

2016 Specimen Paper Question on Entropy

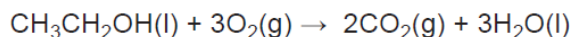
7 (a) The table lists the equations for five processes.

For each process, predict the sign of ΔS .

process	sign of ΔS
$\text{NaBr(s)} + (\text{aq}) \rightarrow \text{NaBr(aq)}$	
$\text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{O(g)}$	
$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O (g)}$	
$\text{CoCl}_2(\text{s}) + 6\text{H}_2\text{O(l)} \rightarrow \text{CoCl}_2 \cdot 6\text{H}_2\text{O(s)}$	

[2]

(b) Ethanol can be combusted as shown in the equation.



Standard entropies are shown in the table.

substance	$\text{CH}_3\text{CH}_2\text{OH(l)}$	$\text{O}_2(\text{g})$	$\text{CO}_2(\text{g})$	$\text{H}_2\text{O(l)}$
$S^\ominus, \text{J K}^{-1} \text{mol}^{-1}$	161	205	214	70

Calculate the standard entropy change, ΔS^\ominus , for this reaction.

$$\Delta S^\ominus = \dots\dots\dots \text{J K}^{-1} \text{mol}^{-1} \quad [2]$$

(c) The combustion of ethanol is an exothermic reaction.

This reaction occurs spontaneously at low temperatures but does **not** occur at very high temperatures. Explain why.

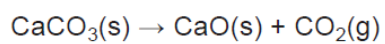
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..... [2]

(d) The decomposition of calcium carbonate is an endothermic reaction.



$$\Delta H = +178 \text{ kJ mol}^{-1} \text{ and } \Delta S = +159 \text{ JK}^{-1} \text{ mol}^{-1}$$

Calculate the **minimum** temperature at which this reaction becomes feasible.
Show all your working.

[3]

[Total: 9]

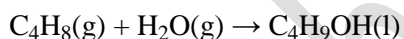
QUESTION ENTROPY

1. Which change leads to an increase in entropy?

- A. $\text{CO}_2(\text{g}) \rightarrow \text{CO}_2(\text{s})$
- B. $\text{SF}_6(\text{g}) \rightarrow \text{SF}_6(\text{l})$
- C. $\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{O}(\text{s})$
- D. $\text{NaCl}(\text{s}) \rightarrow \text{NaCl}(\text{aq})$

(Total 1 mark)

2. The reaction between but-1-ene and water vapour produces butan-1-ol.



The standard entropy values (S^\ominus) for but-1-ene, water vapour and butan-1-ol are 310, 189 and 228 $\text{J K}^{-1} \text{mol}^{-1}$ respectively. What is the standard entropy change for this reaction in $\text{J K}^{-1} \text{mol}^{-1}$?

- A. -271
- B. +271
- C. -107
- D. +107

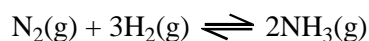
(Total 1 mark)

3. What are the signs of ΔH^\ominus and ΔS^\ominus for a reaction that is non-spontaneous at low temperature but spontaneous at high temperature?

	ΔH^\ominus	ΔS^\ominus
A.	-	-
B.	+	-
C.	-	+
D.	+	+

(Total 1 mark)

4. Consider the following reaction:



- (i) Suggest why this reaction is important for humanity. (1)
- (ii) Using the average bond enthalpy values in Table 10 of the Data Booklet, calculate the standard enthalpy change for this reaction. (4)
- (iii) The absolute entropy values, S , at 238 K for $\text{N}_2(\text{g})$, $\text{H}_2(\text{g})$ and $\text{NH}_3(\text{g})$ are 192, 131 and $193 \text{ J K}^{-1} \text{ mol}^{-1}$ respectively. Calculate ΔS^\ominus for the reaction and explain the sign of ΔS^\ominus . (2)
- (iv) Calculate ΔG^\ominus for the reaction at 238 K. State and explain whether the reaction is spontaneous. (3)
- (v) If ammonia was produced as a liquid and not as a gas, state and explain the effect this would have on the value of ΔH^\ominus for the reaction. (2)

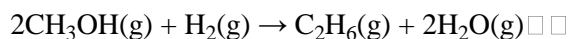
(Total 12 marks)

5. Which reaction causes a decrease in the entropy of the system?

- A. $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
- B. $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$
- C. $2\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{CO}(\text{g})$
- D. $2\text{SO}_3(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g})$

(Total 1 mark)

6. Consider the following reaction.



(a) The standard enthalpy change of formation for $\text{CH}_3\text{OH}(\text{g})$ at 298 K is -201 kJ mol^{-1} and for $\text{H}_2\text{O}(\text{g})$ is -242 kJ mol^{-1} . Using information from Table 11 of the Data Booklet, determine the enthalpy change for this reaction.

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(2)

(b) The standard entropy for $\text{CH}_3\text{OH}(\text{g})$ at 298 K is $238 \text{ J K}^{-1} \text{ mol}^{-1}$, for $\text{H}_2(\text{g})$ is $131 \text{ J K}^{-1} \text{ mol}^{-1}$ and for $\text{H}_2\text{O}(\text{g})$ is $189 \text{ J K}^{-1} \text{ mol}^{-1}$. Using information from Table 11 of the Data Booklet, determine the entropy change for this reaction.

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(2)

- (c) Calculate the standard change in free energy, at 298 K, for the reaction and deduce whether the reaction is spontaneous or non-spontaneous.

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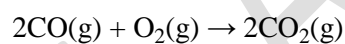
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(3)

(Total 7 marks)

7. What is the standard entropy change, ΔS^\ominus , for the following reaction?



	CO(g)	O₂(g)	CO₂(g)
$S^\ominus/\text{J K}^{-1} \text{mol}^{-1}$	198	205	214

- A. -189
- B. -173
- C. +173
- D. +189

(Total 1 mark)

8. A reaction has a standard enthalpy change, ΔH^\ominus , of $+10.00 \text{ kJ mol}^{-1}$ at 298 K. The standard entropy change, ΔS^\ominus , for the same reaction is $+10.00 \text{ J K}^{-1} \text{ mol}^{-1}$. What is the value of ΔG^\ominus for the reaction in kJ mol^{-1} ?

- A. +9.75
- B. +7.02
- C. -240
- D. -2970

(Total 1 mark)

9. Which reaction has the greatest increase in entropy?

- A. $\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
- B. $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{HCl}(\text{g})$
- C. $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
- D. $\text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g})$

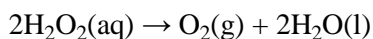
(Total 1 mark)

10. Which reaction has the largest increase in entropy?

- A. $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{HCl}(\text{g})$
- B. $\text{Al}(\text{OH})_3(\text{s}) + \text{NaOH}(\text{aq}) \rightarrow \text{Al}(\text{OH})_4^-(\text{aq}) + \text{Na}^+(\text{aq})$
- C. $\text{Na}_2\text{CO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- D. $\text{BaCl}_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{NaCl}(\text{aq})$

(Total 1 mark)

11. When hydrogen peroxide decomposes, the temperature of the reaction mixture increases.



What are the signs of ΔH , ΔS and ΔG for this reaction?

	ΔH	ΔS	ΔG
A.	-	-	-
B.	-	+	-
C.	+	+	-
D.	-	+	+

(Total 1 mark)

12. Which reaction has the greatest increase in entropy?

- A. $\text{SO}_2(\text{g}) + 2\text{H}_2\text{S}(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + 3\text{S}(\text{s})$
 B. $\text{CaO}(\text{s}) + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s})$
 C. $\text{CaC}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{OH})_2(\text{s}) + \text{C}_2\text{H}_2(\text{g})$
 D. $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$

(Total 1 mark)

13. ΔG^\ominus calculations predict that a reaction is always spontaneous for which of the following combinations of ΔH^\ominus and ΔS^\ominus ?

- A. $+\Delta H^\ominus$ and $+\Delta S^\ominus$
 B. $+\Delta H^\ominus$ and $-\Delta S^\ominus$
 C. $-\Delta H^\ominus$ and $-\Delta S^\ominus$
 D. $-\Delta H^\ominus$ and $+\Delta S^\ominus$

(Total 1 mark)

14. Some words used in chemistry can have a specific meaning which is different to their meaning in everyday English.

State what the term *spontaneous* means when used in a chemistry context.

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(Total 1 mark)

15. Propene can be hydrogenated in the presence of a nickel catalyst to form propane. Use the data below to answer the questions that follow.

Compound	Formula	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
hydrogen	$\text{H}_2(\text{g})$	0	+ 131
propane	$\text{C}_3\text{H}_8(\text{g})$	- 104	+ 270
propene	$\text{C}_3\text{H}_6(\text{g})$	+ 20.4	+ 267

- (i) Outline why the value for the standard enthalpy change of formation of hydrogen is zero.

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(1)

- (ii) Calculate the standard enthalpy change for the hydrogenation of propene.

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(2)

(iii) Calculate the standard entropy change for the hydrogenation of propene.

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(2)

(iv) Determine the value of ΔG^\ominus for the hydrogenation of propene at 298 K.

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(2)

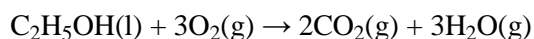
(v) At 298 K the hydrogenation of propene is a spontaneous process. Determine the temperature above which propane will spontaneously decompose into propene and hydrogen.

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(2)

(Total 9 marks)

16. What is the standard free energy change, ΔG^\ominus , in kJ, for the following reaction?



Compound	$\Delta G_f^\ominus / \text{kJ mol}^{-1}$
$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-175
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{g})$	-229
$\text{O}_2(\text{g})$	0

- A. -1650
- B. -1300
- C. -448
- D. +1300

(Total 1 mark)

17. Which reaction has the most negative change in entropy?

- A. $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$
- B. $\text{NH}_4\text{Cl}(\text{s}) \rightarrow \text{NH}_3(\text{g}) + \text{HCl}(\text{g})$
- C. $\text{PbCl}_2(\text{s}) \rightarrow \text{Pb}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq})$
- D. $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$

(Total 1 mark)

MARKING SCHEME

- 1. D [1]
- 2. A [1]
- 3. D [1]

4. (i) fertilizers / increasing crop yields;
production of explosives for mining; 1 max
- (ii) $\Delta H = (\text{sum of energies of bonds broken}) - (\text{sum of energies of bonds formed});$
Can be implied by working.
correct substitution of values and numbers of bonds broken;
correct substitution of values and numbers of bonds made;
 $(\Delta H = (\text{N}\equiv\text{N}) + 3(\text{H}-\text{H}) - 6(\text{N}-\text{H}) = 944 + 3(436) - 6(388) = -76.0 \text{ (kJ)};$ 4
Allow ECF.
Do not penalize for sig. fig. or units.
Award [4] for correct final answer.
- (iii) $(\Delta S^\ominus [2 \times 193] - [192 + 3 \times 131]) = -199 \text{ (J K}^{-1} \text{ mol}^{-1});$ 2
Allow ECF.
four gaseous molecules generating two gaseous molecules /
fewer molecules of gas;
- (iv) $(\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus = -76.0 - 298(-0.199)) = -16.7 \text{ (kJ)};$
Spontaneous;
 ΔG is negative; 3
Do not penalize for SF.
- (v) heat released when gas \rightarrow liquid;
 ΔH^\ominus becomes more negative; 2 [12]
5. B [1]
6. (a) $\Delta H^\ominus_{\text{reaction}} = \Sigma \Delta H^\ominus_{\text{f}}(\text{products}) - \Sigma \Delta H^\ominus_{\text{f}}(\text{reactants})$
 $= [(1)(-85) + (2)(-242)] - [(2)(-201)];$
 $= -167 \text{ (kJ/kJ mol}^{-1});$
Award [1] for (+) 167. 2

(b) $\Delta S^{\ominus}_{\text{reaction}} = \Sigma S^{\ominus}(\text{products}) - \Sigma S^{\ominus}(\text{reactants})$
 $= [(1)(230) + (2)(189)] - [(2)(238) + (1)(131)];$
 $= 1 \text{ (J K}^{-1}\text{/J K}^{-1} \text{ mol}^{-1}\text{);}$

2

(c) $\Delta G^{\ominus}_{\text{reaction}} = (\Delta H^{\ominus} - T\Delta S^{\ominus}) = (-167) - (298)(0.001);$
Award [1] for correct substitution of values.

$$= -167 \text{ kJ}/-167000 \text{ J};$$

Units needed for mark in (c) only.

Accept -167 kJ mol^{-1} or $-167000 \text{ J mol}^{-1}$.

spontaneous;

Award marks for final correct answers throughout in each of (a), (b) and (c).

3

[7]

7. B

[1]

8. B

[1]

9. A

[1]

10. C

[1]

11. B

[1]

12. C [1]
13. D [1]
14. the reaction gives out (Gibbs Free) energy that can do work;
 ΔG for the reaction has a negative value;
 a reaction that occurs without adding energy (beyond that required to overcome energy barrier); 1 max [1]
15. (i) by definition $\Delta H_{\text{f}}^{\ominus}$ of elements (in their standard states) is zero / no reaction involved / *OWTTE*; 1
- (ii) $\Delta H = -104 - (+20.4)$;
 $= -124.4 \text{ (kJ mol}^{-1}\text{)}$; 2
Award [1 max] for 124.4 (kJ mol⁻¹).
Award [2] for correct final answer.
- (iii) $\Delta S = 270 - (267 + 131)$;
 $= -128 \text{ (J K mol}^{-1}\text{)}$; 2
Award [1 max] for +128 (J K⁻¹ mol⁻¹).
Award [2] for correct final answer.
- (iv) $\Delta G = \Delta H - T\Delta S = -124.4 - \frac{(-128 \times 298)}{1000}$;
 $= -86.3 \text{ kJ mol}^{-1}$; 2
Units needed for the mark.
Award [2] for correct final answer.
Allow ECF if only one error in first marking point.
- (v) $\Delta G = \Delta H - T\Delta S = 0 / \Delta H = T\Delta S$;

$$T = \frac{-124.4}{-128/1000} = 972 \text{ K} / 699 \text{ }^\circ\text{C};$$

2

Only penalize incorrect units for T and inconsistent ΔS value once in (iv) and (v).

[9]

16. B

[1]

17. A

[1]

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