

M1. (a) 242

Units not essential

1

(b) Bond is shorter or bonding pair closer to nucleus

*Allow Cl is a smaller atom
Allow fewer electron shells
do not allow smaller molecules*

1

So attraction (between nucleus and) (to) bond pair is stronger

*Allow shared pair (or bonding electrons) held more tightly
Mention of Cl⁻ loses M2*

1

(c) Net attraction between the chlorine nucleus and the extra electron

Allow Cl⁻ ion more stable than Cl

1

(d) (i) step 1 Ag(s) → Ag(g) only change

1

step 2 Ag(s) → Ag⁺(g) + e⁻ only change

1

step 3 ½Cl₂(g) → Cl(g) only change

This step can be first, second or third

1

(ii) 127 + 289 + 732 + 121 – 364

1

= 905 kJ mol⁻¹

–905 scores 1 mark only

1

(e) (i) Ions can be regarded as point charges (or perfect spheres)

*Allow no polarisation
OR only bonding is ionic
OR no covalent character*

1

(ii) Greater

*Electronegativity argument or mention of intermolecular,
CE = 0*

1

Chloride ions are smaller than bromide
Mark independently but see above

1

They are attracted more strongly to the silver ions
Mark independently

1

(iii) AgCl has covalent character
Ignore reference to molecules

1

Forces in the lattice are stronger than pure ionic attractions
Allow stronger bonding OR additional/extra bonding

1

[15]

M2.(a) (i) (At 0 K) particles are stationary / not moving / not vibrating
*Allow have zero energy.
Ignore atoms / ions.*

1

No disorder / perfect order / maximum order
Mark independently.

1

(ii) As T increases, particles start to move / vibrate
*Ignore atoms / ions.
Allow have more energy.
If change in state, CE = 0*

1

Disorder / randomness increases / order decreases

1

- (iii) Mark on temperature axis vertically below second 'step'
Must be marked as a line, an 'x', T_b or 'boiling point' on the temperature axis.

1

- (iv) L₂ corresponds to boiling / evaporating / condensing / l → g / g → l

And L₁ corresponds to melting / freezing / s → l / l → s

There must be a clear link between L₁, L₂ and the change in state.

1

Bigger change in disorder for L₂ / boiling compared with L₁ / melting

M2 answer must be in terms of changes in state and not absolute states eg must refer to change from liquid to gas not just gas.

Ignore reference to atoms even if incorrect.

1

- (b) (i) $\Delta G = \Delta H - T\Delta S$

1

$\Delta H = c$ and $(-\Delta S) = m / \Delta H$ and ΔS are constants (approx)

Allow ΔH is the intercept, and $(-\Delta S)$ is the slope / gradient.

Can only score M2 if M1 is correct.

1

- (ii) Because the entropy change / ΔS is positive / $T\Delta S$ gets bigger

Allow $-T\Delta S$ gets more negative

1

- (iii) Not feasible / unfeasible / not spontaneous

1

- (c) (i) + 44.5 J K⁻¹ mol⁻¹

Allow answer without units but if units given they must be

correct (including mol⁻¹)

1

(c) (ii) At 5440 $\Delta H = T\Delta S$

$$= 5440 \times 44.5 = 242\,080$$

1

(OR using given value = $5440 \times 98 = 533\,120$)

Mark is for answer to (c)(i) $\times 5440$

1

$$\Delta H = 242 \text{ kJ mol}^{-1}$$

(OR using given value $\Delta H = 533 \text{ kJ mol}^{-1}$)

Mark is for correct answer to M2 with correct units (J mol⁻¹ or kJ mol⁻¹) linked to answer.

If answer consequentially correct based on (c)(i) except for incorrect sign (eg -242), max 1 / 3 provided units are correct.

1

[15]

M3. (a) 3-hydroxybutanal

ignore number 1 i.e. allow 3-hydroxybutan-1-al
not hydroxyl

1

(b)
$$k = \frac{2.2 \times 10^{-3}}{(0.10)(0.02)}$$

1

$$= 1.1$$

1

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

1

(c) planar or flat C=O or molecule

allow planar molecule

1

equal probability of attack from above or below

must be equal; not attack of OH

1

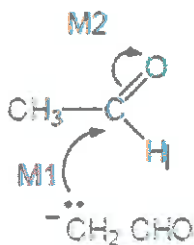
(d) (i) Step 1 if wrong – no mark for explanation. 1

involves ethanal and OH⁻ or species/ "molecules"
in rate equation 1

(ii) (B-L) acid or proton donor
not Lewis acid 1

(iii) nucleophilic addition
QOL 1

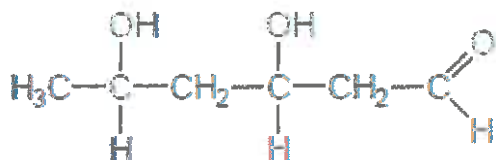
(iv)



*not allow M2 before M1, but allow M1 attack on C⁺ after non-scoring carbonyl arrow
ignore error in product*

2

(e)



1

[13]

M4.(a) Log (1 / time) on the y -axis + log (vol) on x -axis
If axes unlabelled use data to decide that log (1 / time) is on the y -axis

1

Sensible scales

Lose this mark if the plotted points do not cover at least half of the paper

Lose this mark if the graph plot goes off the squared paper

Lose this mark if plots a non-linear / broken scale

Lose this mark if uses an ascending y -axis of negative numbers

1

Plots points correctly \pm one square

1

Line through the points is smooth

Lose this mark if the candidate's line is doubled

1

Line through the points is best fit – ignores last point

Must recognise that point at 25 cm³ is an anomaly

If wrong graph, mark consequentially on anomaly if correctly plotted.

A kinked graph loses smooth and best fit marks

1

(b) Uses appropriate x and y readings

Allow taken from table or taken or drawn on graph

$$\frac{1.65 - 1.2}{1.4 - 0.9}$$

Must show triangle on graph or such as

1

Correctly calculates gradient 0.95 ± 0.02

Ignore positive or negative sign

Correct answer only with no working scores this mark

1

Answer given to 2 decimal places

1

(c) First order or order is 1

Allow consequential answer from candidate's results

1

(d) Thermostat the mixture / constant temperature / use a water bath
or Colorimeter / uv-visible spectrometer / light sensor to monitor colour change

1

Reaction / rate affected by temperature change
or Eliminates human error in timing / more accurate time of colour change

1

[11]

M5.(a) Bonds broken = $2(\text{C}=\text{O}) + 3(\text{H}-\text{H}) = 2 \times 743 + 3 \times \text{H}-\text{H}$

Bonds formed = $3(\text{C}-\text{H}) + (\text{C}-\text{O}) + 3(\text{O}-\text{H}) = 3 \times 412 + 360 + 3 \times 463$

Both required

1

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

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

Both required

1

$$\text{H}-\text{H} = 483 \text{ (kJ mol}^{-1}\text{)}$$

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

(d) 4 mol of gas form 2 mol 1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure 1

This increases the yield of methanol 1

(e) Impurities (or sulfur compounds) block the active sites
Allow catalyst poisoned 1

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



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

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

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

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

M3 is for partial pressures of both reactants

Alternative M3 =

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

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

1

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

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

M4 is for partial pressures of both products

Alternative M4 =

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

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

1

Stage 3: Equilibrium constant calculation

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

1

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

Answer must be to 2 significant figures

1

Units = kPa⁻²

1

[16]

M6.(a) [H₂O] is very high (compared with [H⁺] and [OH⁻])

OR

Very few H⁺ and OH⁻ ions

OR

Only / very slightly dissociates

OR

Equilibrium lies far to the left

Not partially dissociates

M1

1

[H₂O] is (effectively) constant
OR is incorporated into the constant K
Allow changes by only a very small amount

M2

1

(b) (Dissociation OR breaking bonds) is endothermic

1

∴ Equilibrium moves to RHS (at higher T) to absorb heat or to lower T or oppose increase in T

Allow to oppose change only if increase T mentioned

1

(c) [H⁺] = $\sqrt{K_w}$ (or = $\sqrt{5.48 \times 10^{-14}}$)

Correct pH answer scores 3

1

If wrong method no marks

Using alternative K_w (1.00×10^{-14}) gives pH = 7.00 which scores 1

$$= 2.34 \times 10^{-7}$$

1

$$\text{pH} = 6.63$$

Final answer must have 2dp

1

(d) [H⁺] = $K_w / [\text{OH}^-]$ or (= $5.48 \times 10^{-14} / 0.12$)

Correct pH answer scores 3

1

If wrong method no marks

If use alternative K_w (1.00×10^{-14}) again, do not penalise repeat error so pH = 13.08 scores 3

$$= 4.566 \times 10^{-13}$$

1

$$\text{pH} = 12.34$$

If use alternative K_w (1.00×10^{-14}) not as a repeat error, pH = 13.08 scores 1

If AE in K_w value made in part (c) is repeated here, do not penalise again.

Final answer must have 2dp, but if dp penalised in (c) allow

more than 2dp here but not fewer.

1
[10]

$$\text{M7.(a)} \quad [\text{H}^+] = \frac{K_a \times [\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} \quad \text{or} = 1.74 \times 10^{-5} \times \frac{0.186}{0.105}$$

Allow ()

$$= 3.08 \times 10^{-5}$$

If $[\text{HX}] / [\text{X}^-]$ or $\frac{0.186}{0.105}$ upside down, or any addition or subtraction lose M1 & M2.

M1

1

$$\text{pH} = 4.51$$

(correct answer scores 3)

Can score M3 for correct pH conseq to their $[\text{H}^+]$, so pH = 5.01 scores one

Must be to 2 dp

M2

1

M3

1

Alternative using Henderson-Hasselbach Equation

$$\text{pH} = \text{pKa} - \log[\text{HX}] / [\text{X}^-] = -\log(1.74 \times 10^{-5}) - \log\left(\frac{0.186}{0.105}\right)$$

Allow ()

M1

$$\text{pKa} = 4.76 - 0.248$$

If $[\text{HX}] / [\text{X}^-]$ or $\frac{0.186}{0.105}$ upside down, can only score 1

M2

$$\text{pH} = 4.51$$

so pH = 5.01

Must be to 2 dp

M3

(b) mol HX after addition (= 0.251 + 0.015) = 0.266

For HX, if no addition or error in addition (other than AE) (or subsequent extra add or sub) MAX 3

M1

1

mol X⁻ after subtraction (= 0.140 - 0.015) = 0.125

For X⁻ if no subtraction or error in subtraction (other than AE) (or subsequent extra add or sub) MAX 3

M2

1

$$[\text{H}^+] = \left(\frac{K_a \times [\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} \right) = \frac{1.74 \times 10^{-4} \times 0.266}{0.125}$$

If errors above in both addition AND subtraction can only score M3 for insertion of their numbers in rearranged expression. One exception, if addition and subtraction reversed then pH = 4.58 scores 2

M3

1

$$[\text{H}^+] = 3.703 \times 10^{-5} \text{ (mol dm}^{-3}\text{)}$$

If [HX] / [X⁻] upside down, lose M3 & M4 (or next two marks) but can score M5 for correct pH consequent to their [H⁺], so if M1 & M2 correct, pH = 5.09 scores 3.

M4

1

$$\text{pH} = 4.43$$

Correct use of HX and X⁻ values from (d) gives
pH = 4.41 and scores 4

If wrong method, e.g. $\sqrt{\quad}$ or no use of rearranged K_a expression, may score M1 & M2 but no more.

Allow more but not fewer than 2dp here.

M5

1

Alternative using Henderson-Hasselbach Equation

$$\text{mol acid after addition} = 0.251 + 0.015 = 0.266$$

For HX, if no addition or error in addition (other than AE) (or subsequent extra add or sub) MAX 3

M1

$$\text{mol salt after addition} = 0.140 - 0.015 = 0.125$$

For X⁻ if no subtraction or error in subtraction (other than AE) (or subsequent extra add or sub) MAX 3

M2

$$\text{pH} = (\text{pK}_a - \log[\text{HX}] / [\text{X}^-]) = -\log(1.74 \times 10^{-5}) - \log(0.266 / 0.125)$$

If errors above in both addition AND subtraction can only score M3 for insertion of their numbers – except if addition and subtraction reversed then pH = 4.58 scores 2

M3

$$\text{pH} = 4.76 - 0.328$$

M4

$$\text{pH} = = 4.43$$

If [HX] / [X⁻] upside down, lose M3 & M4 (or next two marks) but can score M5 for correct pH conseq to their working, so if M1 & M2 correct, pH = 5.09 scores 3.

Allow more but not fewer than 2dp here.

M5

[8]

M8.(a) (i) G

1

(ii) F

1

(iii) H

1

(b) (i) cresol purple

1

(ii) yellow to red

both colours needed and must be in this order

1

(iii) yellow or pale yellow

Not allow any other colour with yellow

1

[6]

M9.D

[1]

M10.C

[1]

M11.B

[1]

M12.C

[1]

M13.B

[1]

M14.B

[1]

M15.D

[1]

M16.B

[1]

M17.C

[1]

M18.B

[1]

M19.D

[1]

M20.A

[1]

M21.B

[1]