Q11.

Methanol can be manufactured in a reversible reaction as shown by the equation.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) State and explain the effect of using a catalyst on the yield of methanol in this equilibrium.

_____

_____

_____

_____

_____

_____

(2)

(b) Give an expression for the equilibrium constant (K_c) for this reaction.

(1)

(c) A mixture of carbon monoxide and hydrogen was allowed to reach equilibrium in a container of volume 250 cm^3 at temperature *T*.

At equilibrium, the mixture contained 0.340 mol of carbon monoxide, 0.190 mol of hydrogen and 0.0610 mol of methanol.

Calculate the value of the equilibrium constant (K_c) for this reaction at temperature *T*.

K_c _____ mol^{-2} dm^6

(3)

(d) Methanol decomposes on heating in a reaction that is the reverse of that used in its manufacture.

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

Use your answer from part (c) to determine the value of K_c for this equilibrium at temperature T.
State the units for this value of K_c

(If you were unable to complete the calculation in part (c), assume a value of $K_c = 0.825$ mol^{-2} dm^6. This is not the correct value.)

Value of K_c _____

Units of K_c _____

(2)

(Total 8 marks)

Q12.

Compounds **A** and **B** react together to form an equilibrium mixture containing compounds **C** and **D** according to the equation

$$2\mathbf{A} + \mathbf{B} \rightleftharpoons 3\mathbf{C} + \mathbf{D}$$

(a) A beaker contained 40 cm^3 of a 0.16 mol dm^{-3} aqueous solution of A.
9.5×10^{-3} mol of **B** and 2.8×10^{-2} mol of **C** were added to the beaker and the mixture was left to reach equilibrium.
The equilibrium mixture formed contained 3.9×10^{-3} mol of **A**.

Calculate the amounts, in moles, of **B**, **C** and **D** in the equilibrium mixture.

Amount of **B** _____ mol

Amount of **C** _____ mol

Amount of **D** _____ mol

(5)

(b) Give the expression for the equilibrium constant (K_c) for this equilibrium **and** its units.

K_c

Units _____

(2)

(c) A different equilibrium mixture of these four compounds, at a different temperature, contained 0.21 mol of **B**, 1.05 mol of **C** and 0.076 mol of **D** in a total volume of 5.00×10^2 cm^3 of solution.
At this temperature the numerical value of K_c was 116

Calculate the concentration of **A**, in mol dm^{-3}, in this equilibrium mixture.
Give your answer to the appropriate number of significant figures.

Concentration of **A** _____ mol dm^{-3}

(3)

(d) Justify the statement that adding more water to the equilibrium mixture in part (c) will lower the amount of **A** in the mixture.

_____

_____

_____

_____

_____

_____

(3)

(Total 13 marks)

Q13.

When substances **P** and **Q** react together to form substance **R** an equilibrium is established according to the equation

$$P(g) + Q(g) \rightleftharpoons 2R(g)$$

The equilibrium constant expression is $K_c = \dfrac{[R]^2}{[P][Q]}$

1.0 mol of **P** and 1.0 mol of **Q** were mixed in a container with volume 1.0 dm^3

At equilibrium, x mol of **P** had reacted.

(a) The amount, in moles, of each of P and Q at equilibrium is $(1-x)$.

Deduce in terms of x the amount, in moles, of **R** in the equilibrium mixture.

_____

(1)

(b) At 298 K the value of the equilibrium constant $K_c = 3.6$

Calculate a value for the equilibrium concentration, in mol dm^{-3}, of **R**.

Equilibrium concentration of **R** _____ mol dm^{-3}

(3)

(Total 4 marks)

Q14.

Hydrogen can be produced by this reaction.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

In an experiment 4.20 mol of carbon monoxide were mixed with 2.00 mol of steam. When the reaction reached equilibrium, 1.60 mol of hydrogen had been formed.

What is the value of the equilibrium constant, K_c, for this reaction?

A 0.30 ⬭

B 0.41 ⬭

C 1.54 ⬭

D 2.46 ⬭

(Total 1 mark)

Q15.

Ethanoic acid and ethane-1,2-diol react together to form the diester ($C_6H_{10}O_4$) as shown.

$$2CH_3COOH(l) + HOCH_2CH_2OH(l) \rightleftharpoons C_6H_{10}O_4(l) + 2H_2O(l)$$

(a) Draw a structural formula for the diester $C_6H_{10}O_4$

(1)

(b) A small amount of catalyst was added to a mixture of 0.470 mol of ethanoic acid and 0.205 mol of ethane-1,2-diol.

The mixture was left to reach equilibrium at a constant temperature.

Complete **Table 1**.

Table 1

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At the start	0.470	0.205	0	0
At equilibrium	0.180			

Space for working

(3)

(c) Write an expression for the equilibrium constant, K_c, for the reaction.

The total volume of the mixture does not need to be measured to allow a correct value for K_c to be calculated.

Justify this statement.

Expression

Justification _____

_____

(2)

(d) A different mixture of ethanoic acid, ethane-1,2-diol and water was prepared and left to reach equilibrium at a different temperature from the experiment in part (b)

The amounts present in the new equilibrium mixture are shown in **Table 2**.

Table 2

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At new equilibrium	To be calculated	0.264	0.802	1.15

The value of K_c was 6.45 at this different temperature.

Use this value and the data in **Table 2** to calculate the amount, in mol, of ethanoic acid present in the new equilibrium mixture.

Give your answer to the appropriate number of significant figures.

Amount of ethanoic acid _____ mol

(3)

(Total 9 marks)

Q16.

Methanol can be manufactured by the reaction of carbon monoxide with hydrogen

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

In an experiment, 0.73 mol of carbon monoxide was heated with 1.25 mol of hydrogen. An equilibrium mixture was formed that contained 0.43 mol of methanol.

(a) Calculate the amount, in moles, of each reactant present at equilibrium.

Amount of carbon monoxide = ____ mol

Amount of hydrogen = _____ mol

(2)

(b) Write an expression for the equilibrium constant, K_c, for this reaction.

_____

(1)

(c) In another experiment at a different temperature, the equilibrium mixture contained 0.452 mol of carbon monoxide, 0.106 mol of hydrogen and 0.273 mol of methanol in a flask of volume 9.40×10^3 cm^3.

Calculate the value of the equilibrium constant, K_c, at this temperature and state the units.

K_c = _____ Units = _____

(4)

(d) The total pressure of this equilibrium mixture in the flask was 482.9 kPa.

Calculate the temperature, in °C, of the equilibrium mixture.
(The ideal gas constant R = 8.31 J mol^{-1} K^{-1})

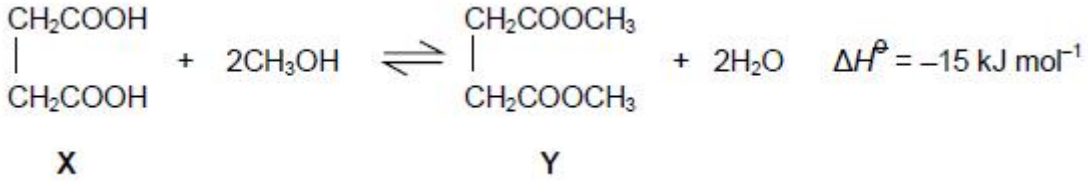
Temperature = _____ °C

(4)

(Total 11 marks)

Q17.

Acid **X** reacts with methanol to form an ester **Y**.



X **Y**

(a) Write an expression for the equilibrium constant, K_c, for this reaction. Use **X** and **Y** in your expression.

_____

_____

(1)

(b) A mixture of 0.32 mol of acid **X** and 0.84 mol of CH_3OH was allowed to reach equilibrium in the presence of a small amount of catalyst.
The equilibrium mixture formed contained 0.26 mol of ester **Y**.

Calculate the amounts, in moles, of **X**, CH_3OH and H_2O in this equilibrium mixture.

Amount of **X** _____

Amount of CH_3OH _____

Amount of H_2O _____

(3)

(c) Calculate the value of K_c and state the units.

K_c _____ units _____

(3)

(d) Predict the effect on K_c if the reaction is carried out at a lower temperature.

_____

(1)

(Total 8 marks)

Q18.

A student carried out an experiment to determine the value of the equilibrium constant (K_c) for the esterification reaction between ethanoic acid and ethanol.

ethanoic acid + ethanol ⇌ ethyl ethanoate + water

(a) Write an equation for this reaction.

_____

(1)

(b) Draw the skeletal formula of ethyl ethanoate.

_____

(1)

(c) The student used a small amount of concentrated sulfuric acid as a catalyst to increase the rate of the reaction.

State, in general terms, how a catalyst works.

_____

_____

_____

_____

(2)

(d) The student mixed 0.0435 mol of ethanol and 0.0435 mol of ethanoic acid.
The student added 5.00×10^{-4} mol of sulfuric acid to the mixture.
This mixture was left for one week to reach equilibrium.
The equilibrium reaction was stopped by adding the mixture to water.

For this reaction, $K_c = 4.07$ at the temperature of the experiment.

Calculate the volume of 0.400 mol dm^{-3} sodium hydroxide solution required to react completely with the acids in the equilibrium mixture.

Volume = _____ cm^3

(6)

(e) Suggest how the student could check that the mixture had reached equilibrium after one week.

_____

_____

_____

_____

_____

(2)

(Total 12 marks)

Q19.

Colourless solutions of **X**(aq) and **Y**(aq) react to form an orange solution of **Z**(aq) according to the following equation.

$$\mathbf{X}(aq) + 2\mathbf{Y}(aq) \rightleftharpoons \mathbf{Z}(aq) \quad \Delta H = -20 \text{ kJ mol}^{-1}$$

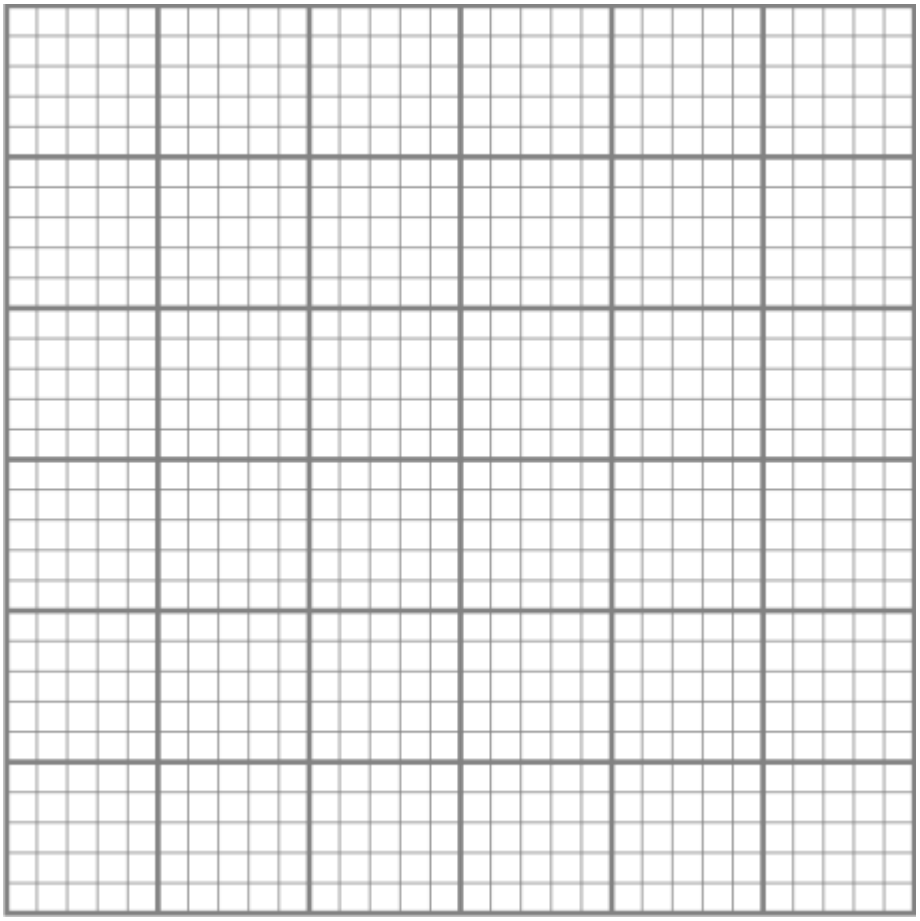
A student added a solution containing 0.50 mol of **X**(aq) to a solution containing 0.50 mol of **Y**(aq) and shook the mixture.
After 30 seconds, there was no further change in colour.
The amount of **Z**(aq) at equilibrium was 0.20 mol.

(a) Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

Amount of **X**(aq) = _____ mol Amount of **Y**(aq) = _____ mol

(2)

(b) On the grid below, draw a graph to show how the amount of **Z**(aq) changed from the time of initial mixing until 60 seconds had elapsed.



(3)

(c) The student prepared another equilibrium mixture in which the equilibrium concentrations of **X** and **Z** were:
X(aq) = 0.40 mol dm^{-3} and **Z**(aq) = 0.35 mol dm^{-3}.

For this reaction, the equilibrium constant K_c = 2.9 mol^{-2} dm^6.
Calculate a value for the concentration of **Y** at equilibrium.
Give your answer to the appropriate number of significant figures.

[**Y**] = _____ mol dm^{-3}

(3)

(d) The student added a few drops of **Y**(aq) to the equilibrium mixture of **X**(aq), **Y**(aq) and **Z**(aq) in part (c).

Suggest how the colour of the mixture changed. Give a reason for your answer.

Colour change_____

Reason _____

_____

_____

_____

(3)

(e) The student warmed the equilibrium mixture from part (c).

Predict the colour change, if any, when the equilibrium mixture was warmed.

_____

_____

(1)

(Total 12 marks)

Mark Scheme

Q11.

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

CE = 0 if yield changes

1

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

*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 equally / by the same amount*

1

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

Must be square brackets

Ignore state symbols

Ignore units

1

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

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

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 cm^3*

*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** $\dfrac{1}{\text{Answer to (c)}}$ = 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]

Q12.

(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

M3

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

M4

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

M5

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

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 $[A]^2 = \dfrac{[C]^3[D]}{K_c\,[B]}$ or $[A] = \sqrt{\dfrac{[C]^3[D]}{K_c\,[B]}}$

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] = <u>0.17</u> (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]

Q13.

(a) mol R = 2*x*

1

(b) $3.6 = \frac{(2x)^2}{(1-x)^2}$

M1 can be awarded for the insertion of their answer from (a) correctly

1

$\sqrt{3.6} = \frac{2x}{1-x}$ (only positive root to be used)

M2 can be awarded if their expression is expanded

1

$\sqrt{3.6} - \sqrt{3.6}\,x = 2x$

$1.9 = 3.9x$

$X = 0.49$

[R] = 0.97 mol dm^{-3} (allow range 0.97–.098)

M3 solve for x from their expression in M1 and use it to calculate [R]

1

[4]

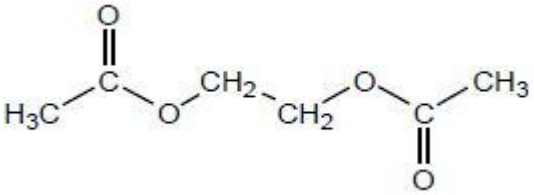
Q14.

D

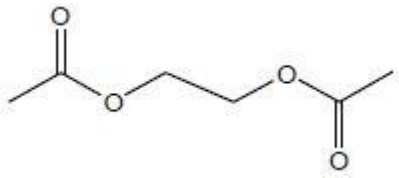
[1]

Q15.

(a)



Allow $CH_3COOCH_2CH_2OOCCH_3$
OR $CH_3COOCH_2CH_2OCOCH_3$
OR



1

(b) Mol $HOCH_2CH_2OH$ = 6.00×10^{-2} OR 0.06(00)

1

Mol $C_6H_{10}O_4$ = 1.45×10^{-1} OR 0.145

1

Mol H_2O = 2.90×10^{-1} OR 0.29(0)

1

(c)

$$(K_c =) \frac{[\text{ester}] \times [H_2O]^2}{[CH_3COOH]^2 \times [HOCH_2CH_2OH]}$$

Allow words for acid and alcohol

1

The volume cancels out (Penalise a contradictory justification from expression if the volumes do not cancel out)
OR
there are equal no of moles on each side of the equation
OR
there are equal no of molecules on each side of the equation

1

(d)

$$(\text{Mol } CH_3COOH / V)^2 = \frac{(8.02 \times 10^{-1}/V)(1.15/V)^2}{6.45 \times (2.64 \times 10^{-1}/V)}$$

M1

$$\text{Mol } CH_3COOH = \sqrt{\frac{(8.02 \times 10^{-1}) \times (1.15)^2}{6.45 \times (2.64 \times 10^{-1})}} = \sqrt{0.623}$$

M2

Mol CH_3COOH = 0.789 (must be 3 sfs) Allow 0.788 – 0.790

M3

0.789 scores 3

Allow without V : $(nCH_3COOH)^2 = \frac{(8.02 \times 10^{-1})(1.15)^2}{6.45 \times (2.64 \times 10^{-1})}$

If $(nCH_3COOH)^2$ =0.623 then award M1 and M2

If K_c is correct in (c) but incorrect rearrangement, then CE=0 except if upside down rearrangement then M3 only awarded for 1.27

If K_c is incorrect in (c) then only M1 can be awarded for correct rearrangement.

[9]

Q16.

(a) Mol CO = (0.73 − 0.43) = 0.30 (mol)

1

Mol H_2 = (1.25 − 2(0.43)) = 0.39 (mol)

1

(b) $K^c = \dfrac{[CH_3OH]}{[CO][H_2]^2}$

1

(c) Divides throughout by volume

1

$K_c = \dfrac{[0.273/9.40]}{[0.1.06/9.40]^2[0.452/9.40]}$

1

$K_c = \dfrac{0.029}{0.0000061146}$

$K_c = 4.75 \times 10^3$

1

Unit = $mol^{-2}\ dm^{+6}$

1

(d) pV = nRT

$T = \dfrac{pV}{nR}$

1

n = 0.452 + 0.106 + 0.273 = 0.831 (mol)

Calculation of moles and substitution of all values

1

$= \dfrac{482.9 \times 10^3 \times 9.40 \times 10^{-3}}{0.831 \times 8.31} = 657\ K$

Correct conversion of p and V

1

= 384 °C

Conversion to °C

1

[11]

Q17.

(a) $\frac{[Y][H_2O]^2}{[X][CH_3OH]^2}$

1

(b) 0.06

1

0.32

1

0.52

1

(c) $\frac{0.26 \times 0.52^2}{0.06 \times 0.32^2}$

1

= (11.44) = 11 (2 sf)

1

No units

1

(d) Increase

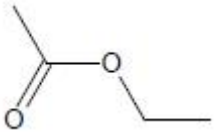
1

[8]

Q18.

(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

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]

Q19.

(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

(e) The orange colour would fade

1

[12]