

3: Controlling reactions 1 – Topic questions

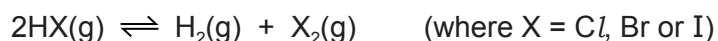
The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
3	2017	June	22
3	2017	June	23
1	2017	November	21

The mark scheme for each question is provided at the end of the document.

- 3 The hydrogen halides, HCl, HBr and HI, can undergo thermal decomposition. In a sealed container an equilibrium is established according to the equation shown.



- (a) Some bond energies are shown in the table.

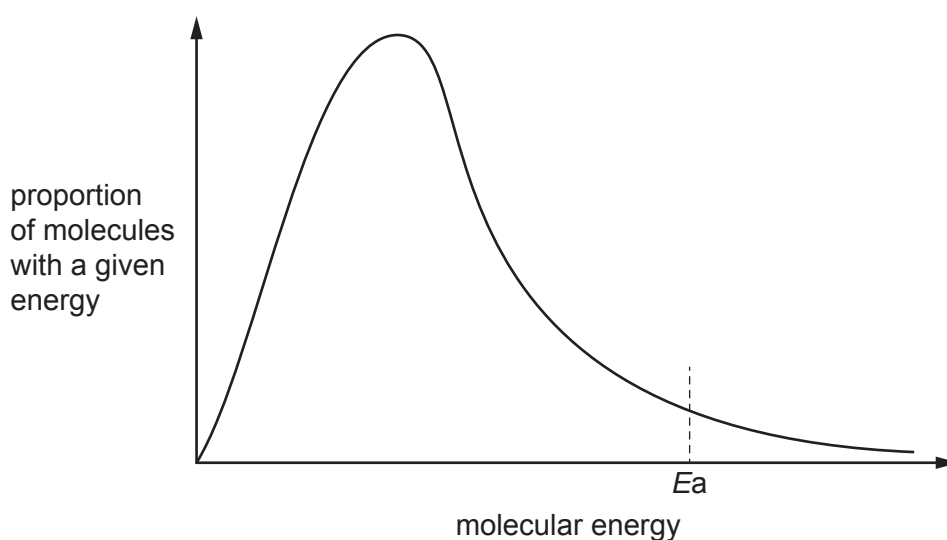
	bond energy kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

Use these data to calculate a value for the enthalpy change, ΔH , for the thermal decomposition of hydrogen bromide, HBr, according to the equation shown.

$$\Delta H = \dots\dots\dots \text{kJ mol}^{-1} \quad [1]$$

- (b) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) With reference to the curves, state and explain the effect of increasing temperature on the rate of decomposition of HBr.

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..... [3]

- (iii) The decomposition of HBr is endothermic.

State the effect of increasing temperature on the percentage of HBr that decomposes.
Use Le Chatelier's principle to explain your answer.

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..... [3]

- (iv) At 700 K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.

Explain this difference with reference to bond strengths and the factors that affect them.

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..... [3]

- (c) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2 .

- (i) Calculate the amounts, in mol, of H_2 and HCl present in the equilibrium mixture.

$\text{H}_2 = \dots\dots\dots$ mol

$\text{HCl} = \dots\dots\dots$ mol
[2]

- (ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of $\text{HCl} = \dots\dots\dots$

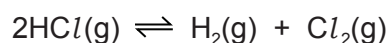
mole fraction of $\text{H}_2 = \dots\dots\dots$

mole fraction of $\text{Cl}_2 = \dots\dots\dots$
[1]

- (d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HCl	0.88
H_2	0.06
Cl_2	0.06

- (i) Write the expression for the equilibrium constant, K_p , for the decomposition of HCl .



$K_p =$

[1]

- (ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

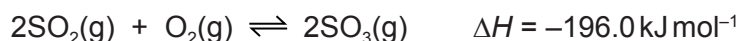
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..... [1]

- (iii) Calculate the value of K_p for this experiment.

$$K_p = \dots\dots\dots [1]$$

[Total: 18]

- 3 Sulfur trioxide, SO_3 , is manufactured from sulfur dioxide and oxygen by the Contact process.



- (a) The enthalpy change of formation of SO_2 , $\Delta H_f^\circ \text{SO}_2(\text{g})$, is $-296.8 \text{ kJ mol}^{-1}$.

- (i) Define the term *enthalpy change of formation*.

.....

 [2]

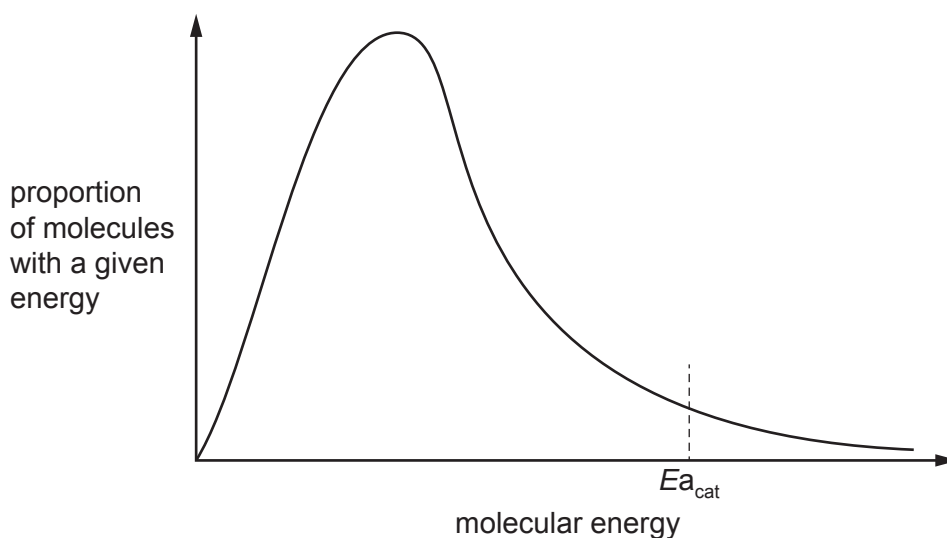
- (ii) Use the data to calculate the enthalpy change of formation of $\text{SO}_3(\text{g})$.

$\Delta H_f^\circ \text{SO}_3(\text{g}) = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

- (b) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5 .

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.

$E_{a_{\text{cat}}}$ represents the activation energy for the reaction in the presence of the catalyst.



- (i) Add a labelled mark, $E_{a_{\text{uncat}}}$, to the diagram to indicate the activation energy in the absence of the catalyst. [1]

(ii) State the benefit of using a catalyst in this reaction. Explain how it achieves this effect.

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..... [2]

(iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate

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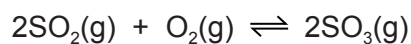
yield

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..... [4]

- (c) At a pressure of $1.50 \times 10^5 \text{ Pa}$, 1.00 mol of sulfur dioxide gas, SO_2 , was mixed with 1.00 mol of oxygen gas, O_2 . The final equilibrium mixture formed was found to contain 0.505 mol of O_2 .



- (i) Calculate the amount, in mol, of SO_2 and SO_3 in the equilibrium mixture.

$\text{SO}_2 = \dots\dots\dots \text{ mol}$

$\text{SO}_3 = \dots\dots\dots \text{ mol}$
[1]

- (ii) Calculate the partial pressure of oxygen gas, $p\text{O}_2$, in the equilibrium mixture.

$p\text{O}_2 = \dots\dots\dots \text{ Pa}$ [2]

- (d) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2 , the partial pressures of SO_2 , O_2 and SO_3 were as shown.

$$p\text{SO}_2 = 8.42 \times 10^2 \text{ Pa}$$

$$p\text{O}_2 = 6.00 \times 10^4 \text{ Pa}$$

$$p\text{SO}_3 = 9.10 \times 10^4 \text{ Pa}$$

- (i) Write the expression for the equilibrium constant, K_p , for the production of SO_3 from SO_2 and O_2 .

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction and state the units.

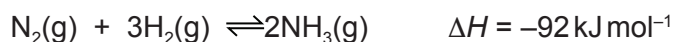
$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 17]

- 1 Ammonia, NH_3 , is manufactured from nitrogen and hydrogen by the Haber process.



- (a) Some bond energies are given.

$$\text{N}\equiv\text{N} = 944 \text{ kJ mol}^{-1}$$

$$\text{H}-\text{H} = 436 \text{ kJ mol}^{-1}$$

- (i) Explain the meaning of the term *bond energy*.

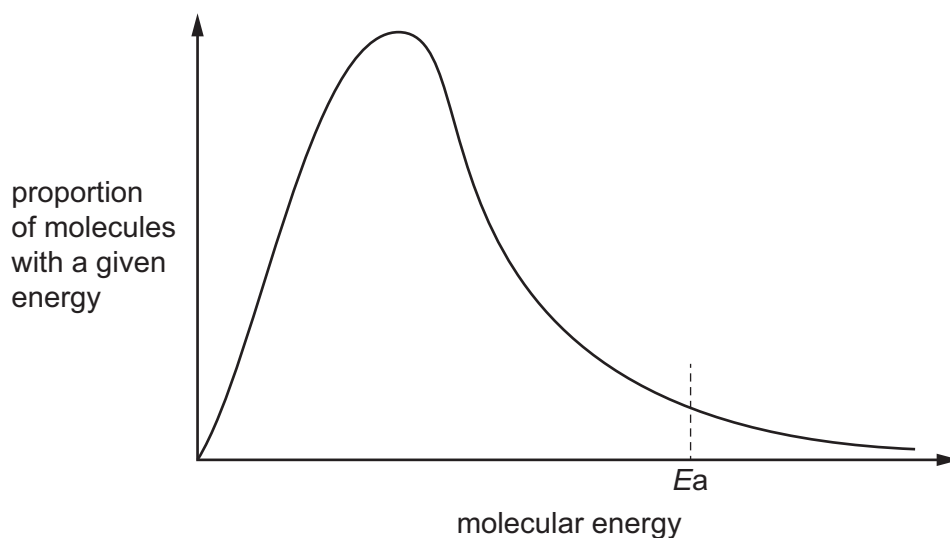
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..... [2]

- (ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = kJ mol^{-1} [2]

- (b) The Haber process is usually carried out at a temperature of approximately 400°C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400°C is shown.
 E_a represents the activation energy for the reaction.



- (i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

- (ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

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.....
..... [3]

- (iii) State and explain the effect of increasing temperature on the yield of ammonia. Use Le Chatelier's principle to explain your answer.

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..... [3]

- (c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $\text{N}_2(\text{g})$, was mixed with 3.00 mol of hydrogen, $\text{H}_2(\text{g})$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $\text{NH}_3(\text{g})$.

- (i) Calculate the amounts, in mol, of $\text{N}_2(\text{g})$ and $\text{H}_2(\text{g})$ in the equilibrium mixture.

$\text{N}_2(\text{g}) = \dots\dots\dots$ mol

$\text{H}_2(\text{g}) = \dots\dots\dots$ mol
[2]

- (ii) Calculate the partial pressure of ammonia, p_{NH_3} , in the equilibrium mixture.

Give your answer to three significant figures.

$p_{\text{NH}_3} = \dots\dots\dots$ Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure Pa
$\text{N}_2(\text{g})$	2.20×10^6
$\text{H}_2(\text{g})$	9.62×10^5
$\text{NH}_3(\text{g})$	1.40×10^4

- (i) Write the expression for the equilibrium constant, K_p , for the production of ammonia from nitrogen and hydrogen.

$$K_p =$$

[1]

- (ii) Calculate the value of K_p for this reaction.

State the units.

$$K_p = \dots\dots\dots$$

$$\text{units} = \dots\dots\dots$$

[2]

- (iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p .

effect on yield of ammonia

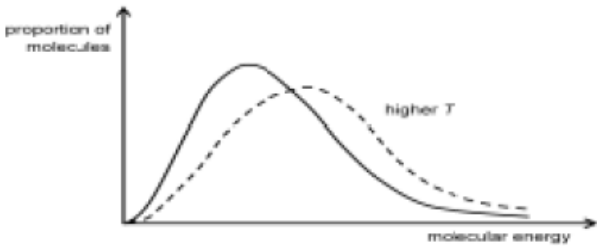
effect on value of K_p

[2]

[Total: 22]

Question	Answer	Marks
3 (a)	(+) 103	1
3 (b) (i)	general shape of the curve and peak are displaced to right of original and starts at origin	1
	the peak is lower and curve crosses once only finishing above original	1
3 (b) (ii)	rate increases AND correct explanation in terms of 'more collisions'	1
	at higher T area above E_a is greater / more molecules with $E \geq E_a$	1
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
3 (b) (iii)	increases (%) decomposition (of HBr)	1
	(increasing T) shifts equilibrium to the right / in the forward direction / endothermic direction / towards $H_2 + Br_2$	1
	to oppose the change or oppose the increase in temperature OR to absorb (additional) energy / heat OR to decrease the temperature	1
3 (b) (iv)	H–I bond strength less than H–Br OR Less energy needed to break H–I <i>ora</i>	1
	I (atom) is big(ger) (than Br) OR I (atom) has more shielding (than Br) <i>ora</i>	1
	Br (atom) has greater (%) orbital / outer shell overlap OR attraction (of nucleus in iodine) for shared (pair of) electrons is weak(er) OR attraction (of nucleus in iodine) for bonding pair (or electrons) is weak(er) <i>ora</i>	1
3 (c) (i)	$H_2 = 0.015$ (mol)	1
	$HCl = 0.27$ (mol)	1
3 (c) (ii)	$HCl = 9 / 10$ AND $xH_2 = 1 / 20$ AND $Cl_2 = 1 / 20$ OR $HCl = 0.9(0)$ AND $H_2 = 0.05$ AND $Cl_2 = 0.05$	1
3 (d) (i)	$(K_p =) \frac{p_{H_2} \times p_{Cl_2}}{p_{HCl}^2}$	1
3 (d) (ii)	equal number of moles (of gas) on either side (of equation) / (total) pressure cancels	1
3 (d) (iii)	4.649×10^{-3}	1
Total: 18		

Question	Answer	Marks
3 (a) (i)	(enthalpy / energy change) when one mole of a compound is formed	1
	from its elements in their standard states / standard conditions	1
3 (a) (ii)	$(\Delta H_f = \sum \Delta H_f \text{ products} - \sum \Delta H_f \text{ reactants})$ $-196 = 2\Delta H_f \text{ SO}_3 - (2 \times -296.8)$ $2\Delta H_f \text{ SO}_3 = -196 + (2 \times -296.8) = -789.6$	1
	$\Delta H_f \text{ SO}_3 = -394.8 \text{ (kJ mol}^{-1}\text{)}$	1
3 (b) (i)	Mark to right of original E_a	1
3 (b) (ii)	2 marks for any two points: <ul style="list-style-type: none"> • benefit of using a catalyst in terms of increasing rate or economic benefit i.e. (less heat required) • creates alternative pathway with lower E_a • more molecules with $E \geq E_a$ 	2
3 (b) (iii)	(rate) increases AND correct explanation in terms of 'more collisions'	1
	more successful collisions per unit time / higher chance of successful per unit time / higher proportion of successful collisions per unit time	1
	(yield) increases and shifts equilibrium to the right / in the forward direction / towards SO_3 / towards the product / in exothermic direction	1
	to oppose the change or oppose the increase in pressure / fewer molecules on RHS so eqn moves to right (to oppose change)	1
3 (c) (i)	$\text{SO}_2 = 0.01 \text{ (mol)}$ AND $\text{SO}_3 = 0.99 \text{ (mol)}$	1
3 (c) (ii)	$n_{\text{TOT}} = 1.505$	1
	$p_{\text{O}_2} = 1.50 \times 10^5 \times (0.505 / 1.505) = 5.03 \times 10^4 \text{ (Pa)}$	1
3 (d) (i)	$(K_p =) \frac{p_{\text{SO}_3}^2}{p_{\text{O}_2} \times p_{\text{SO}_2}^2}$	1
3 (d) (ii)	0.1946737305	1
	Pa^{-1}	1
Total: 17		

Question	Answer	Marks
1 (a) (i)	Energy needed / required to break a mole of (covalent) bonds	1
	(All) in the gaseous state	1
1 (a) (ii)	$-92 = \{944 + 3(436)\} = 6E(\text{N-H})$	1
	$E(\text{N-H}) = (+)390.7 / 390.67 / 391$	1
1 (b) (i)	general shape of the curve and peak are displaced to right of original line and starts at origin	1
	the peak is lower and curve crosses once only finishing above original line	1
		
1 (b) (ii)	rate increases AND explanation in terms of collisions	1
	(at higher T) area above E_a is greater OR (at higher T) more molecules with $E \geq E_a$	1
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
1 (b) (iii)	reduced yield (of ammonia)	1
	(increasing T) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants / in endothermic direction	1
	to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature	1
1 (c) (i)	$\text{N}_2 = 0.850 \text{ (mol)}$	1
	$\text{H}_2 = 2.55 \text{ (mol)}$	1
1 (c) (ii)	$n_{\text{TOTAL}} = 3.7 \text{ mol}$	1
	mol fraction of $\text{NH}_3 = 0.3 / 3.7$	1
	$p_{\text{NH}_3} = 2 \times 10^7 \times (0.3 / 3.7) = 1.62 \times 10^6$	1

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Question	Answer	Marks
1 (d) (i)	$K_p = \frac{p\text{NH}_3^2}{p\text{N}_2 \times p\text{H}_2^3}$	1
1 (d) (ii)	$K_p = 1.00 \times 10^{-16}$	1
	Pa^{-2}	1
1 (d) (iii)	(yield of ammonia) increases	1
	(value of K_p) stays the same	1
		Total: 22

Notes about the mark scheme are available separately.