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
NaBr(s) + (aq) → NaBr(aq)	
$H_2O(l) \rightarrow H_2O(g)$	
$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$	
$CoCl_2(s) + 6H_2O(l) \rightarrow CoCl_2.6H_2O(s)$	

[2]

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

$$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

Standard entropies are shown in the table.

substance	$CH_3CH_2OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(l)$
$S^\ominus$, J K^{-1} mol^{-1}	161	205	214	70

Calculate the standard entropy change, $\Delta S^\ominus$, for this reaction.

$\Delta S^\ominus$ = ... J K^{-1} mol^{-1} [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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(d) The decomposition of calcium carbonate is an endothermic reaction.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

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

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. $CO_2(g) \rightarrow CO_2(s)$

B. $SF_6(g) \rightarrow SF_6(l)$

C. $H_2O(l) \rightarrow H_2O(s)$

D. $NaCl(s) \rightarrow NaCl(aq)$

(Total 1 mark)

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

$$C_4H_8(g) + H_2O(g) \rightarrow C_4H_9OH(l)$$

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

A. –271

B. +271

C. –107

D. +107

(Total 1 mark)

3. What are the signs of $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ for a reaction that is non-spontaneous at low temperature but spontaneous at high temperature?

	$\Delta H^{\ominus}$	$\Delta S^{\ominus}$
A.	–	–
B.	+	–
C.	–	+
D.	+	+

(Total 1 mark)

4. Consider the following reaction:

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

(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 $N_2(g)$, $H_2(g)$ and $NH_3(g)$ are 192, 131 and 193 J K^{-1} mol^{-1} respectively. Calculate $\Delta S^{\ominus}$ for the reaction and explain the sign of $\Delta S^{\ominus}$.

(2)

(iv) Calculate $\Delta G^{\ominus}$ 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 $\Delta H^{\ominus}$ for the reaction.

(2)

(Total 12 marks)

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

A. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

B. $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

C. $2C(s) + O_2(g) \rightarrow 2CO(g)$

D. $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$

(Total 1 mark)

6. Consider the following reaction.

$$2CH_3OH(g) + H_2(g) \rightarrow C_2H_6(g) + 2H_2O(g)$$

(a) The standard enthalpy change of formation for $CH_3OH(g)$ at 298 K is –201 kJ mol^{-1} and for $H_2O(g)$ 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 $CH_3OH(g)$ at 298 K is 238 J K^{-1} mol^{-1}, for $H_2(g)$ is 131 J K^{-1} mol^{-1} and for $H_2O(g)$ is 189 J K^{-1} 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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(3)
(Total 7 marks)

7. What is the standard entropy change, $\Delta S^{\ominus}$, for the following reaction?

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

	CO(g)	**O_2(g)**	**CO_2(g)**
$S^{\ominus}$/J K^{-1} mol^{-1}	198	205	214

A. –189

B. –173

C. +173

D. +189

(Total 1 mark)

8. A reaction has a standard enthalpy change, $\Delta H^{\ominus}$, of +10.00 kJ mol^{-1} at 298 K. The standard entropy change, $\Delta S^{\ominus}$, for the same reaction is +10.00 J K^{-1} mol^{-1}. What is the value of $\Delta G^{\ominus}$ 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. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

B. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

C. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

D. $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$

(Total 1 mark)

10. Which reaction has the largest increase in entropy?

A. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

B. $Al(OH)_3(s) + NaOH(aq) \rightarrow Al(OH)_4^-(aq) + Na^+(aq)$

C. $Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$

D. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$

(Total 1 mark)

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

$$2H_2O_2(aq) \rightarrow O_2(g) + 2H_2O(l)$$

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. $SO_2(g) + 2H_2S(g) \rightarrow 2H_2O(l) + 3S(s)$

B. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$

C. $CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + C_2H_2(g)$

D. $N_2(g) + O_2(g) \rightarrow 2NO(g)$

(Total 1 mark)

13. $\Delta G^{\ominus}$ calculations predict that a reaction is always spontaneous for which of the following combinations of $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$?

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	$\Delta H^{\ominus}_f$ / kJ mol^{-1}	$S^{\ominus}$/ J K^{-1} mol^{-1}
hydrogen	$H_2(g)$	0	+ 131
propane	$C_3H_8(g)$	– 104	+ 270
propene	$C_3H_6(g)$	+ 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 $\Delta G^{\ominus}$ 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, $\Delta G^{\ominus}$, in kJ, for the following reaction?

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

Compound	$\Delta G_f^{\ominus}$ / kJ mol^{-1}
$C_2H_5OH(l)$	–175
$CO_2(g)$	–394
$H_2O(g)$	–229
$O_2(g)$	0

A. –1650

B. –1300

C. – 448

D. +1300

(Total 1 mark)

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

A. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

B. $NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$

C. $PbCl_2(s) \rightarrow Pb^{2+}(aq) + 2Cl^-(aq)$

D. $C(s) + O_2(g) \rightarrow CO_2(g)$

(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) ΔH = (sum of energies of bonds broken) – (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;
(ΔH = (N≡N) + 3(H–H) – 6(N–H) = 944 + 3(436) – 6(388) =) –76.0 (kJ); 4

Allow ECF.
Do not penalize for sig. fig. or units.
*Award **[4]** for correct final answer.*

(iii) ($\Delta S^{\ominus}$[2×193] – [192 + 3×131]) = –199 (J K^{-1} mol^{-1}); 2

Allow ECF.
four <u>gaseous</u> molecules generating two <u>gaseous</u> molecules / fewer molecules of <u>gas</u>;

(iv) ($\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ = –76.0 – 298(–0.199)) = –16.7 (kJ);
Spontaneous;
ΔG is negative; 3

Do not penalize for SF.

(v) heat released when gas → liquid;
$\Delta H^{\ominus}$ becomes more negative; 2

[12]

5. B

[1]

6. (a) $\Delta H^{\ominus}_{reaction} = \Sigma\Delta H_f^{\ominus}$(products) – $\Sigma\Delta H_f^{\ominus}$(reactants)
= [(1)(–85) + (2)(–242)] – [(2)(–201)];
= –167 (kJ/kJ mol^{-1});
*Award **[1]** for (+) 167.* 2

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

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

$= -167$ kJ/-167000 J;
Units needed for mark in (c) only.
Accept –167 kJ mol^{-1} or –167000 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 $\Delta H_h^{\ominus}$ of elements (in their standard states) is zero / no reaction involved / *OWTTE*; 1

(ii) $\Delta H = -104 - (+20.4)$;
$= -124.4$ (kJ mol^{-1}); 2
*Award **[1 max]** for 124.4 (kJ mol^{-1}).*
*Award **[2]** for correct final answer.*

(iii) $\Delta S = 270 - (267 + 131)$;
$= -128$ (J K mol^{-1}); 2
*Award **[1 max]** for +128 (J K^{-1} mol^{-1}).*
*Award **[2]** for correct final answer.*

(iv) $\Delta G = \Delta H - T\Delta S = -124.4 - \frac{(-128 \times 298)}{1000}$;
$= -86.3$ 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 K / 699 °C; 2

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

[9]

16. B

[1]

17. A

[1]