

Entropy, Gibbs energy and reaction feasibility

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet

Name: _____ Date: _____ Class: _____

These problems train you to predict the sign of an entropy change, calculate ΔS° from tables, use $\Delta G = \Delta H - T\Delta S$ to judge feasibility and find changeover temperatures, and link ΔG° to the equilibrium constant. They progress from qualitative reasoning to multi-step data analysis.

The level suits A Level, IB Chemistry, CBSE Class 11-12 and senior WAEC and NECO students. Keep ΔH in kJ and ΔS in J until you convert them, and always use kelvin.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB R1.4

Problem 1 Which has more entropy? (easy)

Aarav in Pune compares pairs of substances at the same temperature.

1. Ice or liquid water (1 mol each)?
2. One mole of $\text{CO}_2(\text{g})$ or one mole of $\text{CO}_2(\text{s})$?
3. $\text{NaCl}(\text{s})$ or NaCl dissolved in water (aq)?
4. Two moles of gas or one mole of gas?

Problem 2 Predicting the sign of ΔS (easy)

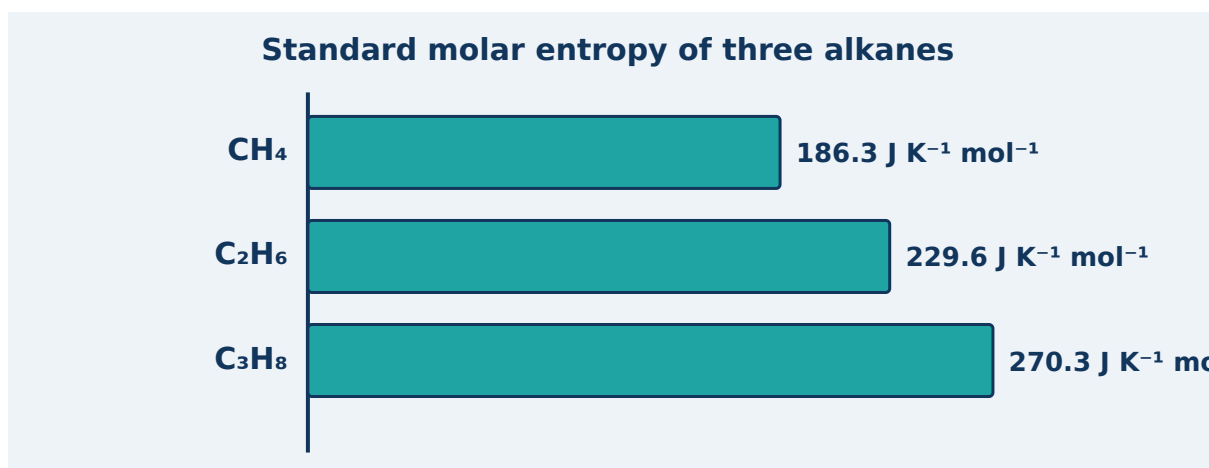
Predict whether ΔS is positive or negative, with a reason.

1. $2\text{H}_2\text{O}_2(\text{l}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
2. $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
3. $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
4. $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$

Problem 3 Entropy of alkanes (easy)

The chart shows standard molar entropies of the first three alkanes (gases).

1. Describe the trend.
2. Calculate the increase in entropy from CH_4 to C_2H_6 and from C_2H_6 to C_3H_8 .
3. Suggest why entropy increases along the series.



Entropy grows with the number of atoms in a gaseous molecule.

Problem 4 Gibbs energy of a hand warmer (easy)

Chiamaka in Lagos studies a reaction in a reusable hand warmer: $\Delta H = -85.0 \text{ kJ/mol}$, $\Delta S = -120 \text{ J K}^{-1} \text{mol}^{-1}$ at 298 K.

1. Convert ΔS to $\text{kJ K}^{-1} \text{mol}^{-1}$.
2. Calculate ΔG .
3. State whether the reaction is spontaneous.

Problem 5 Meaning of the sign of ΔG (easy)

Classify each reaction as spontaneous, non-spontaneous or at equilibrium at the stated temperature.

1. $\Delta G = -12 \text{ kJ/mol}$
2. $\Delta G = +5 \text{ kJ/mol}$
3. $\Delta G = 0$
4. State what a positive ΔG tells you about the reverse reaction.

Problem 6 Entropy change for water formation (medium)

Hydrogen-oxygen reactions power a bus in Kisumu: $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$. S° values in $\text{J K}^{-1} \text{mol}^{-1}$: H_2 130.7, O_2 205.0, $\text{H}_2\text{O}(\text{l})$ 69.9.

1. Calculate $\Sigma S^\circ(\text{products})$ and $\Sigma S^\circ(\text{reactants})$.
2. Calculate ΔS° .
3. Explain the sign.

Problem 7 Four sign combinations (medium)

Complete the table by stating when each combination is spontaneous (all temperatures, low T only, high T only or never). Then give the sign of ΔG at low T for the first row.

1. ΔH negative, ΔS positive
2. ΔH negative, ΔS negative
3. ΔH positive, ΔS positive

4. ΔH positive, ΔS negative

Problem 8 Burning methane (medium)

Wanjiru in Nairobi studies methane in a gas stove: $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$, $\Delta H = -890 \text{ kJ/mol}$. S° values in $\text{J K}^{-1} \text{ mol}^{-1}$: CH_4 186.3, O_2 205.0, CO_2 213.8, $\text{H}_2\text{O}(\text{l})$ 69.9.

1. Calculate ΔS° .
2. Calculate ΔG at 298 K.
3. State whether the reaction is spontaneous and what else controls its speed.

Problem 9 Melting point of ice (medium)

Kofi in Accra keeps drinks cold with ice. For $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\text{l})$, $\Delta H = +6.01 \text{ kJ/mol}$ and $\Delta S = +22.0 \text{ J K}^{-1} \text{ mol}^{-1}$.

1. State the value of ΔG at the melting point.
2. Calculate the melting point in K and $^\circ\text{C}$.
3. Predict whether melting is spontaneous at 290 K.

Problem 10 Boiling point of ethanol (medium)

A distillation lab in Texas uses ethanol: $\text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{g})$, $\Delta H = +38.6 \text{ kJ/mol}$ and $\Delta S = +110 \text{ J K}^{-1} \text{ mol}^{-1}$.

1. Calculate the temperature at which $\Delta G = 0$.
2. Convert it to $^\circ\text{C}$.
3. Explain what happens to the sign of ΔG above this temperature.

Problem 11 Dissolving sodium chloride (medium)

Mei in Singapore dissolves salt: $\text{NaCl}(\text{s}) \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$, $\Delta H = +3.9 \text{ kJ/mol}$. S° values in $\text{J K}^{-1} \text{ mol}^{-1}$: $\text{NaCl}(\text{s})$ 72.1, $\text{Na}^+(\text{aq})$ 59.0, $\text{Cl}^-(\text{aq})$ 56.5.

1. Calculate ΔS° .
2. Calculate ΔG at 298 K.
3. Explain why the endothermic process is spontaneous.

Problem 12 From ΔG to the equilibrium constant (medium)

Use $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ and $T = 298 \text{ K}$.

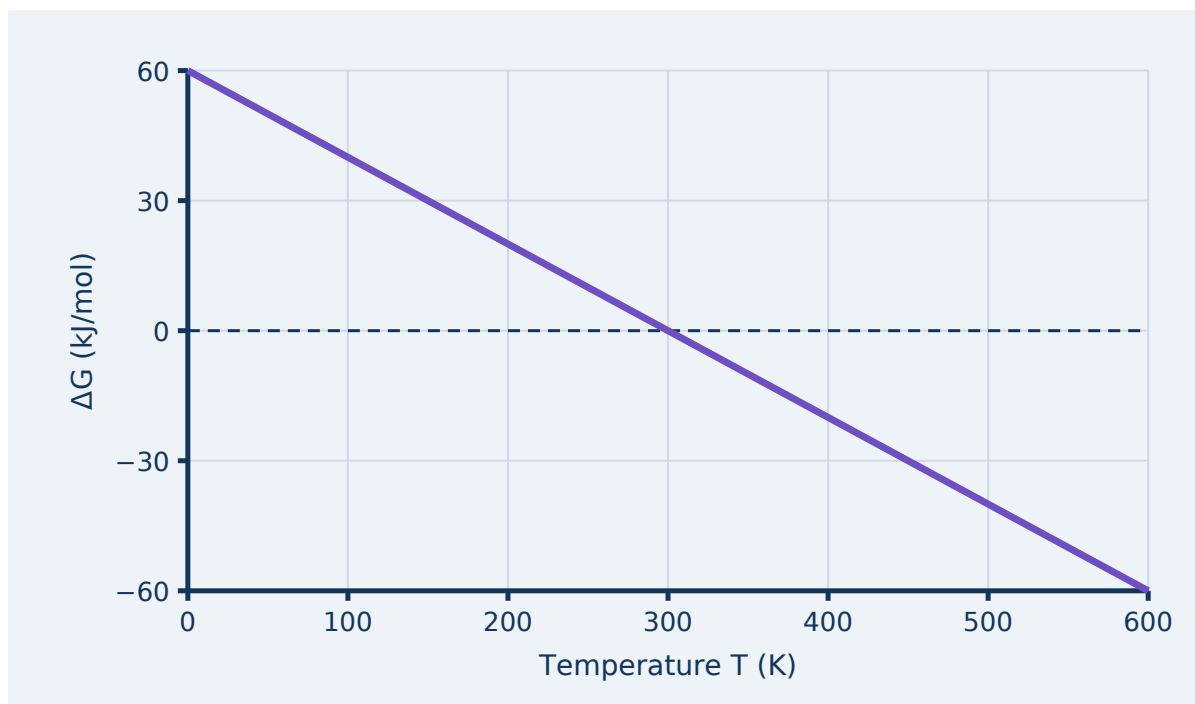
1. A reaction has $K = 4.0 \times 10^3$. Calculate ΔG° in kJ/mol .
2. Another reaction has $\Delta G^\circ = +15.0 \text{ kJ/mol}$. Calculate K .
3. State which reaction favours products.

Problem 13 Reading a ΔG -T graph (medium)

The graph shows ΔG against temperature for a reaction.

1. Read the value of ΔH from the intercept at $T = 0$.

- Calculate ΔS from the gradient.
- Read the temperature where $\Delta G = 0$ and state when the reaction is spontaneous.



ΔG against T for an unknown reaction.

Problem 14 Entropy of the surroundings (medium)

Diego in Texas burns ethanol: $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$, $\Delta H = -1367 \text{ kJ/mol}$ at 298 K, $\Delta S(\text{system}) = -138.4 \text{ J K}^{-1} \text{ mol}^{-1}$.

- Calculate $\Delta S(\text{surroundings})$.
- Calculate $\Delta S(\text{total})$.
- Show that $-T\Delta S(\text{total})$ equals ΔG .

Problem 15 Decomposition of hydrogen peroxide (medium)

A first-aid kit in Leeds contains hydrogen peroxide: $2\text{H}_2\text{O}_2(\text{l}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$, $\Delta H = -196 \text{ kJ/mol}$. S° values in $\text{J K}^{-1} \text{ mol}^{-1}$: $\text{H}_2\text{O}_2(\text{l})$ 109.6, $\text{H}_2\text{O}(\text{l})$ 69.9, $\text{O}_2(\text{g})$ 205.0.

- Calculate ΔS° and ΔG at 298 K.
- Explain why the bottle can be stored for months although ΔG is very negative.

Problem 16 Baking soda decomposition (hard)

Bilal in Lahore heats baking soda: $2\text{NaHCO}_3(\text{s}) \rightarrow \text{Na}_2\text{CO}_3(\text{s}) + \text{H}_2\text{O}(\text{g}) + \text{CO}_2(\text{g})$, $\Delta H = +135.6 \text{ kJ/mol}$. S° values in $\text{J K}^{-1} \text{ mol}^{-1}$: NaHCO_3 101.7, Na_2CO_3 135.0, $\text{H}_2\text{O}(\text{g})$ 188.8, CO_2 213.8.

- Calculate ΔS° .
- Calculate ΔG at 298 K and state whether baking soda decomposes at room temperature.
- Calculate the minimum temperature for decomposition in K and $^\circ\text{C}$.

Problem 17 The contact process (hard)

A sulfuric acid plant in Kampala makes SO_3 : $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$, $\Delta H = -198 \text{ kJ/mol}$. S° values in $\text{J K}^{-1} \text{ mol}^{-1}$: SO_2 248.2, O_2 205.0, SO_3 256.8.

1. Calculate ΔS° .
2. Calculate ΔG at 298 K and at 1200 K.
3. Calculate the temperature above which the forward reaction stops being spontaneous.
4. Explain why the plant uses about 700 K even though low T favours products.

Problem 18 Dinitrogen tetroxide equilibrium (hard)

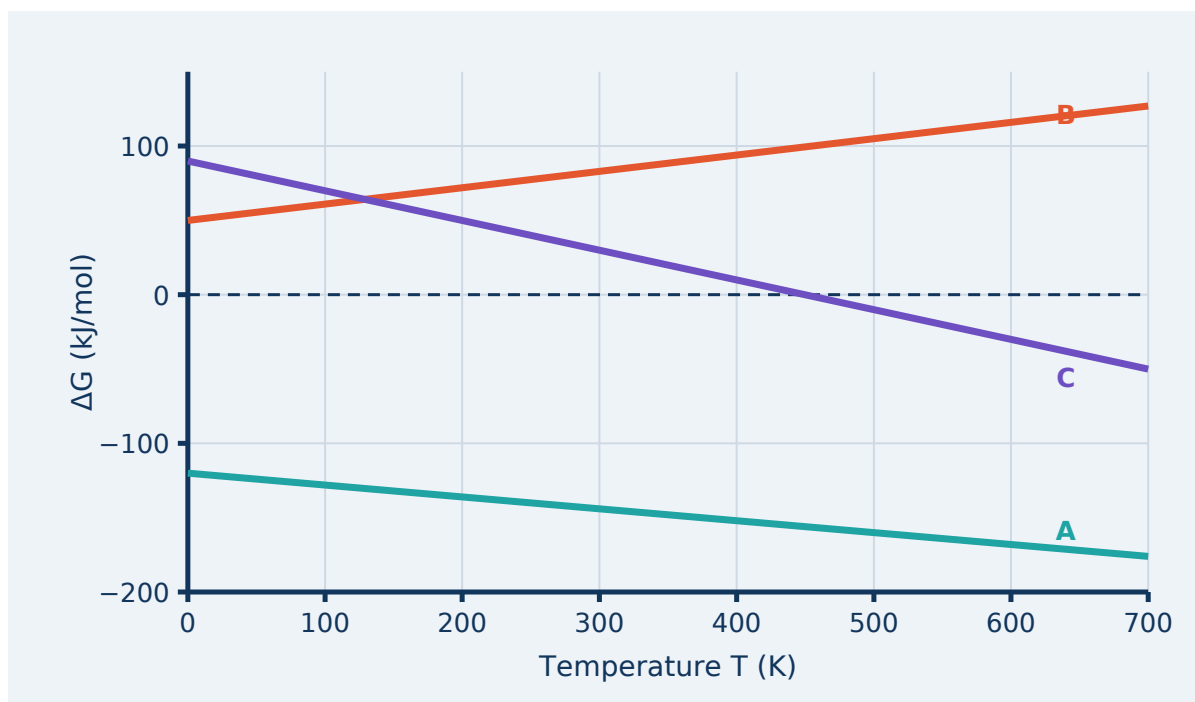
Colourless $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ (brown). $\Delta H = +57.2 \text{ kJ/mol}$ and $\Delta S = +175.8 \text{ J K}^{-1} \text{ mol}^{-1}$. Use $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$.

1. Calculate ΔG at 298 K.
2. Calculate K at 298 K.
3. Calculate the temperature at which $K = 1$ and predict the colour change on heating.

Problem 19 Three reactions on one graph (hard)

The graph shows ΔG against T for reactions A, B and C. Their data are: A $\Delta H = -120 \text{ kJ/mol}$, $\Delta S = +0.080 \text{ kJ K}^{-1} \text{ mol}^{-1}$; B $\Delta H = +50 \text{ kJ/mol}$, $\Delta S = -0.110 \text{ kJ K}^{-1} \text{ mol}^{-1}$; C $\Delta H = +90 \text{ kJ/mol}$, $\Delta S = +0.200 \text{ kJ K}^{-1} \text{ mol}^{-1}$.

1. Match each line on the graph to A, B or C by its starting point and gradient.
2. State which reaction is spontaneous at all temperatures and which at none.
3. Calculate the crossover temperature for C and its ΔG at 298 K.



ΔG against T for reactions A, B and C.

Problem 20 Spot the errors (hard)

A student calculates ΔG for a reaction with $\Delta H = -50.0 \text{ kJ/mol}$ and $\Delta S = -100 \text{ J K}^{-1} \text{ mol}^{-1}$ at 298 K and writes: $\Delta G = -50.0 - 298 \times (-100) = +29\,750 \text{ kJ/mol}$, so the reaction does not happen.

1. Identify the error.
2. Calculate the correct ΔG .
3. Calculate the temperature above which the reaction stops being spontaneous.