent

OR

Reduce(s) (WO_3/tungsten oxide)

OR

electron donor

OR

to remove oxygen (from WO_3/tungsten oxide or to form water);

1

(ii) $WO_3 + \mathbf{3}H_2 \rightarrow W + \mathbf{3}H_2O$

Or multiples

1

(iii) *One from*

H_2 is

- explosive
- flammable or inflammable
- easily ignited

Ignore reference to pressure or temperature

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1

(b) (i) Addition

Ignore "electrophilic"

Penalise "nucleophilic addition"

OR

(catalytic) hydrogenation

OR

Reduction

1

(ii) Geometric(al)

OR

cis/trans OR E Z OR E/Z

1

(c) (i) (If any factor is changed which affects an equilibrium), the position of equilibrium will shift/move/change/respond/act so as to oppose the change.

OR

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

A variety of wording will be seen here and the key part is the last phrase and must refer to movement of the equilibrium.

QoL

1

(ii) **M1 – Statement of number of moles/molecules**
There are more moles/molecules (of gas) on the left/of reactants

OR

fewer moles/molecules (of gas) on the right./products

OR

there are 4 moles/molecules (of gas) on the left and 2 moles/ molecules on the right.

Ignore "volumes" for M1

Mark independently

M2 – Explanation of response/movement in terms of pressure
Increase in pressure is opposed (or words to that effect)

OR

pressure is lowered by a shift in the equilibrium (from left) to right/favours forward reaction.

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2

(d) ΣB(reactants) – ΣB(products) = Δ*H* (**M1**)

OR

Sum of bonds broken – Sum of bonds formed = ΔH (**M1**)

B(H–H) + ½B(O=O) – 2B(O–H) = – 242 (**M1**)

B(H–H) = – 242 – ½(+496) + 2(+463) (this scores **M1** and **M2**)

B(H–H) = (+)436 (kJ mol^{-1}) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

M1 could stand alone
Award full marks for correct answer.
Ignore units.
Two marks can score with an arithmetic error in the working.

3

[11]

Q33.

(a) **M1** Concentrations of reactants and products remain constant

For M1
NOT "equal concentrations"
NOT "amount"

1

M2 Forward rate = Reverse / backward rate

Credit the use of [ ] for concentration
Ignore dynamic, ignore closed system

1

(b) **M1** The (forward) reaction / to the right is exothermic or releases heat OR converse for reverse reaction.

1

M2 The equilibrium responds by absorbing heat / lowering temperature
OR
Promotes the endothermic reaction by absorbing heat / lowering temperature
OR
Temperature increase is opposed (by shift to the left)
OR
Change is opposed by absorbing heat / lowering temperature.

1

(c) (i) A substance that speeds up / alters the rate but is unchanged at the end / not used up.

Both ideas needed
Ignore references to activation energy and alternative route.

1

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(ii) None OR no change OR no effect OR nothing OR Does not affect it / the position (of equilibrium) OR (The position is) the same or unchanged.

1

(d) (i) An activity which has no <u>net / overall</u> (annual) carbon emissions to the atmosphere
OR
An activity which has no <u>net / overall</u> (annual) greenhouse gas emissions to the atmosphere.
OR
There is no change in the <u>total amount</u> of carbon dioxide / carbon /greenhouse gas present in the atmosphere.

The idea that the carbon / CO_2 given out equals the carbon / CO_2 that was taken in

Ignore carbon monoxide

1

(ii) A method which shows (see below) OR states in words that two times the first equation + the second equation gives the correct ratio.

$$\begin{array}{lcl} 2\,(CH_4 + H_2O & \rightarrow & CO + 3H_2) \\ \underline{\;CH_4 + CO_2\;} & \underline{\rightarrow} & \underline{\;2CO + 2H_2\;} \\ 3CH_4 + 2H_2O + CO_2 & \rightarrow & 4CO + 8H_2 \end{array}$$

Ratio = 1 : 2

1

[8]

Q34.

(a) **M1** $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

1

OR multiples

M2 An oxidising agent is an <u>electron acceptor</u> OR <u>receives / accepts / gains electrons</u>

Ignore state symbols

M2 NOT an "electron pair acceptor"

1

M3 MnO_2 is the oxidising agent

Ignore "takes electrons" or "takes away electrons"

1

(b) **M1** Formation of SO_2 and Br_2 (could be in an equation)

1

M2 Balanced equation
Several possible equations
$\mathbf{2}KBr + \mathbf{3}H_2SO_4 \rightarrow \mathbf{2}KHSO_4 + Br_2 + SO_2 + \mathbf{2}H_2O$
OR
$\mathbf{2}KBr + 2H_2SO_4 \rightarrow K_2SO_4 + Br_2 + SO_2 + \mathbf{2}H_2O$

1

M3 $\mathbf{2}KBr + Cl_2 \rightarrow \mathbf{2}KCl + Br_2$

M2 Could be ionic equation with or without K^+

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$2Br^- + 6H^+ + 3SO_4^{2-} \rightarrow Br_2 + 2HSO_4^- + SO_2 + 2H_2O$
$(3H_2SO_4)$
$2Br^- + 4H^+ + SO_4^{2-} \rightarrow Br_2 + SO_2 + 2H_2O$
$(2HBr + H_2SO_4)$
Accept HBr and H_2SO_4 in these equations as shown or mixed variants that balance.
Ignore equations for KBr reacting to produce HBr
M3 Could be ionic equation with or without K^+
$2Br^- + Cl_2 \rightarrow 2Cl^- + Br_2$

1

M4 % atom economy of bromine

$$= \frac{Br_2}{2KBr + Cl_2} \times 100 = \frac{(2 \times 79.9)}{238 + 71} \times 100 = \frac{159.8}{309} \times 100$$

= **51.7%** OR **52%**

M4 Ignore greater number of significant figures

1

M5 One from:

- High atom economy
- Less waste products
- Cl_2 is available on a large-scale
- No SO_2 produced
- Does not use concentrated H_2SO_4
- (Aqueous) KBr or bromide (ion) in seawater.
- Process 3 is simple(st) or easiest to carry out

M5 Ignore reference to cost
Ignore reference to yield

1

(c) **M1** HBr **–1**

1

M2 HBrO **(+)1**

1

M3 Equilibrium will shift <u>to the right</u>
OR
<u>L to R</u>
OR
Favours forward reaction
OR
Produces more HBrO

1

M4 **<u>Consequential on correct M3</u>**
OR
to <u>oppose the loss</u> of HBrO

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OR
<u>replaces</u> (or implied) the HBrO (that has been used up)

1

[12]

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Q1.

(a) Most students answered this question well, with just over half of students scoring both marks, although many thought that the time that equilibrium was achieved was the point that the concentrations of SO_3 and O_2 were the same as each other.

(b) Many students were able to sketch accurate curves although they didn't always appreciate that the SO_2 and O_2 concentrations would be in the ratio 2:1.

(c) This proved to be demanding for many students (62.7% scored zero). Explanations and predictions in terms of Le Chatelier's Principle were often vague and did not refer to a shift in the position in equilibrium. A good number of students also confused rate arguments with equilibrium arguments when giving an explanation.

Q2.

(a) Most students knew that a catalyst does not affect the equilibrium yield, but few could explain that this is because it increases the rate of both the forwards and reverse reactions equally.

(b) Most students (78.5%) could write the expression for K_c.

(c) The most common mistake in the calculation of K_c was to use the amount in moles rather the concentration of each reagent. Others failed to square the concentration of hydrogen. A good number of candidates (44.1%) did, however, gain all three marks.

(d) The idea of the answer being equal to (1/answer to 08.3) was quite well known and many could deduce the units. A surprisingly high proportion of students (14.2%), however, made no attempt at this question.

Q3.

Most students (60.1%) could use Le Chatelier's principle to deduce which statement was correct.

Q4.

(a) Many students gained high marks in this question – over 70% scored 4 or 5. Others often failed to use the mole ratio from the equation when deducing the amounts, in moles, of reagents at equilibrium.

(b) The expression and its units were given correctly by over 82% of students.

(c) In this question, many students were able to re-arrange the expression for K_c but significant numbers failed to divide the amounts in moles that they were given by the correct volume in dm^3. Some failed to gain a mark by giving the answer as the amount, in moles, of A rather than its concentration. Since the least precise data in the question were given to two significant figures, the final answer for concentration should have been given to two significant figures, so some students failed to gain the final mark because the answer was given to the wrong number of significant figures.

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(d) This question was poorly answered and showed that students were unfamiliar with the idea of the equilibrium moving to the side with a larger amount, in moles, to oppose the fall in concentrations of all reagents when more water was added to the equilibrium mixture. Credit was given to those few students who adopted a mathematical approach. 65.8% of students failed to score here.

Q5.

D was the commonest incorrect response, suggesting that the effect of pressure on equilibrium position was understood better than the effect of temperature. The success rate on the final question was 76.3%.

Q6.

Students showed a good understanding of qualitative equilibrium ideas, with 64% gaining this mark.

Q7.

(a) Students answered this question quite well, with a good awareness of the range of temperatures and pressures needed. Most students failed to describe the information given in the graph; only the best students noted that the yield plateaued over about 850 °C. The relationship between pressure and rate was often missed and this also limited students' marks. Many students discussed conclusions that could be drawn from using *Le Chatelier's* Principle; this was not what the question was asking.

(b) Only a few students did not understand what was being asked for; most errors were either arithmetic errors or rounding errors.

(c) Many completely correct answers were seen (48.9% of students). Some students, however, could not calculate the total number of moles or could not calculate the partial pressures of the gases. Most students could write the expression for K_p but some forgot to square the partial pressure of hydrogen. Units were sometimes incorrectly given in moles.

Q14.

Many students were distracted by incorrect responses to this question due to a misunderstanding of the factors that affect the value of the equilibrium constant.

Q16.

In part (a) most students were able to sketch an appropriate curve, although some made the mistake of joining the end of their curve to the original curve or to the horizontal axis. The explanation depended on it being clear that <u>many</u> more molecules would have $E > E_a$ and that therefore the <u>frequency</u> of <u>successful</u> collisions would greatly increase. Too many answers simply referred to an increase in energy leading to an increase in collisions.

The first part of (b) was generally well answered although, when applying le Chatelier's principle to a specific situation, students must be clear that the shift in position of an equilibrium is in order to oppose a specific change. In this case the shift is to oppose the increase in pressure. In part (b)(ii) quite a lot of answers were expressed in a confused manner. Students are advised to tailor their answer to the actual question rather than repeat generic responses related to the idea. In this case the phrase in the question 'rather than at a higher temperature' was key, with the expectation being that students

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would suggest that, although a higher temperature would increase the rate, it would decrease the yield so the chosen value was a compromise. Students who introduced the idea of lower temperatures could still earn credit but a mention of compromise or optimum conditions was required in order to score the second mark.

Q17.

Students have begun to demonstrate considerable ability in using Le Chatelier's principle to explain the effect of changing reaction conditions on equilibrium yield, but are less effective in their explanations concerning rates of reaction. The low demand first mark in part (a)ii proved elusive for some and the higher demand mark was marred by incomplete answers missing important ideas such as more collisions *in a given time* and more particles *in a given volume* or words to that effect in each case. In part (a)iii the idea that there is an increase in the available surface area when a catalyst is spread onto an inert honeycomb was understood by many, but the necessity to state that this would lead to an increase in *successful* collisions was often missed. Overall only about one fifth of students scored both marks in part (a)ii and part (a)iii.

Q18.

The equation in part (a) was generally well known but common errors included the formation of Mg^{+}, the formation of one mole of chloride ions and the inclusion of water as a reagent. The calculation in part (b) was well done by many students; a common error was a failure to use 2x the enthalpy of hydration of the chloride ion. Students generally used their answer to part (b) to give a good explanation in part (c).

Q19.

Parts (a), (b) and (c) of this question were generally answered well, with the main error in part (b) being the inclusion of s^{-1} in the units and the main errors in part (c) being the omission or incorrect use of the volume and the incorrect rounding of 2.5 / 1.5 (= 1.666) to 1.6. In parts (d) and (e) respectively, most students correctly gave 'decrease' and 'T_1', but many struggled to give clear explanations, often repeating generic Le Chatelier statements rather than discussing these particular situations. The term 'favours' was not credited unless qualified.

Q20.

In part (a)(i), some students missed either the fact that the catalyst has to be a concentrated strong acid or that the unreacted ethene is re-circulated to achieve an overall yield of 95% and this meant that only a small number of students scored both marks. Considerable latitude was allowed in the responses for part (a)(ii), since it was clear that many students did not really understand what was happening in this process and this approach to the marking enabled the majority of students to gain at least two marks out of three. In part (a)(iii), some students recognised the possibility of poly(ethene) being formed and approximately 17% of students gained both marks.

It has been a while since a question like part (b) has been asked and it was not well answered with few students gaining full marks and over half scoring zero. Balancing the correct equation and then including the correct state symbols were both needed for full marks. Parts (c) and (d) proved straightforward for many and full marks were seen from over a third of students in each of parts (c)(i) and (c)(ii), respectively.

Q21.

This question was high scoring. In part (b)(i), almost 48% scored full marks and for those

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who did not, it was the idea that catalysts alter the rate of a reaction and are chemically unchanged at the end of the reaction that was missed most often.

Q22.

The standard enthalpy change calculation in part (a) was straightforward and high scoring. In parts (b) and (c), good discrimination occurred and a great many well–articulated responses were seen. It is worth noting that no marks were scored in either of parts (b) or (c), if the effect on the yield was assigned incorrectly. The meaning of *carbon–neutral* in part (d) is spelled out in the specification and needs to refer to net emissions of carbon dioxide to the atmosphere. Parts (d)(ii) and (d)(iii) were challenging and only the best students were able to arrive at the equation for the overall reaction between hydrogen and oxygen to make water. Most students scored at least one mark in part (e); the commonest error was a failure to give the final answer a negative sign for this exothermic process.

Q23.

Most students scored highly in this question apart from part (a)(iii) where many repeated the mathematical information given in the question (that the units cancelled) and did not give a chemical explanation (that the number of moles on each side of the equation was equal). Part (b) was answered well with parts (i) and (iii) proving easier than (ii) and (iv).

Q24.

Questions that test ideas about equilibria are being answered with greater precision than in the past. In part (b), the idea that a catalyst increases the rate of the forward reaction and the rate of the reverse reaction equally was not well known and many answers either defined catalysis or explained how catalysts work. Part (c) was high scoring and most answers stated clearly the necessary information about the reaction (eg the forward reaction is exothermic) followed by the idea that the equilibrium shifts to oppose the specified change. In part (d), the idea that higher temperatures lead to higher rates of reaction was understood, but the linkage between operate at high pressures and either increase in equipment costs or increase in pumping costs was not well known.

Q25.

Candidates struggled to balance the equation in part (a)(i) with 30% failing to complete it correctly. Part (b)(i) is straight from the specification and two thirds of candidates did not have a problem. In parts (b)(ii) and (b)(iii) candidates demonstrated that they are learning how to express their ideas with clarity and some very good answers were seen. Some answers suffered from contradictory statements while others included statements that were open to different interpretations.

Q26.

The first three sections of part (a) were well answered, but in part (a)(iv) a large number of students failed to convert moles into concentration. Some also over–rounded numbers at an early stage and this led to answers outside the accepted range. Part (c) proved more challenging, with a very large number of students giving T_2 as the higher temperature.

Q27.

Most scored at least one mark in part (a). Incomplete responses noted that the forward and backward reactions both happened at the same time, but did not say that the rates were equal. Statements about the amounts of reactants and products were often missing

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or in some cases these amounts were described as the same (as each other?) rather than as constant.

Most were able to write the correct expression in part (b), but part (c) proved to be very difficult. It was disappointing to see how few candidates were able to rearrange the mathematical expression for *K*c and how often basic errors in mathematics cost the candidates marks. Other errors included confusion between moles and concentration for all three substances involved.

Part (h) was generally well answered, although many candidates spent time on a full calculation rather than simply taking the reciprocal of the equilibrium constant for the forward reaction.

Q28.

This question was not as high scoring as might have been expected. Candidates were unfamiliar with the equations that show how chlorine atoms catalyse the decomposition of ozone, even though these are in the specification. The ability to articulate a correct argument using Le Chatelier's principle in part (c)(ii) was well done, although candidates should be urged to refer to the "equilibrium" rather than the "system".

Q29.

This question was high scoring. In the explanation of the effect of an increase in temperature on the equilibrium, candidates often lost the final mark, because they failed to state that the equilibrium moves to lower the temperature by absorbing the heat. Too often the answer referred simply to opposing the change.

Q30.

Overall this was one of the most discriminating questions on the paper and even the weakest candidates were able to score some marks. In part (a) many candidates were able to appreciate that the equilibrium would shift to the right to replace the lost CO_2 even if they did not express the idea as fully as they might have. In part (b) most candidates could extract information from the story and appreciate that there is a significant difference between waste gases being released into the atmosphere and collecting the SO_2 and making sulfuric acid from it. The expense associated with electrolysis in part (c) was well known but candidates often missed the fact that the zinc is pure and it is this that justifies the expense. A few candidates confused yield with purity. Quite a few candidates failed to use Zn^{2+} ions in their half-equation in part (d), but most knew that the reaction occurred at the negative electrode. Part (e) proved relatively demanding despite two possible equations that were not redox. Part (f) was well answered and credit was awarded for formation of either the oxide or the hydroxide.

Q31.

This question was answered well. In part (a) most candidates calculated the amount of hydrogen in the equilibrium mixture correctly but many did not use the ratio in the equation so their answer to the amount of steam was wrong. The expression for K_c in part (b) was very well understood but it was clear that some candidates struggled to use their calculators correctly to raise values to the power of 2 or 4. In part (d), the effect on the equilibrium mixture of a change of temperature was answered better than the effect of a change of volume and therefore of pressure.

Q32.

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This question took hydrogen as its theme and asked questions across the subject. Overall it was a high scoring question. The application of Le Chatelier's principle was done well with only 10% of candidates failing to score any marks. By contrast, the calculation of a value for the H-H bond enthalpy proved very demanding and half the candidates scored no marks.

Q33.

Part (a) was taken straight from the Specification but only 20% of candidates scored full marks. The explanation in part (b) was generally done well and part (c) was relatively high scoring, even though the demand in (c)(i) required reference both to the change in rate and the idea that a catalyst is not used up in the reaction. Most candidates gave a correct answer to part (d)(i), but only a minority of candidates could work out what to do in part (d)(ii).

Q34.

This question aimed to test areas of the Specification in the context of the historical methods used for the extraction of bromine and a real application of the chemistry of bromine in its use in swimming pools in France and the USA. Part (a) proved quite demanding although almost 75% of candidates gained some credit. Part (b) discriminated well with the full range of marks seen and more than half of the candidates were able to gain at least 2 marks. Candidates who could balance the equation had no difficulty with this part of the question. Part (c) was often well answered with 80% of the candidates gaining at least 2 marks.

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Q1.

(a) Low temperature
Reaction is exothermic

1

Low T reduces effect of heat evolved
or heat evolved opposes the change in temperature

1

High pressure
3 mol gas → 1 mol gas

1

High p favours fewer moles by lowering p
or forward reaction reduces volume and lowers p

1

(b) High T gives a low yield

1

but Low T gives a low rate ∴ compromise

1

increases reaction rate/catalyst surface contact

1

[7]

Q2.

(a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$

1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] - (391 \times 3)$

1

$= -46.5 \text{ kJ mol}^{-1}$

1

Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors

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	of grammar, punctuation and spelling
2-3	– claims partially supported by evidence – good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC

1

but, since the reaction is exothermic

1

the equilibrium yield is lower QWC

1

The higher the pressure the greater the equilibrium yield QWC

1

because there is a reduction in the number of moles of gas in the reaction

1

but higher pressure is expensive to produce or plant is more expensive to build QWC

1

A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

Q3.

(a) Rate forward reaction = rate backward reaction (1)

Concentrations of reactants and products are constant (1)

2

(b) System opposes change (1)

Moves to the side with fewer moles (1)

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In this case NH_3 (2 moles) on right side < N_2 + H_2 together (4 moles) on left side of equation (1)

3

(c) Too expensive to generate etc (1)

1

(d) (i) Yield of ammonia increases (1)

Exothermic reaction favoured (1)

System moves to raise temp / or oppose decrease in temp (1)

3

(ii) Faster reaction (1)

1

(iii) Balance between rate and yield (1)

1

[11]

Q4.

(a) (i) Increase (if wrong no further marks in part (i)

1

higher *P* gives lower yield or moves to left

1

Eqm shifts to reduce *P* or eqm favours side with fewer moles

1

(ii) Endothermic if wrong no further marks in part (ii)

1

increase *T* increases yield or moves to right

1

Eqm shifts to reduce *T* or eqm favours endothermic direction

1

(b) (i) Moles of iodine = 0.023

If wrong no marks in (i)

1

Moles of HI = 0.172

1

If × 2 missed, max 1 in part (iv)

(ii) $K_c = \frac{[H_2][I_2]}{[HI]^2}$

must be square brackets (penalise once in paper) – if round, penalise but mark on in (iv)

if K_c wrong, no marks in (iv) either but mark on from a minor slip in formula

1

(iii) V cancels in K_c expression

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or no moles same on top and bottom of expression
or total moles reactants = moles products,
i.e. total no of moles does not change

1

(iv) $K_c = \frac{(0.023)^2}{(0.172)^2}$

Conseq on (i)

1

= 0.0179 or 1.79×10^{-2}

Allow 0.018 or 1.8×10^{-2}

1

(v) K_c = 55.9 or 56

Conseq i.e. (answer to (iv))$^{-1}$

1

[13]

Q5.

D

[1]

Q6.

(a) removal/loss of electrons

1

(b) no change

1

equal number of gaseous moles on either side

1

both sides affected equally

1

increases

1

equilibrium moves to lower the temperature/oppose the change

1

endothermic reaction favoured /forward reaction is endothermic

1

(c) (i) +2

1

+5

1

(ii) $NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$

1

(iii) $Ag \rightarrow Ag^+ + e^-$

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1

(iv) $NO_3^- + 4H^+ + 3Ag \rightarrow NO + 2H_2O + 3Ag^+$

1

[12]

Q7.

(a) (i) $C + 3D \longrightarrow 2A + B$

1

(ii) mol dm^{-3}

1

(iii) (forward reaction is) exothermic or more products formed

1

(b) (i) for N_2O_4 $M_r = 92.0$

1

Mol = $\frac{36.8}{92.0} = 0.400$

1

(ii) mol N_2O_4 reacted = 0.400 – 0.180 = 0.220

1

mol NO_2 formed = 0.440

1

(iii) $K_c = \frac{(NO_2)^2}{(N_2O_4)}$

1

$= \frac{(0.44/16)^2}{(0.18/16)}$

1

$= 0.067$

1

(iv) move to NO_2/ to right / forwards

1

none

1

[12]

Q8.

(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

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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 H_2 = 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 $$K_p = \frac{PCH_3OH}{PCO \times P^2H_2}$$

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

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M7 0.022(1) $2.2(l)\times10^{-8}$ $2.2(l)\times10^{-14}$

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 H_2 = 73.2 (i.e. double CO), M2 and M3 lost)
(If M1 gained but mol H_2 = 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 in M6 and allow M8 for kPa^{-2})

[14]

Q9.

(a) effect on reaction rate: catalyst provides an alternative reaction route.;

1

with a lower E_a;

1

more molecules able to react or rate increased;

1

equilibrium: forward and backward rates changes by the same amount;

1

hence concentration of reactants and products constant or yield unchanged;

1

(b) heterogeneous: catalyst in a different phase or state to that of the reactants;

1

active site: place where reactants adsorbed or attached or bond etc.;

1

reaction occurs or an explanation of what happens;
(allow absorbed)

1

reasons: large surface area;
reduce cost or amount of catalyst;

2

catalyst poison: lead adsorbed;

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lead not desorbed or site blocked;

(lead adsorbed irreversibly scores both of these marks)

2

(c) reaction slow as: both ions negatively charged or ions repel;

1

$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ Species;
Balanced;

2

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Species ;
Balanced;

2

[17]

Q10.

C

[1]

Q11.

A

[1]

Q12.

(a) (i) <u>enthalpy change</u> when 1 mol of a substance (or compound) (QL mark)

1

is (completely) burned in oxygen (or reacted in <u>excess</u> oxygen)

1

at 298 K and 100 kPa (or under standard conditions)

1

(ii) heat produced = mass of water × Sp heat capacity
$x\Delta T$ (or $mc\Delta T$)

1

= 150 × 4.18 × 64 (note if mass = 2.12 lose first 2 marks then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2 must have correct units)

1

moles methanol = mass/M_r = 2.12/32 (1)
= 0.0663

1

ΔH = – 40.1/0.0663 = – 605 kJ (mol^{-1})

1

(allow –602 to –608 or answer in J)

(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks

(b) (i) equilibrium shifts to left at high pressure

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1

because position of equilibrium moves to favour fewer moles (of gas)

1

(ii) at high <u>temperature</u> reaction yield is low (or at low *T* yield is high)

1

at low <u>temperature</u> reaction is slow (or at high *T* reaction is fast)

1

therefore use a balance (or compromise) between <u>rate</u> and <u>yield</u>

1

(c) $\Delta H = \Sigma \Delta H_c^{\ominus}$(reactants) – $\Sigma \Delta H_c^{\ominus}$(products) (or correct cycle)

1

$\Delta H_c^{\ominus}(CH_3OH) = \Delta H_c^{\ominus}(CO) + 2 \times \Delta H_c^{\ominus}(H_2) - \Delta H$

1

= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ mol^{-1}) (*units not essential but lose mark if units wrong)*
(note + 764 scores 1/3)

1

[15]

Q13.

(a) (i) moles of C_2F_2 = <u>0.40</u> mark independently from HC1

1

moles of HC1 = <u>0.80</u> **not** consequential

1

(ii) $K_c = \dfrac{[C_2F_4][HCl]^2}{[CHClF_2]^2}$

wrong K_c means they can only

score for units in (iii) consequ

on their K_c

1

(iii) $K_c = \dfrac{(0.40/18.5)(0.8/18.5)^2}{(0.20/18.5)^2}$

1

= 0.35

1

mol dm^{-3}

1

(b) (i) increase

1

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(ii) decrease

1

(c) addition or radical

1

[9]

Q14.

(a) Same

1

(b) (i) Decreases

1

More moles on left hand side

1

Equilibrium moves to increase the pressure

(Or to oppose the change or to compensate for low pressure)

1

(ii) Cost of producing high pressure **(1)**
Cost of plant to resist high pressure **(1)**
Correct safety factor with reason **(1)**

max 2

(c) No change

1

Catalyst has no effect on equilibrium position

(Or catalyst affects rate of forward and backwards reactions equally)

1

(d) Negative

1

Reaction *(or equilibrium)* moves in the exothermic direction *(or to the right)*

1

In order to oppose the change *(or to raise the temperature)*

1

(e) Recycled (*or re-used or 'put back in'*)

1

[12]

Q15.

(a) 12 (kPa)

1

pp = mole fraction × total pressure **or** mole fraction = 12/104

1

= 0.115

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(allow 0.12)

1

(b) 68 (kPa)

1

(c) $K_p = \frac{(pSO_3)^2}{(pSO_2)^2 \times (pO_2)}$

(If K_p wrong, allow consequential units only)

(penalise square brackets in expression but then mark on)

1

$= \frac{68^2}{24^2 \times 12}$

1

= 0.669

(Allow 0.67)

(Allow full marks in calculation consequential on their values in (a) and (b))

1

kPa^{-1}

1

(d) T_2

(Must be correct to score any marks in this section)

1

<u>Exothermic</u>

1

Reduce T to shift equilibrium to the right
or forward reaction favoured by low T
or K_p increases for low T
or low T favours exothermic reaction

1

(e) Increase

1

None

1

[13]

Q16.

(a) *M1* $K_p = ({}_PY)^3 . ({}_PZ)^2 / ({}_PW)^2 . ({}_PX)$ *NB [ ] wrong*

1

M2 temperature

1

M3 increase

1

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M4 particles have more energy or greater velocity/speed

1

M5 more collisions with $E > E_a$ or more successful collisions

1

M6 Reaction exothermic or converse

1

M7 Equilibrium moves in the left

1

Marks for other answers

Increase in pressure or concentration	*allow M1, M5, M6*	*Max 3*
Addition of a catalyst;	*allow M1, M5, M6*	*Max 3*
Decrease in temperature;	*allow M1, M2, M6*	*Max 3*
Two or more changes made;	*allow M1, M6*	*Max 2*

(b) (i) Advantage; reaction goes to completion, not reversible or faster

1

Disadvantage; reaction vigorous/dangerous

(exothermic must be qualified)

or HCl(g) evolved/toxic
or CH_3COCl expensive

NB Allow converse answers
Do not allow reactions with other reagents e.g. water or ease of separation

1

(ii) $\Delta S = \Sigma S$ products $- \Sigma S$ reactants

1

$\Delta S = (259 + 187) - (201 + 161)$

1

$\Delta S = 84$ (JK^{-1} mol^{-1}) *(Ignore units)*

*Allow – 84 to score **(1)** mark*

1

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

1

$= -21.6 - 298 \times 84/1000$
$= -46.6$ kJ mol^{-1} or $-46\,600$ J mol^{-1}

1

*Allow **(2)** for – 46.6 without units*
(Mark ΔG consequentially to incorrect ⊿S)
(e.g. ⊿S = –84 gives ⊿G = +3.4 kJ mol^{-1})

1

[15]

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Q17.

(a) An equilibrium opposes change **(1)**

1

(b) (i) *Effect on yield of hydrogen:* decreases **(1)**

Note C.E. if not decrease, but mark on if no answer

Explanation: pressure lowered (or increase opposed) **(1)**
by favouring fewer moles (of gas) **(1)**

(ii) *Effect on yield of hydrogen*: increase **(1)**

CE if wrong as above

Explanation: pressure / concentration / reactants / steam reduced **(1)**
by shifting to right **(1)**

or steam removed or forward reaction favoured

6

(c) *Reason 1*: cost of high temperature / energy **(1)**

Reason 2: cost of plant (to resist high T) too high **(1)**
OR plant could not contain high T

2

[9]

Q18.

(a) $K_p = \frac{P_{SO_2} \times P_{Cl_2}}{P_{SO_2Cl_2}}$ **(1)**

1

(b) 0.25 + 0.75 + 0.75 = 1.75 **(1) (1)**

2

(c) (i) *p* = Total pressure × mol fraction **(1)**

(ii) *Partial of SO_2Cl_2*: $125 \times \frac{0.25}{1.75}$ = 17.9 kPa **(1)**

Partial pressure of Cl_2: $125 \times \frac{0.75}{1.75}$ = 53.6 kPa **(1) (1)**

5

(d) $K_p = \frac{53.6 \times 53.6}{17.9}$ **(1)** = 161 **(1)** kPa **(1)**

3

(e) *Effect on K_p*: increase **(1)**
Explanation: increase T sends equilibrium in endothermic direction **(1)**

2

(f) no effect **(1)**

1

Notes

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(a) If K_p has [ ] lose mark in (a) but allow full marks in (d)

If K_p wrong/upside down etc, allow max 2 in (d) for substitution of numbers **(1)** and consequential units **(1)**

(b) Mark for moles of SO_2Cl_2 can be scored in part (c) (ii) if not gained in (b)

1.75 get **(2)**

If moles of SO_2Cl_2 = 1, this is a Chemical Error, hence a 2 mark penalty

- If total moles given in (b) = 1.75, this scores [2] in (b); but if the no moles of SO_2Cl_2 = 1 in (c)(ii), lose both marks in (c)(ii) for pp of SO_2Cl_2 = (1/1.75) × 125, i.e. the 2 mark penalty is in (c)(ii).
- If total moles given in (b) = 2.5, score zero in (b), but can gain full marks in (c)(ii) consequentially, i.e. the 2 mark penalty is in (b).
- If moles of SO_2Cl_2 = 1 and total in (b) does not equal 2.5, still lose both in (b) but can get all 4 conseq in (c)(ii) for 1/x etc and 0.75/x etc

(c) (i) Allow "Total pressure = sum of partial pressures" for **(1)** or $p_A = x_A \times p_{tot}$

(ii) First mark is for mole fraction.
If either number in either mole fraction is not consequential on (b), then lose both marks for that partial p.

(d) If pCl_2 is not equal to pSO_2 or any number used in K_p is not conseq on (c)(ii), allow units only

SIG FIGS; must be 3 sig figs in (b) but then allow 2 sig figs in (c) and (d); (ignore extra figs) but penalise incorrect rounding

(e) If effect wrong, no marks for explanation.
If effect missing, e.g. answer states "equm shifts to right", mark on.
In the explanation, the word "endothermic" (or its equivalent) is essential.

[14]

Q19.

D

[1]

Q20.

C

[1]

Q21.

(a) <u>rate</u> forward reaction = <u>rate</u> backward reaction **(1)**
concentration remains constant **(1)**

NOT 'Equal',
Allow 'The same' if clear that means constant

2

(b) fewer moles (of gas) on R.H.S **(1) (or converse)**

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(methanol favoured) by reducing applied pressure **(1)**

Or removing constraint

2

(c) Power / energy required to provide high pressure / pumping **(1)**
Strong pressure vessel / or equipment **(1)**

*High maintenance costs **(1)***
*High insurance costs **(1)***
Any two

2

(d) Effect: decreases **(1)**
Explanation: reaction exothermic (or reverse reaction endothermic) **(1)**
system tries to lower T or remove constraint or
oppose the change
or endothermic reaction favoured

3

(e) to speed up reaction **(1)**

or otherwise to slow
or takes too long
or to give more molecules $E > E_A$

1

[10]

Q22.

(a) **Increase in temperature:**

Yield is increased **(Allow if for H_2 (g) or products) (1)**
Reaction endothermic **(1)**
Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to oppose change **OR** to absorb heat **(1)**

If "Yield statement" incorrect allow max one if reaction stated to be endothermic

Increase in pressure:

Yield is decreased **(Allow if for H_2 (g) or products) (1)**
Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles on right **(1)**
Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to oppose change **OR** to reduce pressure **(1)**

If "Yield statement" incorrect allow max one if number of moles change is correct.

6

(b) **Equilibrium yield:**
Unaffected **or** equilibrium unchanged **(1)**
Rate or speed increased **(1)**
Forward and backwards reactions equally or by the same amount **(1)**

Amount of hydrogen produced:
More hydrogen produced (1)

4

[10]

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Q23.

D

[1]

Q24.

(a) (i) *Rates:* Rates are equal, forward and backward **(1)**
Concentrations: Concentrations are constant **(1)**

Q of L mark

(ii) *Equilibrium yield:* Decreases **(1)**

if wrong allow max 1 for a correct moles statement

Explanation: More moles / molecules of product (or 2 → 4) **(1)**
Reaction / equilibrium moves to left / reduce constraint **(1)**

NOT "volume" answers

Allow one for "Reaction favours fewer molecules"

(iii) Enthalpy of reaction is positive / endothermic **(1)**

(iv) Both forward and backward rates changed / increased **(1)**
by equal amount (same proportion) **(1)**

allow one for "Ea of forward and backward reactions reduced by an equal amount"

8

(b) (i) The reaction is exothermic **(1)**
High temperature gives a low equilibrium yield **(1)**
Rate of reaction higher at higher temperature **(1)**

An "equilibrium statement" needed e.g. low temp favours the reaction
Do not allow answers based on cost of higher temperature etc

(ii) Higher pressure gives a higher yield **(1)**
4 moles of gaseous reactant form 2 moles of gaseous product **(1)**
Higher pressure generation or equipment is expensive to produce **(1)**

Equilibrium statement required
Cost factor
N.B. NOT a safety answer

6

[14]

Q25.

B

[1]

Q26.

A

[1]

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Q27.

C

[1]

Q28.

D

[1]

Q29.

B

[1]

Q30.

A

[1]

Q31.

C

[1]

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Q3.

There were a surprisingly large number of candidates who missed out the word rate in their answer to (a), simply stating that the forward reaction was equal to the backward reaction. Many candidates did not refer to constant concentrations of reactants and products. Parts (b) and (c) were generally well answered by most candidates. Part (d) was answered well apart from the weakest candidates. Errors included no reference to the exothermic reaction in part (d) (i) and failure to give a comparative answer in (d) (ii).

Q4.

In part (a) the changes were deduced well and although the explanations were less clear, marks on this part of the question were high. Part (b), however, differentiated well. This was particularly the case in part (b)(i) where only the best candidates correctly calculated the number of moles of HI. The expression for K_c in part (b)(ii) was well answered although a smaller number realised that the volume term cancelled in the expression because the numbers of moles of reactants and products were equal in the equation. Marks were gained in part (iv) for correct use of the data from part (i) and the better candidates were able to deduce that the answer to part (v) was the reciprocal of that to part (iv) although many repeated a K_c calculation.

Q6.

Part (a) was answered well by almost all candidates. The answers to part (b) were more discriminating. Only a few candidates realised that in order to have no change in the yield with an increase in pressure, both sides would be affected equally since there were two moles on each side of the equation. Answers involving the temperature effect were generally tackled better. The calculation of oxidation states was done well by the majority of candidates although the half equations and deduction of the final equation was only done well by the most able candidates. It is a concern that few candidates are able to write correctly balanced half equations at AS level.

Q7.

Part (a) was well done, but in part (b)(i) it was disappointing to see the considerable number of candidates who were unable to calculate the Mr correctly. In part (b)(ii), 0.22 or 0.36 were common wrong answers often given without any explanation. Only the better candidates were able to answer the question correctly. Most were able to write a correct expression for Kc, but many failed to score the calculation marks (even consequentially on their incorrect answers in part (b)) because they forgot that Kc involves concentrations rather than numbers of moles and failed to divide the number of moles by the volume in dm^3. Part (iv) was fairly well answered.

Q8.

Part (a) was answered well as expected as the topic overlaps with qualitative equilibria in CHM2. Some candidates lost marks by discussing only the effect of increased temperature on the yield and not on the rate also. Several also suggested that the rate was unaffected or decreased by an increase of pressure. Part (b) was answered impressively by the better candidates, who were able to set out the answer clearly. Most were able to score marks for the expression for K_p or the definition of partial pressure (stated or inferred from a calculation). Too many, however, failed to realise that the amounts of the reagents at equilibrium were less than the initial amounts given. Even

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those who realised that the equilibrium amount of carbon monoxide was 62.8 – 26.2 mol did not always realise that, because of the 1:2 ratio in the equation, the equilibrium amount of hydrogen was 62.8 – (2 × 26.2) mol. However if this was their only error, six marks were still available. The pressure was given in MPa and the answer for K_p was expected with units MPa^{-2}. Many attempted unnecessarily to convert the pressure into kPa or even into Pa and got into difficulties with the powers often.

Q9.

Parts (a) and (b) were both well answered and many candidates scored full, or nearly full, marks. Almost all candidates stated that the reaction between I^- and $S_2O_3^{2-}$ was slow as they were both negative and would repel each other, few gave correct equations showing the involvement of iron(II) and iron(III) ions in the reaction. Sadly some candidates, who gave correct species, lost a mark as they failed to balance the equations.

Q12.

In this question, good candidates were able to score full marks. Weaker candidates were less successful though they were usually able to pick up at least five or six marks.

Answers to part (a) usually gained all three marks. Answers to part (b) by weaker candidates were less successful. One common error in the expression $mc\Delta T$ was to use the mass of methanol (2.12 g) instead of the mass of water (100 g). Another common error was to give an incorrect sign for the final value of the enthalpy of combustion. Candidates were expected to recognise that this exothermic process should lead to a negative value for the enthalpy of combustion of methanol. Weaker candidates also lost marks for incorrect units or for giving no units. It is important for candidates to give correct units for intermediate values in the calculation as well as for the answer. In this case, if a candidate gave a wrong final answer, it was still possible to gain an intermediate mark for the heat released to the 100 g of water. However, if the candidate did not make it clear whether the intermediate value was expressed in Joules or in kJ, it was not possible to give any credit.

Answers to part (b) were of a good standard and in part (b) (i) almost all candidates were awarded the two marks. Answers to part (b) (ii) were not quite so accurate and, in particular, only the best candidates stated that 500 K achieves the best balance between rate of reaction and yield.

Good candidates found part (c) straightforward but weaker candidates often omitted to allow for two moles of hydrogen and also used the wrong sign for the enthalpy of reaction (–91 kJ mol^{-1}) relative to the enthalpies of combustion of carbon monoxide and hydrogen.

Q13.

Only the better candidates were able to calculate the number of moles of C_2F_2 and of HC1 correctly. However, if the rest of the answer used correct chemistry, no further marks were lost. The expression for K_c was well known, but there was uncertainty over the use of the volume of the container in the calculation. Many forgot to include it at all and so used a number of moles instead of the concentration in mol dm^{-3}. Some tried to include the number 18.5 dm^3 in the expression for K_c and others tried to convert the volume into m^3. Parts (b) and (c) were well answered even by those who lost marks in the calculation in part (a).

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Q14.

This question was answered reasonably well; it proved to be the easiest question on the paper. Answers to part (a) were usually correct. For part (b) (i) the decreased yield was usually correct and, as part of the explanation, most candidates mentioned that there were more moles of gas on the left hand side of the equilibrium. However, the link between increased pressure, decreased yield and the number of moles of gaseous reactants was not explained by many candidates. For part (b) (ii), in line with previous marking schemes, no credit was awarded for answers that simply stated cheaper (or less expensive) but gave no associated reason. Candidates were expected to link lower costs to the energy required for pumping and the capital investment required to manufacture pressure-resistant plant. Answers to part (c) by good candidates usually gained full marks. However, weaker candidates often gave incomplete answers such as stating that a catalyst increases the rate of a reaction but these candidates did not state that the rates of the forward and backward reactions are increased equally. In part (d), weaker candidates found it difficult to explain the sign of the enthalpy change but answers to part (e) were almost always correct.

Q15.

This question was answered well by most candidates, particularly part (a). The 2:1 ratio or moles of sulphur dioxide to moles of oxygen was sometimes reversed, but marks were allowed in this part and in part (b) for correct use of their incorrect number of moles of oxygen. Most were able to write the expression for K_p correctly in part (c), although some were penalised for the use of square brackets. Full marks were available for correct substitution of wrong partial pressure values from parts (a) and (b). No marks were allowed for the calculation if the expression for K_p was wrong, but a mark was allowed for units correctly consequential on their expression. In part (d), better candidates were able both to predict and explain that T_2 was the lower temperature using the information given that the reaction was exothermic.
In part (e) most correctly stated that the yield of SO_3 would increase, but only the better candidates remembered that K_p is independent of pressure changes.

Q16.

Many candidates gave a correct expression for the equilibrium constant, K_p, for the reaction given in part (a). Some, who gave correct indices, lost a mark as they included square brackets, which are specific used to indicate concentration, in their expression. Identifying the one change which would increase the rate of reaction and decrease the value of K_p proved challenging but part marks were awarded for answers which addressed either of the two required changes. Candidates who gave more than one change of condition were able to score one mark for a correct K_p expression. There were many vague answers to part (b)(i), some of which assumed there were other reactants present with the most common example being water in Reaction 2. By contrast, (b)(ii) was very well answered with many candidates scoring full marks. Most candidates now remember to use either kJ mol^{-1} or J mol^{-1} throughout these calculations but a small number still failed to do this. Consequential marks were awarded in each part of the calculation.

Q17.

This question was answered well by most candidates though part (c) proved to be a good discriminator. In part (a) Le Chatelier's principle was usually stated correctly. Candidates were expected to refer to an equilibrium and not just a 'system'. In parts (b) (i) and (ii) the question required candidates to 'use Le Chatelier's principle' to answer the questions. Some candidates lost marks because they restricted their answers to mentioning the direction of equilibrium-shift without mentioning that the increases in overall pressure and concentration of steam would be countered. In part (c) the cost of the energy required to

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achieve a high temperature was often given correctly but a second reason was rarely correct. Common incorrect answers included erroneous references to a shift of the equilibrium to the left and hence a reduced yield of hydrogen at very high temperatures.

Q18.

This question was well answered by many candidates and full marks were common for the most able. In part (a) a few candidates were penalised for using square brackets, e.g. $[SO_2]$ meaning concentration of SO_2 instead of using p for partial pressure, and a very few wrote the expression for K_p upside down. Part (b) caused the most problems. Many candidates forgot that, in order to produce 0.75 mol of Cl_2 (and 0.75 mol of SO_2), 0.75 mol of SO_2Cl_2 would be used up leaving only 0.25 mol in the equilibrium mixture. Both of the marks in part (b) were lost for this error, but full marks could be gained subsequently in parts (c)(ii) and (d) for correct working in the calculations. In part (e) most were able to deduce and explain that an increase in temperature would cause K_p to increase. However there were many who thought, incorrectly, that pressure had a similar effect.

Q21.

This question also proved to be effective at discriminating between candidates and a wide range of marks were obtained. In part (a), most candidates gained the mark for mentioning equal rates for the forward and the backward reactions but weaker candidates failed to add that the concentrations of species remain constant at equilibrium. In part (b), most candidates stated that, on the right hand side of the equilibrium, there is a reduction in the number of moles of gas. Many, however, did not go on to explain, using the idea of Le Chatelier's Principle, why the equilibrium shifts to the right at high pressure. Part (c) was not answered well. In many cases responses by candidates were too vague to gain marks. For example, a statement saying that energy is expensive was not given credit. However, if a candidate explained that energy was used to drive the pumps that create pressure, a mark was awarded. Similarly, an answer suggesting that expensive equipment is required was not credited but candidates were awarded a mark if they gave a reason why plant or equipment is expensive if it is constructed to resist high pressure. Part (d) was answered well by most candidates. In part (e), a common error was to state that the activation energy is reduced at an increased temperature.

Q22.

This question was well answered. Many candidates in part (a) used Le Chatelier's principle to predict correctly the effect of increasing temperature and increasing pressure on the yield of hydrogen in the given equilibrium reaction. Candidates who made the wrong prediction were able to score one mark for each change if they stated correctly that the reaction was endothermic and that there was a reduction in the number of moles of gas in the reaction as written. Part (b) was also well answered but some candidates did not differentiate clearly between the equilibrium yield of hydrogen and the amount of hydrogen produced in a given time.

Q24.

Most candidates knew that the rates of forward and backward reactions are equal when a dynamic equilibrium is established but some candidates then stated incorrectly that at equilibrium the concentration of the reactants and products would also be equal. The effect of an increase in pressure on the given equilibrium, required in (a)(ii), was well known and most candidates were also able to deduce that the given reaction was endothermic. In part (a)(iv) candidates were required to explain why the equilibrium yield is unchanged when a catalyst is added. Answers such as 'a catalyst does not alter the equilibrium concentrations' were merely a restatement of the question and scored no

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marks. The reasons why 450 ºC and 20 MPa are compromise conditions for the production of ammonia from nitrogen and hydrogen were well known and part (b) was generally well answered.

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