AH Exercise 1.5

Reaction Feasibility

2002 AH MC16 (60%) and 2007 AH MC20 (75%) and 2016 AH MC10 (69%)

16. Which is likely to have the lowest standard entropy value at 100 °C?

A Mercury

B Neon

C Phosphorus

D Sulphur

2004 AH MC21 (41%)

21. In which of the following are the molecules likely to have the lowest degree of disorder?

A $H_2O(g)$

B $Br_2(g)$

C $H_2O(\ell)$

D $Br_2(\ell)$

2006 AH MC20 (79%) and 2008 AH MC19 (85%)

20. Which of the following reactions results in a **decrease** in entropy?

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

B $N_2O_4(g) \rightarrow 2NO_2(g)$

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

D $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$

2011 AH MC23 (74%)

23. Which of the following reactions would show the greatest decrease in entropy?

A $H_2(g) + F_2(g) \rightarrow 2HF(g)$

B $KNO_3(s) \rightarrow KNO_2(s) + \frac{1}{2}O_2(g)$

C $CO_3^{2-}(aq) + 2H^+(aq) \rightarrow H_2O(\ell) + CO_2(g)$

D $CO_3^{2-}(aq) + CO_2(g) + H_2O(\ell) \rightarrow 2HCO_3^-(aq)$

2013 AH MC27 (87%)

27. In which of the following changes will there be an increase in entropy?

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

B Combustion of ethanol

C Hydrogenation of ethene

D Phenylethene → poly(phenylethene)

2013 AH MC28 (57%) and 2013 revAH MC20 (47%)

28. One mole of which of the following chlorides would have the greatest entropy at **750 °C**?

A Sodium chloride

B Calcium chloride

C Potassium chloride

D Magnesium chloride

2011 AH MC24 (61%)

24. Which of the following alcohols would have the greatest entropy at 90 °C?

A Propan-1-ol

B Propan-2-ol

C Butan-1-ol

D Butan-2-ol

2003 AH MC26 (82%)

26. Which of the following reactions exhibits a positive entropy change?

A The formation of ice from water

B The combination of ammonia and hydrogen chloride gases to give solid ammonium chloride

C The polymerisation of propene

D The decomposition of solid ammonium nitrate into nitrogen, oxygen and steam

2005 AH MC20 (76%)

20. Which of the following reactions will have a positive $\Delta S°$ value?

A $2H_2(g) + C_2H_2(g) \rightarrow C_2H_6(g)$

B $LiH(s) + H_2O(\ell) \rightarrow LiOH(aq) + H_2(g)$

C $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(\ell)$

D $C_2H_4(g) + Br_2(\ell) \rightarrow C_2H_4Br_2(\ell)$

2001 AH MC14 (77%)

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

$\Delta H° = 178\ kJ\ mol^{-1}$ $\quad \Delta S° = 161\ JK^{-1}\ mol^{-1}$

This reaction is thermodynamically feasible

A at any temperature

B at all temperatures below 904 K

C at all temperatures above 904 K

D only at temperatures above 1106 K.

2003 AH MC22 (58%) and 2007 AH MC22 (59%)

22. A reaction **must** be exothermic if

A $\Delta G°$ is negative

B $\Delta S°$ is positive

C both $\Delta G°$ and $\Delta S°$ are negative

D both $\Delta G°$ and $\Delta S°$ are positive.

2004 AH MC22 (43%)

22. For a certain reaction

$\Delta H° = +7{\cdot}3\ kJ\ mol^{-1}$ and $\Delta S° = -200\ J\ K^{-1}\ mol^{-1}$.

This reaction will

A never be thermodynamically feasible

B be thermodynamically feasible above a certain temperature

C be thermodynamically feasible below a certain temperature

D be thermodynamically feasible at all temperatures.

2005 AH MC23 (80%)

23. For a certain reaction at 298 K,

$\Delta H° = +240\ kJ\ mol^{-1}$ and $\Delta G° = -92\ kJ\ mol^{-1}$.

The reaction is

A endothermic and feasible

B exothermic and feasible

C endothermic and not feasible

D exothermic and not feasible.

2009 AH MC18 (52%)

18. When water evaporates from a puddle which of the following applies?

A ΔH positive and ΔS positive

B ΔH positive and ΔS negative

C ΔH negative and ΔS positive

D ΔH negative and ΔS negative

2004 AH MC15 (54%)

15. $\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g)$

$\Delta G° = +51{\cdot}8\ kJ\ mol^{-1}$

$N_2(g) + 2O_2(g) \rightarrow N_2O_4(g)$

$\Delta G° = +97{\cdot}7\ kJ\ mol^{-1}$

What is the free energy change $\Delta G°$, in $kJ\ mol^{-1}$, for the conversion of nitrogen dioxide to one mole of dinitrogen tetroxide?

A $-45{\cdot}9$

B $-5{\cdot}9$

C $+5{\cdot}9$

D $+45{\cdot}9$

2005 AH MC22 (86%)

22. Tin can exist in two different forms, "white tin" and "grey tin". For the change

"white tin" $\rightarrow$ "grey tin"

$\Delta H° = 2{\cdot}5\ kJ\ mol^{-1}$

$\Delta S° = -6{\cdot}7\ J\ K^{-1}\ mol^{-1}$

and hence, $\Delta G°$ at 298 K, in $kJ\ mol^{-1}$, will be

A $-0{\cdot}5$

B $-4{\cdot}2$

C $+4{\cdot}5$

D $+9{\cdot}2$.

2002 AH MC13 (62%) and
2009 AH MC19 (64%) and 2015 AH MC21 (71%)

13. For which of the following reactions would the value of $\Delta G° - \Delta H°$ be approximately zero?

A $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$

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

C $Cu^{2+}(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + Cu(s)$

D $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

2012 AH MC21 (47%)

21. Which line in the table is correct for the enthalpy change and entropy change when steam condenses?

	ΔH	ΔS
A	+ve	+ve
B	+ve	−ve
C	−ve	−ve
D	−ve	+ve

2002 AH MC10 (43%)

10. $P + Q \rightleftharpoons R + S$

At 298 K the equilibrium constant for this reaction is $1{\cdot}2 \times 10^{10}$.

Which of the following must be true?

A Increasing the concentration of P will not change the equilibrium constant.

B The value of $\Delta G°$ is positive.

C Adding a catalyst will change the equilibrium constant.

D The value of $\Delta S°$ is positive.

2004 AH MC23 (60%)

23. The equilibrium constant for the reaction

$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$

at 298 K has a numerical value of 2×10^{37}.

Which of the following statements about the reaction is correct?

A The free energy change associated with the reverse reaction has a large negative value.

B The free energy change associated with the forward reaction has a small negative value.

C The reverse reaction does not occur to any appreciable extent.

D The value of the equilibrium constant is not dependent on temperature.

2012 AH MC20 (89%)

20. For any liquid, $\Delta S_{vapourisation} = \dfrac{\Delta H_{vapourisation}}{T_b}$

where T_b = boiling point of that liquid.

For many liquids,

$\Delta S_{vapourisation} = 88\ J\ K^{-1}\ mol^{-1}$.

Assuming that this value is true for water and that its $\Delta H_{vapourisation} = 40{\cdot}6\ kJ\ mol^{-1}$, then the boiling point of water is calculated as

A 0·46 K

B 2·17 K

C 373 K

D 461 K.

2005 AH MC21 (52%)

21. For a reaction in dynamic equilibrium, which of the following must be correct?

A $\Delta G = 0$.

B $K = 1$.

C Activation energy of forward reaction = activation energy of reverse reaction.

D ΔH for forward reaction = ΔH for reverse reaction.

2015 AH MC20 (77%) and 2015 revAH MC24 (75%)

20. The reaction

$2SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons 2SO_3(g)$

is reversible. After equilibrium has been established the reaction mixture was found to contain 0·2 moles of SO_2, 0·2 moles of O_2 and 16 moles of SO_3.

Which of the following is correct?

A $K > 1$ and $\Delta G° > 0$

B $K > 1$ and $\Delta G° < 0$

C $K < 1$ and $\Delta G° > 0$

D $K < 1$ and $\Delta G° < 0$

2013 revAH MC19 (66%)

19. Which of the following always increases in a spontaneous process?

A The free energy

B The total entropy

C The total enthalpy

D The surrounding temperature

2008 AH MC18 (72%)
2015 AH MC18 (75%) and 2015 revAH MC22 (79%)

18. The entropy of a perfect crystal is zero at

A 0 K

B 25 K

C 273 K

D 298 K.

2001 AH grid31

31. The boxes in the grid below contain certain symbols used in chemistry.

A $\Delta G°$	B K	C $\Delta S°$
D k	E $\Delta H°$	F ΔG

(*a*) Identify the **two** symbols which always have positive values when a solid melts.

(*b*) Identify the symbol which has a value greater or equal to one when a reaction is feasible.

(*c*) Identify the symbol which has a zero value when a chemical reaction is in a state of equilibrium.

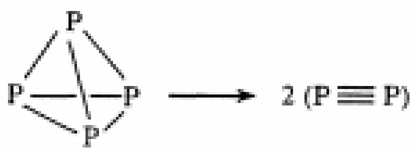
(*d*) Identify the symbol whose usage is **not** relevant to thermodynamics.

2001 AH L9d

9. When phosphorus is heated the following transition occurs at 800 °C.

$$P_4(g) \rightarrow 2P_2(g)$$

Using structural formulae, the transition may be represented as:



(*d*) Explain why there is an increase in entropy in the above transition. **1**

2002 AH L3

3. Information about the decomposition of silver(I) nitrate is given below.

$$AgNO_3(s) \rightarrow Ag(s) + \tfrac{1}{2}O_2(g) + NO_2(g)$$

Substance	$\Delta H_f°$/ kJ mol^{-1}	$S°$/JK^{-1} mol^{-1}
$AgNO_3$	−123·6	141·5
Ag	0	42·6
O_2	0	205·2
NO_2	34·0	241·4

For the decomposition of $AgNO_3$, calculate

(*a*) $\Delta H°$ **1**

(*b*) $\Delta S°$ **1**

(*c*) the theoretical temperature at which the reaction just becomes feasible. **2**

2006 AH L1a

1. Molten iron, made in a blast furnace, often contains sulphur and phosphorus impurities which must be removed.

Bubbling carbon dioxide gas through molten iron removes the sulphur.

The carbon dioxide gas is produced by the decomposition of calcium carbonate.

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

(*a*)

Substance	Standard enthalpy of formation, $\Delta H°$/kJ mol^{-1}	Standard entropy, $S°$/J K^{-1} mol^{-1}
CO_2	–393·5	213·8
$CaCO_3$	–1206·9	92·9
CaO	–635·1	38·1

For the decomposition of calcium carbonate, use the data in the table to calculate:

(i) the standard enthalpy change, $\Delta H°$, in kJ mol^{-1}; **1**

(ii) the standard entropy change, $\Delta S°$, in J K^{-1} mol^{-1}; **1**

(iii) the theoretical temperature at which the reaction just becomes feasible. **2**

2007 AH L1

1. Barium carbonate decomposes on heating.

$$BaCO_3(s) \longrightarrow BaO(s) + CO_2(g) \qquad \Delta H° = +266\,\text{kJ mol}^{-1}$$

(*a*) Using the data from the table below, calculate the standard entropy change, $\Delta S°$, in J K^{-1} mol^{-1}, for the reaction.

Substance	Standard entropy, $S°$/J K^{-1} mol^{-1}
$BaCO_3(s)$	112·0
$BaO(s)$	72·1
$CO_2(g)$	213·8

1

(*b*) Calculate the temperature at which the decomposition of barium carbonate just becomes feasible. **3**

2008 AH L5a

5. The equation for the decomposition of ammonium dichromate is

$$(NH_4)_2Cr_2O_7(s) \longrightarrow N_2(g) + 4H_2O(\ell) + Cr_2O_3(s)$$

Consider the following data for the reaction at 298 K.

Substance	$\Delta H_f°$/kJ mol^{-1}	$S°$/J K^{-1} mol^{-1}
$(NH_4)_2Cr_2O_7(s)$	–1806	336
$N_2(g)$	0	192
$H_2O(\ell)$	–286	70
$Cr_2O_3(s)$	–1140	81

(*a*) For the decomposition of $(NH_4)_2Cr_2O_7$, calculate

(i) $\Delta H°$ **1**

(ii) $\Delta S°$ **1**

(iii) $\Delta G°$. **2**

2009 AH L2

2. Iron(III) oxide can be reduced to iron using hydrogen.

$$Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(g)$$

Substance	$\Delta H_f°$/kJ mol^{-1}	S°/J K^{-1} mol^{-1}
$Fe_2O_3(s)$	–822	90
$H_2(g)$	0	131
Fe(s)	0	27
$H_2O(g)$	–242	189

For the reduction of iron(III) oxide with hydrogen, use the data in the table to calculate

(*a*) the standard entropy change, ΔS° **1**

(*b*) the standard enthalpy change, ΔH° **1**

(*c*) the theoretical temperature above which the reaction becomes feasible. **2**

2010 AH L3

3. The Thermit process can be used to extract iron from iron(III) oxide.

$$2Al(s) + Fe_2O_3(s) \rightarrow 2Fe(s) + Al_2O_3(s)$$

Substance	Standard enthalpy of formation, ΔH°/kJ mol^{-1}	Standard entropy, S°/J K^{-1} mol^{-1}
Al(s)	0	28·0
$Fe_2O_3(s)$	-824	87·0
Fe(s)	0	27·0
$Al_2O_3(s)$	-1676	51·0

For the Thermit process, use the data in the table to calculate

(*a*) the standard enthalpy change, ΔH° **1**

(*b*) the standard entropy change, ΔS° **1**

(*c*) the standard free energy change, ΔG°. **2**

2014 AH L3 and 2014 revAH L3

3. Methane gas can be converted into methanol in a series of steps.

The overall equation for the reaction is

$$CH_4(g) + \tfrac{1}{2}O_2(g) \longrightarrow CH_3OH(\ell)$$

Substance	**$\Delta H_f°$/kJ mol^{-1}**	**S°/J K^{-1} mol^{-1}**
$CH_4(g)$	–75	187
$O_2(g)$	–	205
$CH_3OH(\ell)$	–239	127

(*a*) For the conversion of methane into methanol, calculate

(i) the standard enthalpy change, ΔH° **1**

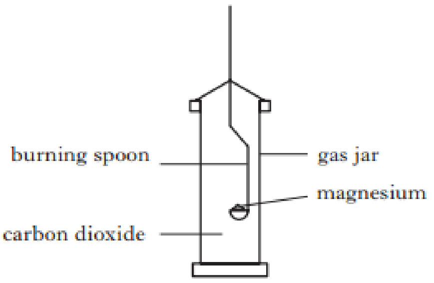
(ii) the standard entropy change, ΔS°. **1**

(*b*) Calculate the maximum temperature above which the reaction becomes no longer feasible. **2**

2013 AH L2

2. Burning magnesium continues to burn when placed in a gas jar of carbon dioxide according to the equation

$$2Mg(s) + CO_2(g) \rightarrow 2MgO(s) + C(s)$$



Substance	$S°/JK^{-1}\ mol^{-1}$
Mg(s)	33·0
$CO_2(g)$	214
MgO(s)	27·0
C(s)	5·70

(*a*) Using the values from the table above, calculate ΔS° for the reaction. **1**

(*b*) Using the information below and your answer to (*a*), calculate ΔG° for the burning of magnesium in carbon dioxide.

$Mg(s) + ½O_2(g) \rightarrow MgO(s)$ $\Delta H° = -493\ kJ\ mol^{-1}$

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H° = -394\ kJ\ mol^{-1}$ **3**

2015 AH L2 and 2015 revAH L2

2. Zinc oxide can be reduced to zinc in a blast furnace.

One of the reactions taking place in the furnace is shown.

$$ZnO(s) + CO(g) \rightarrow Zn(g) + CO_2(g)$$

Substance	Standard enthalpy of formation, ΔH_f°/kJ mol^{-1}	Standard entropy, $S°/J\ K^{-1}\ mol^{-1}$
ZnO(s)	−348	44
CO(g)	−110	198
Zn(g)	+130	161
$CO_2(g)$	−394	214

For the reduction of zinc oxide with carbon monoxide, use the data in the table to calculate:

(*a*) the standard enthalpy change, ΔH°, in kJ mol^{-1}; **1**

(*b*) the standard entropy change, ΔS°, in J K^{-1} mol^{-1}; **1**

(*c*) the theoretical temperature above which the reaction becomes feasible. **2**

2012 AH L3d

3. Two common crystal lattice structures adopted by ionic compounds can be described as simple cubic and face-centred cubic.

(*d*) Many ionic compounds are soluble in water.

(i) Which two factors determine whether the enthalpy of solution is exothermic or endothermic? **1**

(ii) The enthalpy of solution of sodium chloride is 0 kJ mol^{-1}.

Suggest what makes the dissolving of sodium chloride in water a feasible process. **1**

2016 AH L1

1. Ethene can be hydrated to produce ethanol.

$$C_2H_4(g) + H_2O(\ell) \rightarrow C_2H_5OH(\ell)$$

Compound	*Standard free energy of formation, $\Delta G°$ (kJ mol^{-1})*	*Standard enthalpy of formation, $\Delta H°_f$ (kJ mol^{-1})*
Ethene	68	52
Water	−237	−286
Ethanol	−175	−278

(a) For the hydration of ethene, use the data in the table to calculate:

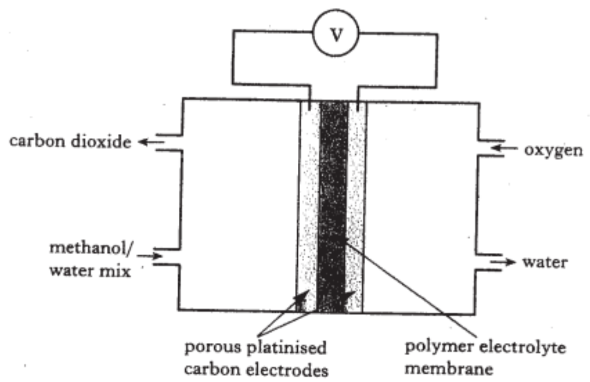
(i) the standard enthalpy change, $\Delta H°$, in kJ mol^{-1}; 1

(ii) the standard entropy change, $\Delta S°$, in J K^{-1} mol^{-1}. 3

(b) Calculate the temperature, in K, at which this reaction just becomes feasible. 2

2003 AH L10a

10. The methanol fuel cell below was designed to power military radios.



The cell can be represented as:

$$CH_3OH(\ell)\,|\,CO_2(g)\,\|\,O_2(g)\,|\,H_2O(\ell).$$

The overall reaction occurring in the cell is:

$$CH_3OH(\ell) + \tfrac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell) \quad \Delta H° = -727 \text{ kJ mol}^{-1}.$$

Substance	$S°$/J K^{-1} mol^{-1}
$CH_3OH(\ell)$	127·0
$O_2(g)$	205·2
$CO_2(g)$	213·8
$H_2O(\ell)$	69·9

(a) Calculate the entropy change, $\Delta S°$, in J K^{-1} mol^{-1}, for the overall cell reaction. 1

3. (*a*) Using the data from the table below calculate the standard enthalpy change, in kJ mol^{-1}, for the following reaction.

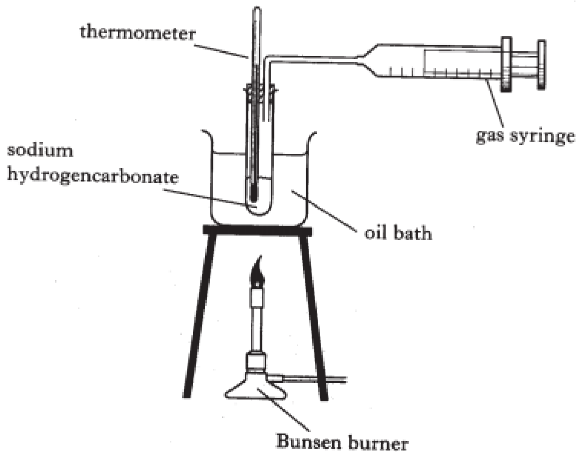
$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

Compound	Standard enthalpy of formation/kJ mol^{-1}
$NaHCO_3(s)$	−948
$Na_2CO_3(s)$	−1131
$H_2O(g)$	−242
$CO_2(g)$	−394

1

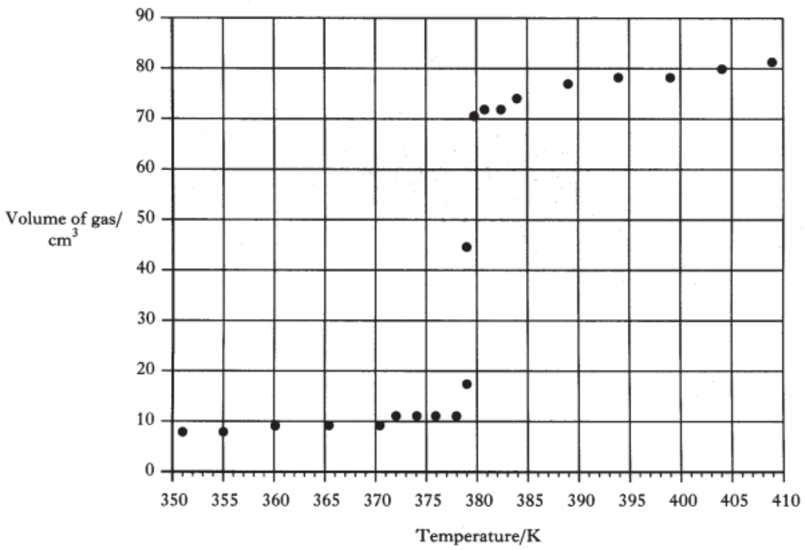
(*b*) Given that the entropy change for the reaction is +335 J K^{-1} mol^{-1}, calculate the temperature at which the reaction just becomes feasible. **2**

(*c*) A student set up an experiment to measure the temperature at which sodium hydrogencarbonate begins to decompose on heating, using the apparatus below.



3. (*c*) (continued)

From the student's results below, what is the experimental value for the temperature at which the sodium hydrogencarbonate begins to decompose?



1

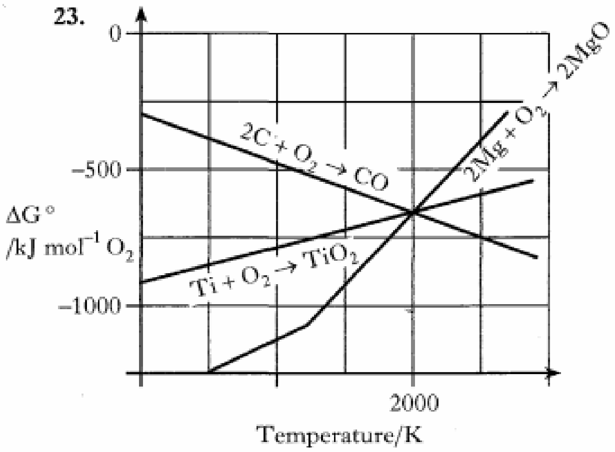
(*d*) Suggest a reason why the calculated and experimental decomposition temperatures may be different. **1**

AH Exercise 1.5b

Reaction Feasibility: Ellingham Diagrams

2002 AH MC23 (50%)

23.



From the graph above it can be deduced that

A magnesium can be used to reduce titanium oxide **below** 2000 K, and carbon can be used to reduce titanium oxide **below** 2000 K

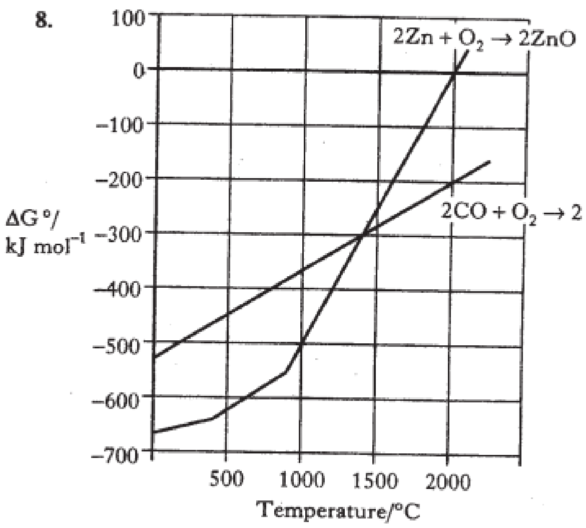
B magnesium can be used to reduce titanium oxide **above** 2000 K, and carbon can be used to reduce titanium oxide **below** 2000 K

C magnesium can be used to reduce titanium oxide **below** 2000 K, and carbon can be used to reduce titanium oxide **above** 2000 K

D magnesium can be used to reduce titanium oxide **above** 2000 K, and carbon can be used to reduce titanium oxide **above** 2000 K.

2003 AH MC8 (29%)

8.



At approximately which temperature does zinc oxide decompose?

A 400 °C

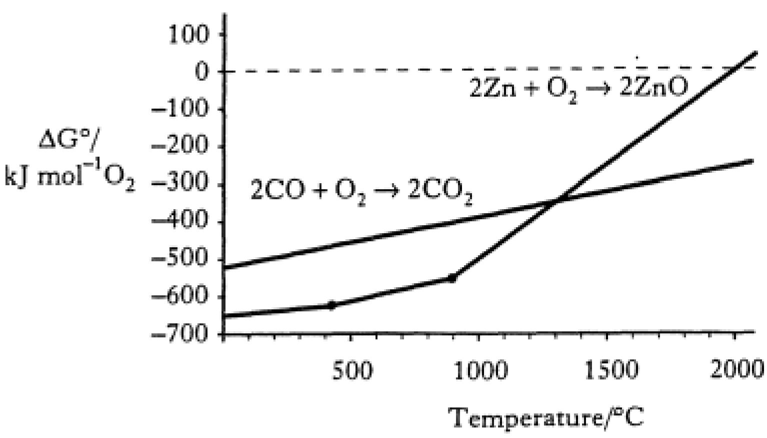
B 900 °C

C 1400 °C

D 2000 °C

2001 AH MC17 (65%)

17.



Carbon monoxide will reduce zinc oxide

A at all temperatures below 1300 °C

B only at a temperature of 1300 °C

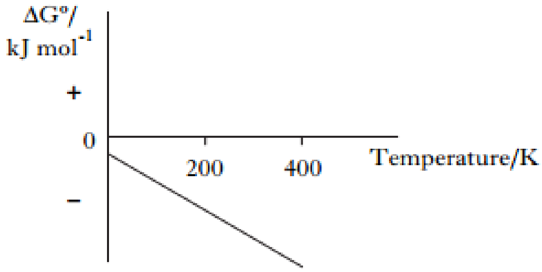
C at all temperatures above 1300 °C

D only at temperatures above 2000 °C.

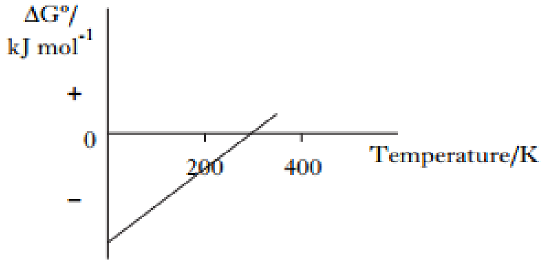
2009 AH MC17 (84%) and 2015 AH MC19 (89%) and 2015 revAH MC23 (85%)

17. Which of the following graphs shows the variation in $\Delta G°$ with temperature for a reaction which is always feasible?

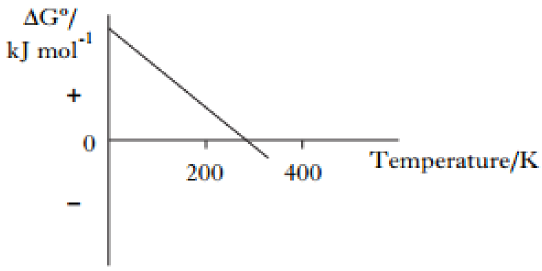
A



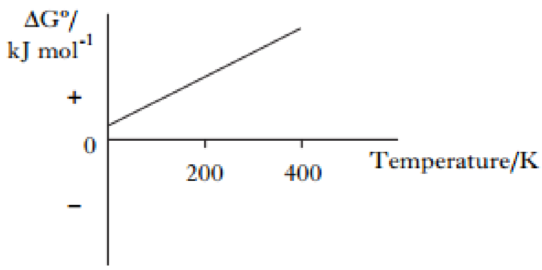
B



C



D



2001 AH MC10 (63%)

10. At 1400 K

$2C + O_2 \rightarrow 2CO$ $\quad \Delta G° = -475\ \text{kJ mol}^{-1}$ of O_2

$2Zn + O_2 \rightarrow 2ZnO$ $\quad \Delta G° = -340\ \text{kJ mol}^{-1}$ of O_2

For the reaction

$C + ZnO \rightarrow Zn + CO$

the standard free energy change at 1400 K is

A $+67{\cdot}5\ \text{kJ mol}^{-1}$

B $-67{\cdot}5\ \text{kJ mol}^{-1}$

C $+135\ \text{kJ mol}^{-1}$

D $-135\ \text{kJ mol}^{-1}$.

2007 AH MC21 (88%)

21. An Ellingham diagram shows how $\Delta G°$ for a chemical reaction varies with

A $\Delta H°$

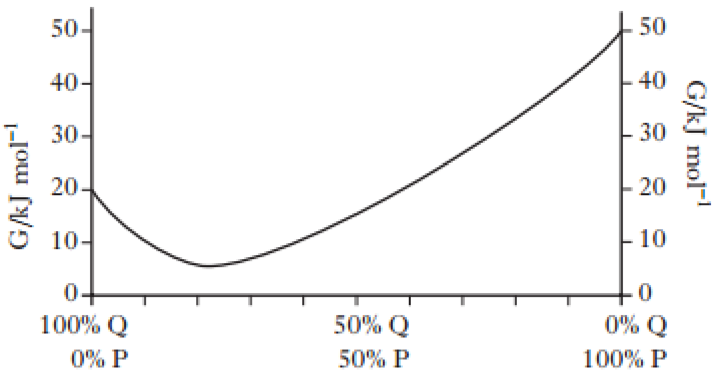
B $\Delta S°$

C time

D temperature.

2012 AH MC22 (76%)

22.



Assuming that liquids P and Q are in their standard states when 100 % of either is present, what is the value of $\Delta G°$, in kJ mol^{-1}, for the reaction represented by the stoichiometric equation,

$$Q(\ell) \rightarrow P(\ell)?$$

A −15

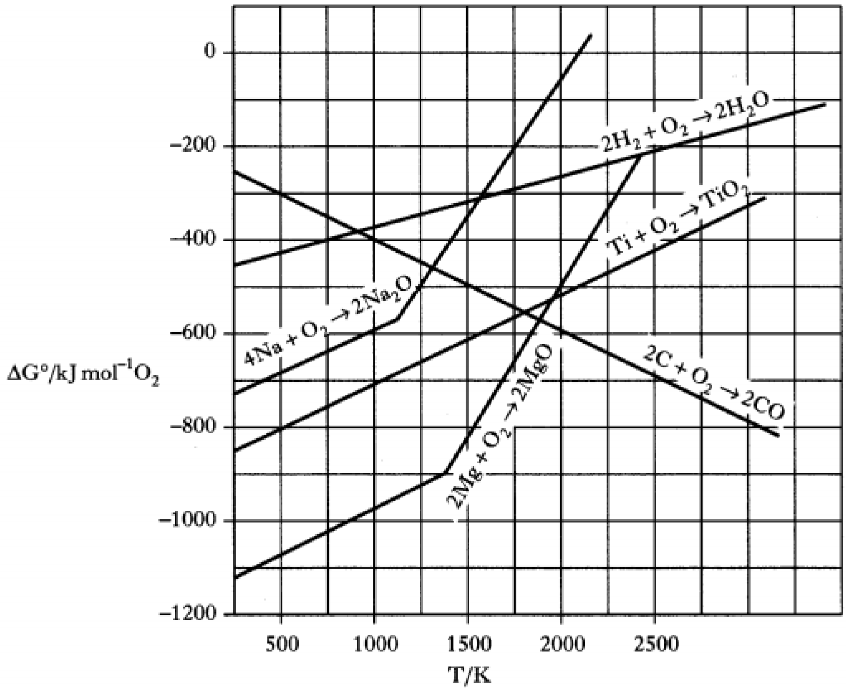
B −30

C +30

D +45

2006 AH MC22 (70%)

22.



The reduction of TiO_2 to Ti is thermodynamically feasible at 1500 K using

A hydrogen

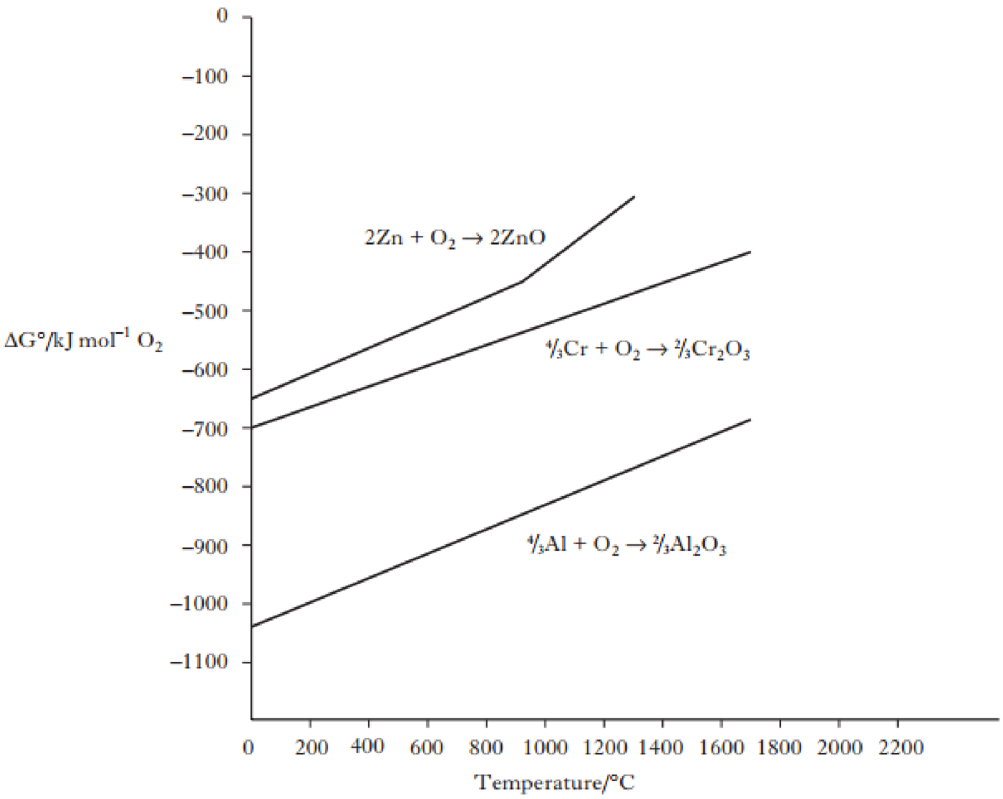
B magnesium

C carbon

D sodium.

2013 AH L7c

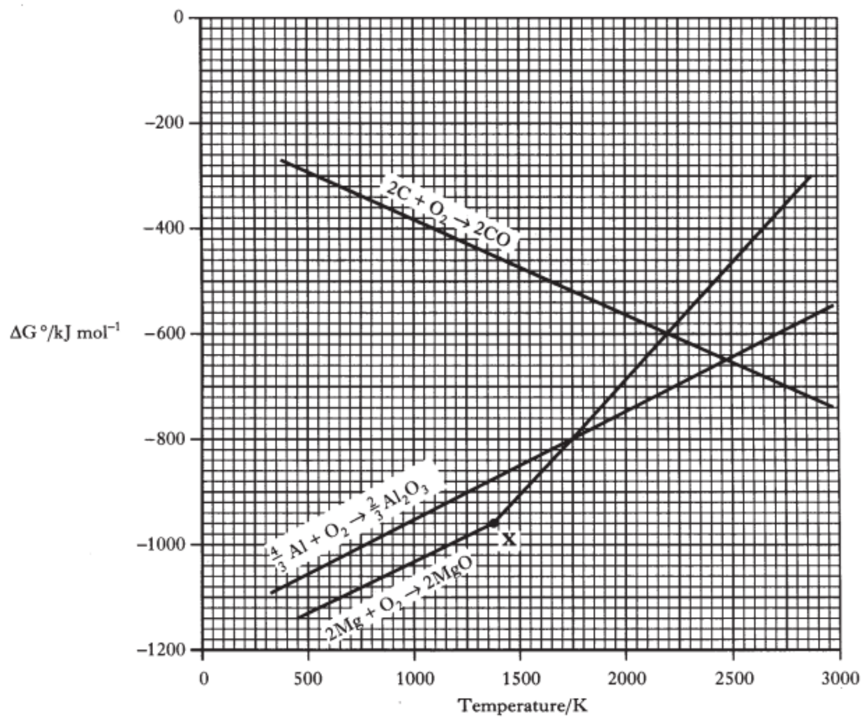
(*c*) Use the Ellingham diagram below to **explain** whether zinc or aluminium should be chosen to extract chromium from chromium oxide. **1**



2005 AH L2c

2. Silicon dioxide reacts with alkalis, magnesium oxide reacts with acids and aluminium oxide reacts with both acids and alkalis.

(*c*) Aluminium metal can be produced from its oxide by heating it with magnesium.



(i) Using the Ellingham diagram, determine a temperature range in which the reduction of aluminium oxide by magnesium is feasible. **1**

(ii) Suggest what causes the change in the gradient of the line at point **X**. **1**

2011 AH L6

6. The standard free energy change for a chemical reaction is given by the expression

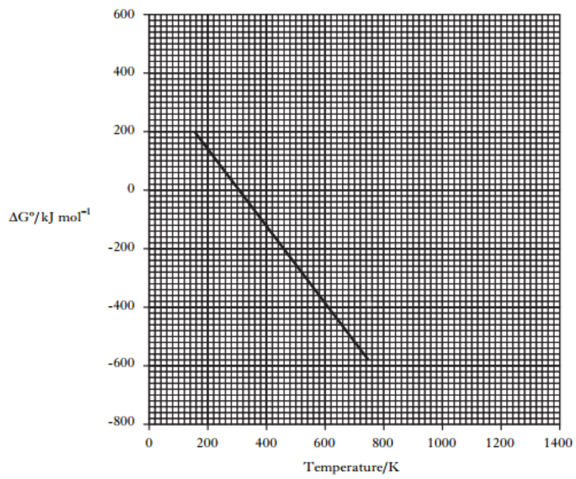
$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$$

The expression can be rearranged to give

$$\Delta G^{\circ} = -\Delta S^{\circ}T + \Delta H^{\circ}$$

Plotting values of ΔG° against T will therefore produce a straight line with gradient equal to $-\Delta S^{\circ}$.

The graph shows how ΔG° varies with temperature for a particular chemical reaction.



Use the graph to

(*a*) deduce the temperature at which the reaction just becomes feasible under standard conditions **1**

(*b*) estimate the value of ΔH°, in kJ mol^{-1}, for the reaction **1**

(*c*) calculate the value of ΔS°, in J K^{-1} mol^{-1}. **2**