



Topic Chem 7

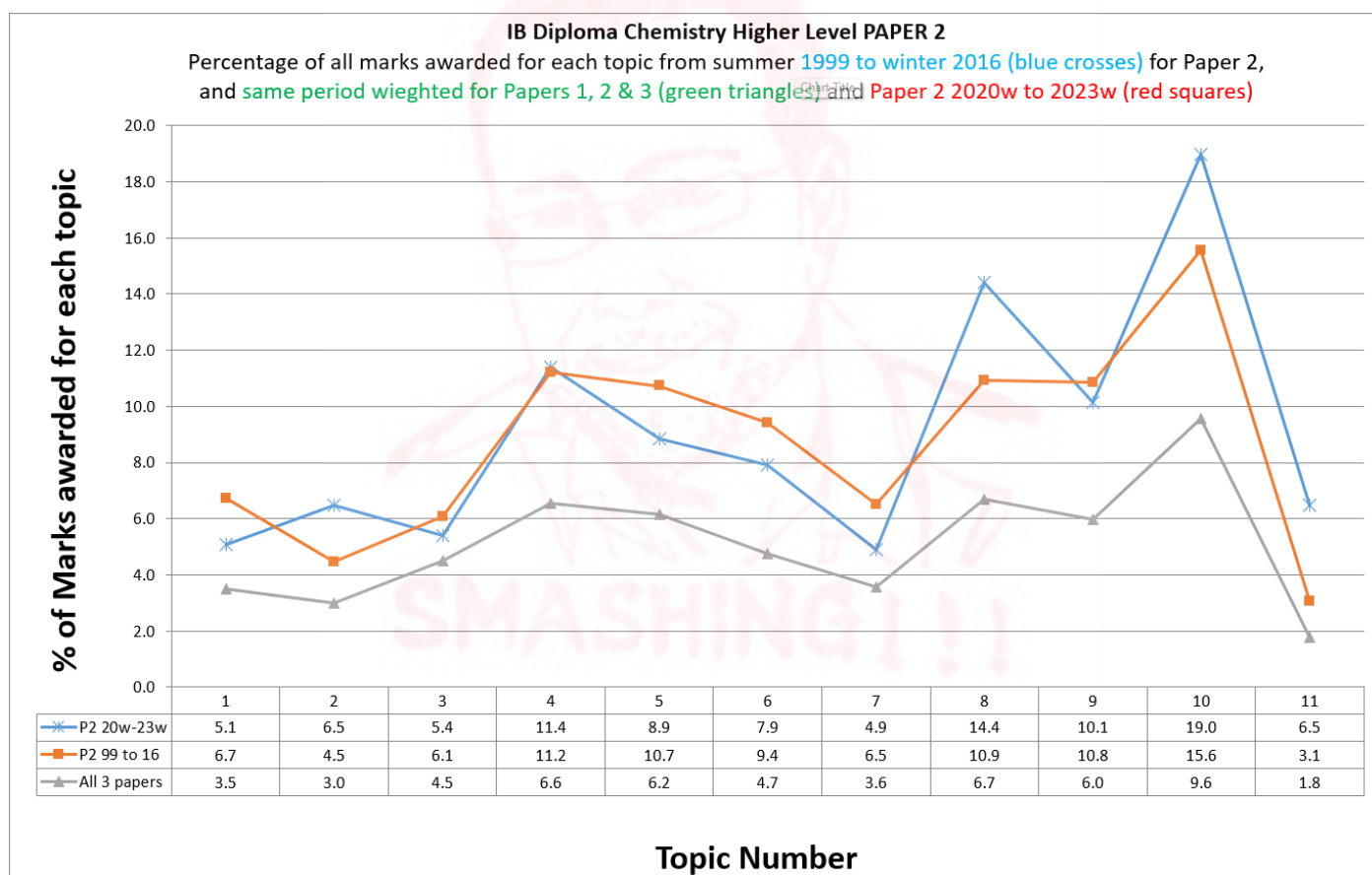
Equilibrium 31marks

For a digital version of this document scan the code below, or go here:

<https://www.smashingscience.org/ib-chemistry-hl-sl>

A note on the topic numbers used here:

IB Chemistry topic numbers from 12 onwards have been merged with their SL counterparts, so “Topic 3” in this booklet includes marks for both IB Chemistry Topic 3 (Periodicity) and Topic 13 (The periodic table—the transition metals). For more information see the syllabus (“Chemistry Guide: First Assessment 2016”). For exams in 2025 and later changes to the ordering of the syllabus have been made which are not addressed here.

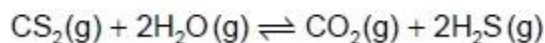


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Entire exam paper was not published



4. Carbon disulfide, CS₂, undergoes gas phase hydrolysis according to the overall equation



- (iii) Neglecting any entropy change, use your answer to 4(a)(i), section 1 and section 2 of the data booklet to estimate the equilibrium constant, K_c , at 500K.

(If you did not obtain an answer to 4(a)(i), use a value of $-50.0 \text{ kJ mol}^{-1}$, although this is not the correct answer.)

[2]

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- (iv) The concentrations of the species involved at equilibrium are:

CS ₂ (g)	H ₂ O(g)	CO ₂ (g)	H ₂ S(g)
0.0400 mol dm ⁻³	0.100 mol dm ⁻³	x mol dm ⁻³	2x mol dm ⁻³

Calculate the numerical value of x, the concentration of carbon dioxide at equilibrium, using your answer from 4(a)(iii).

(If you did not obtain an answer to 4(a)(iii), then use a value of 1.68×10^5 , although this is not the correct answer.)

[2]

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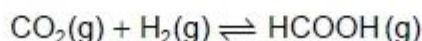
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2. Methanoic acid can be produced by the hydrogenation of carbon dioxide according to the equilibrium



(b) State the equilibrium constant expression for this reaction.

[1]

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The enthalpy change, which was calculated in part (c) for this reaction is $+5 \text{ kJ mol}^{-1}$

(d) Suggest why temperature has a very small effect on the value of the equilibrium constant.

[1]

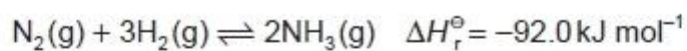
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2. The periodic table is a useful tool in explaining trends of chemical behaviour.



(d) (i) Ammonia is manufactured by the Haber process.



Outline what is meant by dynamic equilibrium.

[1]

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(ii) Deduce the K_c expression for the reaction in part (d)(i).

[1]

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(iii) Determine the entropy change, ΔS^\ominus for the forward reaction to **four** significant figures, using the data given.

[2]

Substance	Entropy (S^\ominus) $\text{J K}^{-1} \text{ mol}^{-1}$
H_2	130.7
N_2	191.6
NH_3	192.8

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- (iv) Calculate the temperature, in K, below which this reaction becomes spontaneous. Use section 1 of the data booklet. (If you were unable to obtain an answer for part (d)(iii) use $-210.0 \text{ J K}^{-1} \text{ mol}^{-1}$, but this is not the correct value.) [2]

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- (v) The value of K_c for this reaction is 6.84×10^{-5} at 500°C . Suggest, with a reason, how lowering the temperature affects the value of K_c . [1]

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- (vi) Calculate the standard Gibbs free energy change, ΔG^\ominus , in kJ mol^{-1} , for this reaction. Use sections 1 and 2 of the data booklet. [2]

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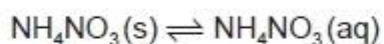
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Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ammonium nitrate, NH_4NO_3 , is used as a high nitrogen fertilizer.



- (vii) Calculate the value of the equilibrium constant for the dissolution of ammonium nitrate at 298 K using the answer to question part (d)(vi) and section 1 of the data booklet.



If you did not obtain an answer in (d)(vi), use -7.84 kJ/mol , although this is not the correct answer.

[2]

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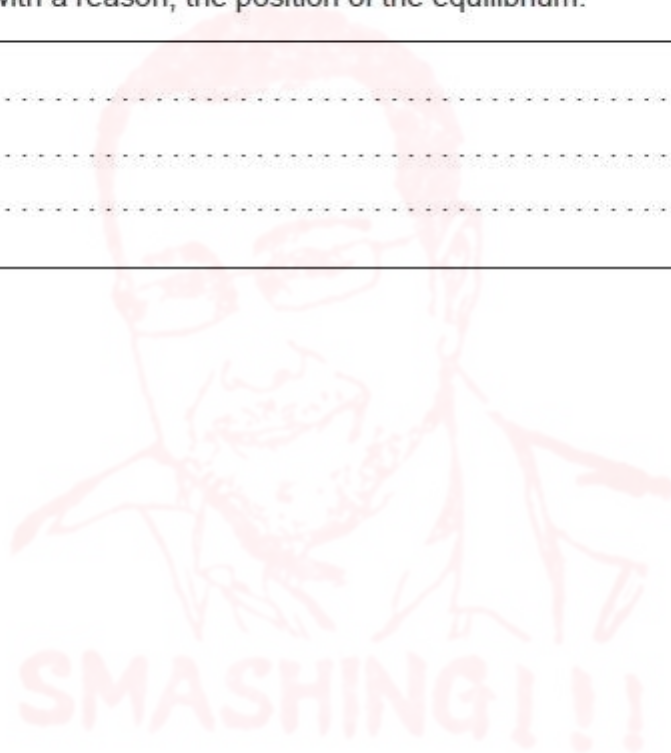
- (viii) Deduce, with a reason, the position of the equilibrium.

[1]

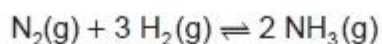
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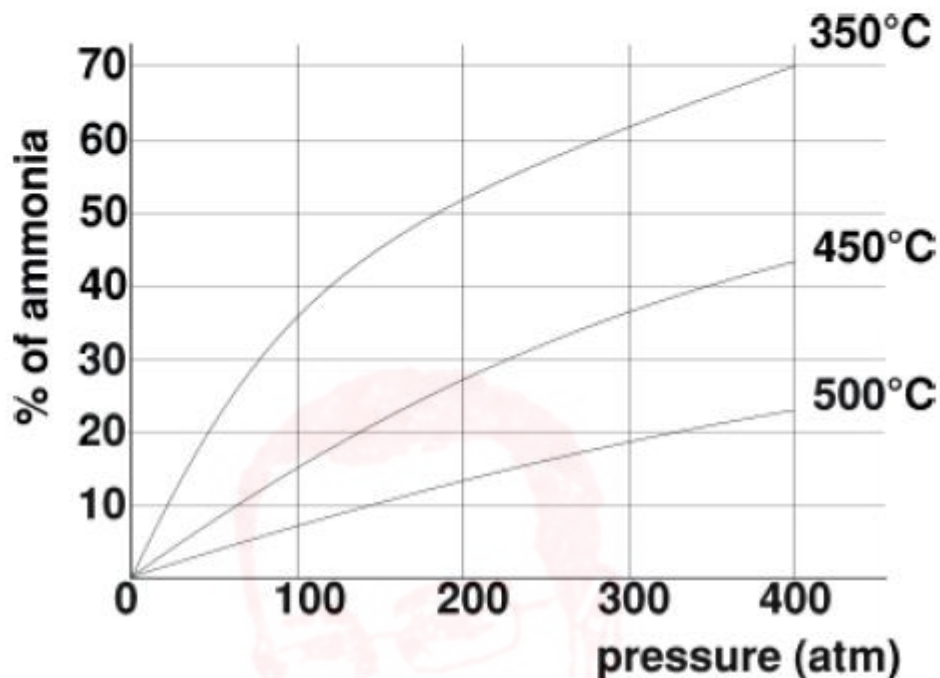
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3. Ammonia is produced by the Haber–Bosch process which involves the equilibrium:



The percentage of ammonia at equilibrium under various conditions is shown:



(a) (i) Deduce the expression for the equilibrium constant, K_c , for this equation. [1]

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(ii) State how the use of a catalyst affects the position of the equilibrium. [1]

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- (iii) With reference to the reaction quotient, Q , explain why the percentage yield increases as the pressure is increased at constant temperature.

[3]

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(b) One factor affecting the position of equilibrium is the enthalpy change of the reaction.

- (i) Determine the enthalpy change, ΔH , for the Haber–Bosch process, in kJ.

The answer to the enthalpy change of the forward reaction in (b)(i) is -93 kJ

- (iii) Demonstrate that your answer to (b)(i) is consistent with the effect of an increase in temperature on the percentage yield, as shown in the graph.

[2]

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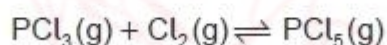
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3. White phosphorus is an allotrope of phosphorus and exists as P_4 .

- (c) An equilibrium exists between PCl_3 and PCl_5 .



- (iv) Determine the equilibrium constant, K , for this reaction at 25°C , referring to section 1 of the data booklet.

If you did not obtain an answer in (c)(iii), use $\Delta G = -43.5 \text{ kJ mol}^{-1}$, but this is not the correct answer.

[2]

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- (v) State the equilibrium constant expression, K_c , for this reaction.

[1]

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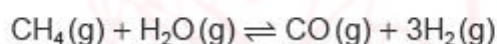
- (vi) State, with a reason, the effect of an increase in temperature on the position of this equilibrium.

[1]

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- (d) Consider the first stage of the reaction.



- (iii) State the expression for K_c for this stage of the reaction.

[1]

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- (iv) State and explain the effect of increasing temperature on the value of K_c .

[1]

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4	a	iii	$\Delta G^\ominus \ll \Delta H^\ominus - T\Delta S^\ominus \gg = -39.8 \ll \text{kJ mol}^{-1} \gg \checkmark$ $\ll \ln K_c = -\frac{\Delta G^\ominus}{R.T} = \frac{39800 \text{ J mol}^{-1}}{8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 500 \text{ K}} = 9.58 \gg$ $K_c = 1.45 \times 10^4 \checkmark$	Award [2] for correct final answer. Using $-50.0 \text{ kJ mol}^{-1}$ gives $K_c = 1.68 \times 10^6$. If student obtained $+48.2 \text{ kJ mol}^{-1}$ for 4(a) then ECF gives $K_c = 9.16 \times 10^6$.	2
4	a	iv	$K_c \ll = 1.45 \times 10^4 = \frac{[\text{CO}_2] \times [\text{H}_2\text{S}]^2}{[\text{CS}_2] \times [\text{H}_2\text{O}]^2} \gg$ $= \frac{X \times (2X)^2}{0.0400 \times (0.100)^2} / \frac{4X^3}{4.00 \times 10^{-4}} \checkmark$ $X \ll = \sqrt[3]{1.45} \gg = 1.13 \ll \text{mol dm}^{-3} \gg \checkmark$	Award [2] for correct final answer. Students who obtain $K \sim 1$ in 4(a)iii will obtain answers ~ 0.046 by ECF. Using 1.68×10^6 gives $2.56 \ll \text{mol dm}^{-3} \gg$.	2

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2	b		$\ll K_c = \frac{[\text{HCOOH}]}{[\text{CO}_2][\text{H}_2]} \gg \checkmark$		1
2	d		enthalpy change is very small \checkmark		1

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2.	(d)	(i)	«in a closed system» the rate of the forward reaction equals the rate of the reverse reaction. \checkmark		1
2.	(d)	(ii)	$[\text{NH}_3]^2/([\text{N}_2][\text{H}_2]^3) \checkmark$		1
2.	(d)	(iii)	$\Delta S^\ominus = \Delta S^\ominus_{\text{(products)}} - \Delta S^\ominus_{\text{(reactants)}}$ OR $(2 \times 192.8 \ll \text{J mol}^{-1} \text{ K}^{-1} \gg) - (3 \times 130.7 \ll \text{J mol}^{-1} \text{ K}^{-1} \gg + 191.6 \ll \text{J mol}^{-1} \text{ K}^{-1} \gg)$ $-198.1 \ll \text{J K}^{-1} \text{ mol}^{-1} \gg \checkmark$	Award [2] for correct final answer with four significant figures.	2
2.	(d)	(iv)	$\ll \Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus \gg$ $\Delta S^\ominus = -0.1981 \text{ kJ K}^{-1} \text{ mol}^{-1}$ AND $\Delta H^\ominus = -92.0 \text{ kJ mol}^{-1} \checkmark$ $\ll 0 \text{ kJ mol}^{-1} = (-92.0 \text{ kJ mol}^{-1}) - (T \text{ K} \times -0.1981 \text{ kJ K}^{-1} \text{ mol}^{-1}) \gg$ $464 \ll \text{K} \gg \checkmark$ Alternate: $\Delta S^\ominus = -0.2100 \text{ kJ K}^{-1} \text{ mol}^{-1}$ AND $\Delta H^\ominus = -92.0 \text{ kJ mol}^{-1} \checkmark$ $\ll 0 \text{ kJ mol}^{-1} = (-92.0 \text{ kJ mol}^{-1}) - (T \text{ K} \times -0.2100 \text{ kJ K}^{-1} \text{ mol}^{-1}) \gg$ $438 \ll \text{K} \gg \checkmark$	M1 for conversion to common units for ΔH^\ominus and ΔS^\ominus . Award [2] for correct final answer.	2
2.	(d)	(v)	«reaction» exothermic AND K_c increases «as equilibrium moves right» \checkmark		1
2.	(d)	(vi)	$\ll \Delta G^\ominus = -RT \ln K_c \gg$ $\ll \Delta G^\ominus = (-8.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 773 \text{ K} \times \ln 6.84 \times 10^{-5})/1000 \gg = \ll + \gg 61.6 \ll \text{kJ mol}^{-1} \gg \checkmark$ OR $\ll \Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus \gg$ $\ll \Delta G^\ominus = -92.0 \text{ kJ mol}^{-1} - 773 \text{ K} \times (-0.1981 \text{ kJ K}^{-1} \text{ mol}^{-1}) \gg = \ll +61.1 \ll \text{kJ mol}^{-1} \gg \checkmark$	Award [2] for the correct final answer.	2

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1.	(d)	(vii)	$\ll \Delta G^\ominus = -RT \ln K \gg$ $\ll -6.70 \text{ kJ} \times \frac{1000 \text{ J}}{\text{kJ}} = -8.31 \text{ J K}^{-1} (298 \text{ K}) \ln K \gg$ $\ll \ln K = \gg 2.71 \checkmark$ $\ll K = e^{2.71} = \gg 15.0 \checkmark$	Award [2] for correct final answer. If -7.84 kJ is used then answer is 23.7.	2
1.	(d)	(viii)	product/right/solution/ $\text{NH}_4\text{NO}_3(\text{aq})$ is favoured AND $K > 1 \checkmark$	Accept K large. Accept other valid ways of justifying equilibrium position such as $\Delta G < 0$ /spontaneous/ $\Delta H < 0$ AND $\Delta S > 0$.	1



3.	a	i	$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} \checkmark$		1
3.	a	ii	same/unaffected/unchanged \checkmark		1
3.	a	iii	increasing pressure increases «all» concentrations OR increasing pressure decreases volume \checkmark Q becomes less than K_c OR affects the lower line/denominator of Q expression more than upper line/numerator \checkmark «for Q to once again equal K_c ,» ratio of products to reactants increases OR «for Q to once again equal K_c ,» equilibrium shifts to right/products \checkmark	Award [2 max] for answers that do not refer to Q.	3
3.	b	iii	increased temperature decreases yield «as shown on graph» \checkmark shifts equilibrium in endothermic/reverse direction \checkmark		2

3.	c	iv	$\Delta G = -41.8 \text{ kJ mol}^{-1} = -\frac{8.31 \text{ J mol}^{-1} \text{ K}^{-1}}{1000} \times 298 \text{ K} \times \ln K$ OR $\Delta G = -41800 \text{ J mol}^{-1} = -8.31 \text{ J mol}^{-1} \text{ K}^{-1} \times 298 \text{ K} \times \ln K$ $\ln K = \Rightarrow 16.9 \checkmark$ $K = e^{16.9} \Rightarrow 2.19 \times 10^7 \checkmark$	Award [2] for correct final answer. Accept range of $1.80 \times 10^6 - 2.60 \times 10^7$. If -43.5 is used then 4.25×10^7 .	2
3.	c	v	$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]} \checkmark$		1
3.	c	vi	«shifts» left/towards reactants AND «forward reaction is» exothermic/ ΔH is negative \checkmark		1

4.	d	iii	$K_c = \frac{[CO][H_2]^3}{[CH_4][H_2O]} \checkmark$		1
4.	d	iv	K_c increases AND «forward» reaction endothermic \checkmark		1

