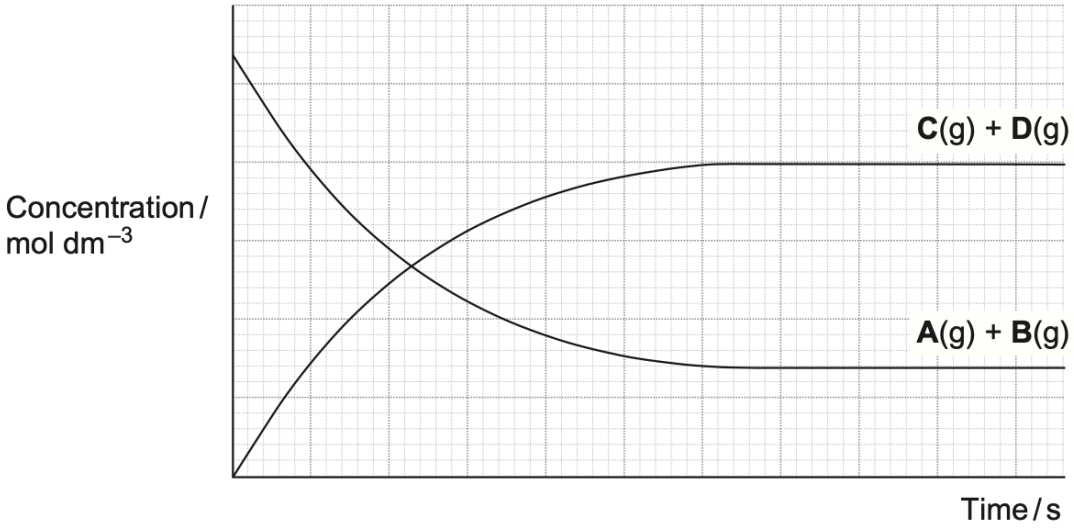
Q1. A dynamic equilibrium is established when gas **A** is mixed with gas **B** at a given temperature.

$$\mathbf{A}(g) + \mathbf{B}(g) \rightleftharpoons \mathbf{C}(g) + \mathbf{D}(g)$$

Figure 1 shows how the concentrations of reactants and products change with time.

Figure 1



(a) (i) On the appropriate axis of **Figure 1**, place an **X** to show the time when equilibrium is first established.

[1 mark]

(a) (ii) State how the rate of the forward reaction and the rate of the reverse reaction are related to each other at equilibrium.

[1 mark]

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(b) Give the meaning of the term **dynamic** in the context of a dynamic equilibrium.

[1 mark]

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(c) The total pressure on the system is increased at constant temperature.

(c) (i) State and explain the effect, if any, of this change on the position of this equilibrium.

[2 marks]

Effect .....

Explanation .....

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(c) (ii) State and explain the effect, if any, of this change on the time taken to reach this equilibrium.

[3 marks]

Effect .....

Explanation .....

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Q2.

Hydrogen is produced in industry from methane and steam in a two-stage process.

(a) In the first stage, carbon monoxide and hydrogen are formed.
The equation for this reaction is

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

(a) (i) Use Le Chatelier's principle to state whether a high or low temperature should be used to obtain the highest possible equilibrium yield of hydrogen from this first stage.
Explain your answer.

[3 marks]

Temperature .....

Explanation .....

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(a) (ii) Le Chatelier's principle suggests that a high pressure will produce a low yield of hydrogen in this first stage.

Explain, in terms of the behaviour of particles, why a high operating pressure is used in industry.

[2 marks]

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(a) (iii) A nickel catalyst is used in the first stage.

Explain why the catalyst is more effective when coated onto an unreactive honeycomb.

[2 marks]

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(b) The second stage is carried out in a separate reactor. Carbon monoxide is converted into carbon dioxide and more hydrogen is formed.

The equation for this reaction is

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -41 \text{ kJ mol}^{-1}$$

Use Le Chatelier's principle to state the effect, if any, of a **decrease** in the total pressure on the yield of hydrogen in this second stage. Explain your answer.

[2 marks]

Effect .....

Explanation .....

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Q3.

Sulfuric acid is manufactured by the Contact Process.

(a) In this process, sulfur dioxide reacts with oxygen.
The equation for the equilibrium that is established is

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \qquad \Delta H = -98\ kJ\ mol^{-1}$$

(a) (i) State and explain the effect of a **decrease** in temperature on the equilibrium yield of SO_3

Effect of a decrease in temperature on yield .....

Explanation .....

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(3 marks)

(Extra space) .....

.....

(a) (ii) Give **two** features of a reaction at equilibrium.

Feature 1 .....

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Feature 2 .....

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(2 marks)

(b) Explain why a catalyst has no effect on the position of an equilibrium.

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(2 marks)

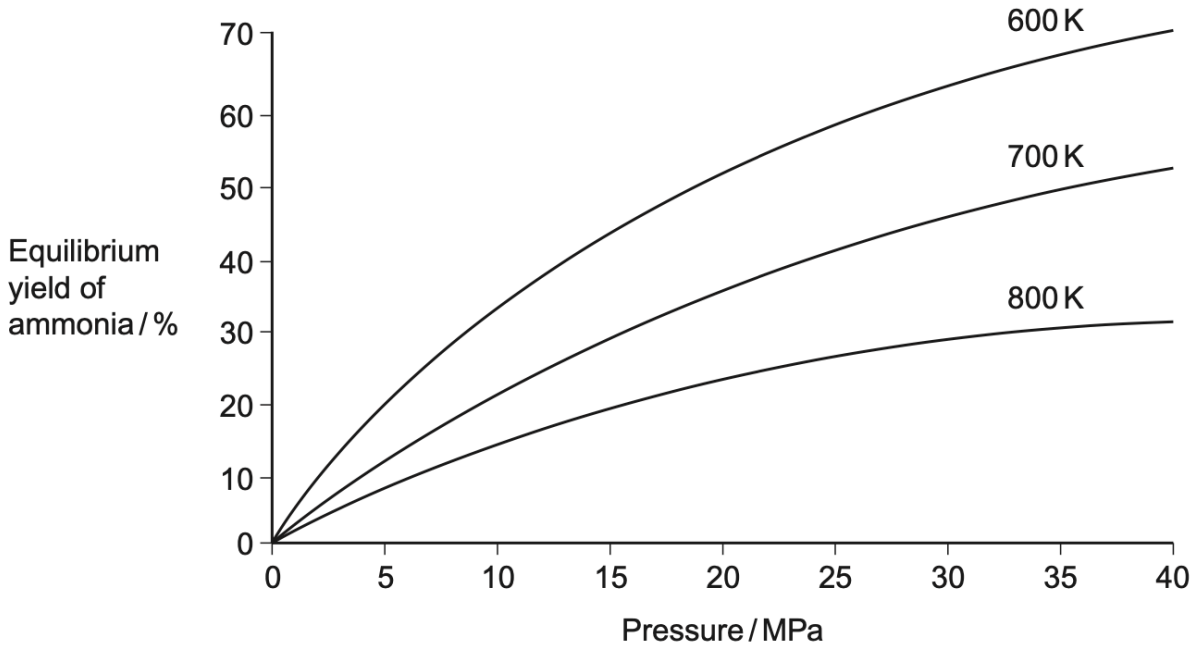
(Extra space) .....

.....

Ammonia is manufactured by the Haber process in which the following equilibrium is established.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(c) The diagram shows how the equilibrium yield of ammonia varies with changes in pressure and temperature.



(c) (i) Use the diagram to state the effect of an **increase** in pressure at constant temperature on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield .....

Explanation .....

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.....

(3 marks)

(Extra space) .....

.....

(c) (ii) Use the diagram to state the effect of an **increase** in temperature at constant pressure on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield .....

Explanation .....

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(3 marks)

(Extra space) .....

.....

(d) At equilibrium, with a pressure of 35 MPa and a temperature of 600 K, the yield of ammonia is 65%.

(d) (i) State why industry uses a temperature higher than 600 K.

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(1 mark)

(d) (ii) State why industry uses a pressure lower than 35 MPa.
Do **not** include references to safety.

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(1 mark)

Q4.

Ethene reacts with steam in the presence of an acid catalyst to form ethanol.

$$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$$

. 1 Write an expression for the equilibrium constant K_c for this equilibrium.
Deduce the units of K_c.

[2 marks]

Expression _____

_____

_____

Units _____

. 2 An equilibrium mixture was found to contain 0.700 mol of ethene, 1.20 mol of steam and 4.40 mol of ethanol at a temperature ***T***. The volume of the container was 2.00 dm^3.

Calculate a value of K_c for this equilibrium at this temperature.

Give your answer to an appropriate number of significant figures.

[2 marks]

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Q5. Colourless solutions of **X**(aq) and **Y**(aq) react to form an orange solution of **Z**(aq) according to the following equation.

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

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.

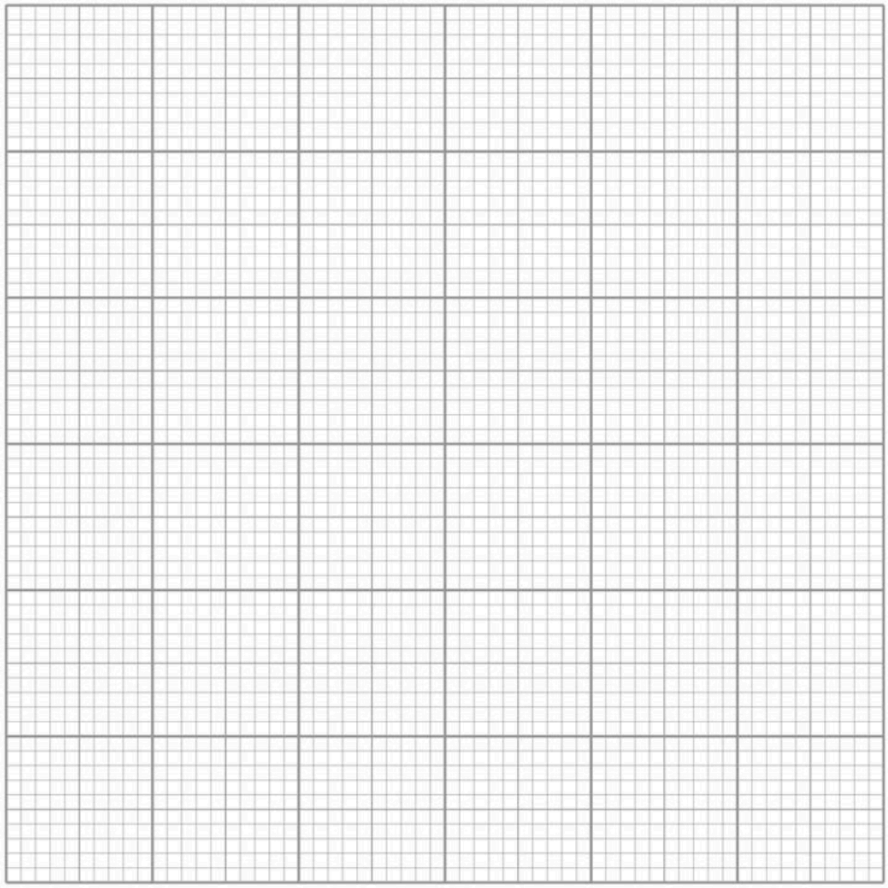
. 1 Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

[2 marks]

Amount of **X**(aq) =_____mol Amount of **Y**(aq) =_____mol

. 2 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 marks]



. **3** 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.

[3 marks]

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

. **4** The student added a few drops of **Y**(aq) to the equilibrium mixture of **X**(aq), **Y**(aq) and **Z**(aq) in Question **4.3**.

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

[3 marks]

Colour change _____

Reason _____

_____

_____

_____

. **5** The student warmed the equilibrium mixture from Question **4.3**.

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

[1 mark]

_____

_____

CHEMICAL EQUILIBRIA (3.1.6) MS

Q1.

Question	Marking Guidance	Mark	Comments
1(a)(i)	Award mark for **X on the time axis** at the point where the lines just become **horizontal**	1	Allow this mark If **X** is above the letters "sh" in the word "show' in Question 1(a)(ii) - in the range of lines 31 to 33
1(a)(ii)	They are equal / the same **OR** Forward (rate) = Reverse / backward (rate)	1	Allow the word 'speed' in this context. Ignore reference to concentration.
1(b)	Both **OR** forward and reverse reactions occur at the same time **OR** both are occurring at once **OR** both occur all of the time **OR** both are ongoing **OR** both never stop	1	Ignore 'at equal rates'. Ignore reference to concentration or equilibrium. The idea that both reactions occur simultaneously is essential. The simple idea of 'both reactions occurring' is insufficient for the mark.
1(c)(i)	**M1** No effect / no change / none / stays the same **M2** requires correct **M1** **M2** Equal (number of) moles / molecules on both sides	2	In **M2**, ignore reference to particles or atoms.

Q1.

1(c)(ii)	**M1** Less time or it decreases or (equilibrium) reached faster (ie **M1** is a reference to time taken) **M2** More particles / molecules in a given volume / space **OR** the particles / molecules are closer together **M3** More successful / productive collisions in a given time **OR** more collisions with $E>E_{Act}$ in a given time **OR** more frequent successful / productive collisions **OR** increased / greater successful / productive collision frequency / rate	3	If **M1** is 'more time / it increases' or 'no effect', then **CE=0** for the clip. Reference to faster / increased rate / increased speed alone penalises **M1**, but mark on **M2** and **M3** If **M1** is blank, then look for all three marks in the text. Ignore reference to reactants / products. Penalise **M3** if an increase / decrease in the value of E_{Act} is stated.

Q2.

Question	Marking Guidance	Mark	Comments
(a)(i)	**M1** High (temperature) OR Increase (the temperature) **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** At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature	3	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** **M3** depends on a correct statement for **M2** For **M3**, the position of equilibrium shifts/moves to absorb heat OR to lower the temperature OR to cool down the reaction

Q2.

(a)(ii)	**M1** The reaction <u>gets to equilibrium faster / in less time</u> ***OR*** Produces a small yield <u>faster / in less time</u> ***OR*** <u>Increases the rate</u> (of reaction / of attainment of equilibrium) **M2** High pressure leads to **one** of the following • <u>more particles / molecules in a given volume</u> • <u>particles / they are closer together</u> • <u>higher concentration of particles /molecules</u> ***<u>AND</u>*** • <u>more collisions in a given time</u> / <u>increased collision frequency</u>	2	Mark independently Penalise **M2** for reference to <u>increased</u> energy of the particles

Q2.

(a)(iii)	**M1** Increase in / more / large(r) / big(ger) surface area / surface sites **M2** increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)	2	Mark independently For **M1** accept "an increase in surface" For **M2** not simply "more collisions" Ignore "the chance or likelihood" of collisions

(b)	**M1** No effect / None **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	2	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** depends on a correct statement for **M1** In **M2 not** "atoms"

Q3.

Question	Marking Guidance	Mark	Comments
(a)(i)	**M1 (**Yield) increases / goes up / gets more **M2** The (forward) reaction / to the right is <u>exothermic</u> or <u>gives out / releases heat</u> ***OR*** The reverse reaction / to the left is <u>endothermic</u> or <u>takes in / absorbs heat</u> **M3 depends on correct M2 and must refer to temperature/heat** The (position of) <u>equilibrium shifts / moves</u> left to right to <u>oppose the decrease in temperature</u>	3	If **M1** is blank, mark on and seek to **credit the correct information in the explanation.** If **M1** is incorrect **CE=0** for the clip. **M3** depends on a correct statement for **M2** For **M3**, the <u>equilibrium shifts/moves</u> to <u>release heat</u> ***OR*** to <u>raise the temperature</u> ***OR*** to <u>heat up the reaction.</u>
(a)(ii)	**M1** <u>Concentration(s)</u> (of reactants and products) remain or stay constant / the same **M2** <u>Forward rate</u> = <u>reverse / backward rate</u>	2	For **M1** credit [ ] for concentration. Not “equal concentrations”. Not “concentrations <u>is / are the same</u>”. Not “amount”. Ignore “dynamic” and ignore “speed”. Ignore “closed system”. It is possible to score both marks under the heading of a single feature.

Q3.

(b)	**M1** Catalysts increase rate of / speed up both forward and reverse / backward reactions **M2** increase in rate / affect on rate / speed is equal / the same	2	If M1 is given as “no effect” / ”no change” then CE= 0 for clip Ignore references to “decrease in rate”
(c)(i)	**M1** (The yield) increases / goes up / gets more **M2** 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. ***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	3	If M1 is given as “decreases” / “no effect” / ”no change” then CE= 0 for clip, but mark on from a blank. Ignore ”volumes”, “particles” “atoms” and “species” for M2 For M3, not simply “to oppose the change” For M3 credit the equilibrium shifts / moves to lower / decrease the pressure (There must be a specific reference to the change that is opposed)

Q3.

(c)(ii)	**M1** The yield decreases / goes down / gets less **M2** (Forward) reaction is exothermic ***OR*** gives out / releases heat ***OR*** reverse reaction is endothermic ***OR*** takes in / absorbs heat **Can only score M3 if M2 is correct** The equilibrium shifts / moves (from right to left) to oppose the increase in temperature	3	If M1 is given as "increase" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank. For M3, not simply "to oppose the change" For M3 credit the equilibrium shifts / moves 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)

(d)(i)	Must be comparative Higher rate of reaction ***OR*** increase / speed up the rate (of reaction) ***OR*** Gets to equilibrium faster/ quicker ***OR*** faster or quicker rate / speed of attainment of equilibrium	1	Credit correct reference to rate being too (s)low / (s)lower at temperatures less than 600 K Ignore statements about the "yield of ammonia"

(d)(ii)	Less electrical pumping cost ***OR*** Use lower pressure equipment / valves / gaskets / piping etc. ***OR*** Uses less expensive equipment	1	Not just "less expensive" alone Not just "less energy or saves energy" alone Credit correct qualified references to higher pressures Ignore references to safety

Q4.

Question	Marking Guidance	Mark	Comments
.1	M1 $(K_c =) \frac{[CH_3CH_2OH]}{[CH_2{=}CH_2][H_2O]}$ M2 $mol^{-1}\ dm^3$	1 1	M1 penalise missing brackets or use of (); allow correct molecular formulae in correct expression (and allow CH_2CH_2); ignore powers shown as 1 M2 units must be in simplest form on one line (or $dm^3\ mol^{-1}$) M2 units are consequential on expression in M1 ($mol^{-1}\ dm^3$ only scores if it is the units for the expression in M1)
.2	M1 $\frac{[\frac{4.40}{2.00}]}{[\frac{0.70}{2.00}]\times[\frac{1.20}{2.00}]}$ or $\frac{2.20}{0.35 \times 0.60}$ or $\frac{4.40}{0.70 \times 1.20} \times 2.00$ M2 10.5 (must be 3sf)	1 1	10.5 (3sf) scores both marks; correct value to 2sf (10) or 4sf or more (10.476…) scores 1 mark Volume not used is CE=0 If use incorrect expression for K_c in 1.2 then no marks in 1.2 If a value from the question is copied incorrectly into the expression, could still score M2 if then used correctly in calculation (AE -1) Ignore units

Q5.

Question	Marking guidance	Mark	AO	Comments
.1	amount of X = 0.50 – 0.20 = 0.30 (mol)	1	AO2h	
	amount of Y = 0.50 – 2 × 0.20 = 0.10 (mol)	1	AO2h	
.2	Axes labelled with values, units and scales that use over half of each axis	1	AO2h	All three of values, units and scales are required for the mark
	Curve starts at origin	1	AO2h	
	Then flattens at 30 seconds at 0.20 mol	1	AO2h	
.3	Expression = $K_c = \frac{[Z]}{[X][Y]^2}$	1	AO1a	
	$[Y]^2 = \frac{[Z]}{[X]\,K_c}$	1	AO2b	
	$[Y] = (0.35 / 0.40 \times 2.9)^{0.5} = 0.5493 = 0.55$ (mol dm^{-3})	1	AO1b	Answer must be to 2 significant figures
.4	Darkened / went more orange	1	AO2g	
	The equilibrium moved to the right	1	AO2g	
	To oppose the increased concentration of Y	1	AO2g	
.5	The orange colour would fade	1	AO3 1a	