

Entropy, Gibbs energy and spontaneity

AP Chemistry · Worksheet

Name: _____ Date: _____ Class: _____

These problems train Unit 9 of AP Chemistry: predicting the sign of entropy change, calculating ΔS° , ΔH and ΔG , finding crossover temperatures, and linking ΔG° to the equilibrium constant. They also suit A Level and first-year university chemistry.

Level 1 problems work on signs and one-step substitution. Level 2 problems combine several quantities and interpret graphs. The last five problems are level 3: multi-step reactions, coupled processes and the entropy of the universe.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 9

Problem 1 Predict the sign of ΔS (easy)

Predict whether ΔS is positive or negative for (a) $\text{NaCl(s)} \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$, (b) $2\text{NO}_2(\text{g}) \rightarrow \text{N}_2\text{O}_4(\text{g})$, (c) $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO(s)} + \text{CO}_2(\text{g})$, (d) $\text{H}_2\text{O(g)} \rightarrow \text{H}_2\text{O(l)}$.

Problem 2 Rank by entropy (easy)

Rank from lowest to highest standard molar entropy: He(g) , Fe(s) , $\text{H}_2\text{O(l)}$.

Problem 3 Entropy of water formation (easy)

Calculate ΔS° for $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O(l)}$ using $S^\circ = 130.7, 205.1$ and $69.9 \text{ J/(mol}\cdot\text{K)}$.

Problem 4 A simple ΔG calculation (easy)

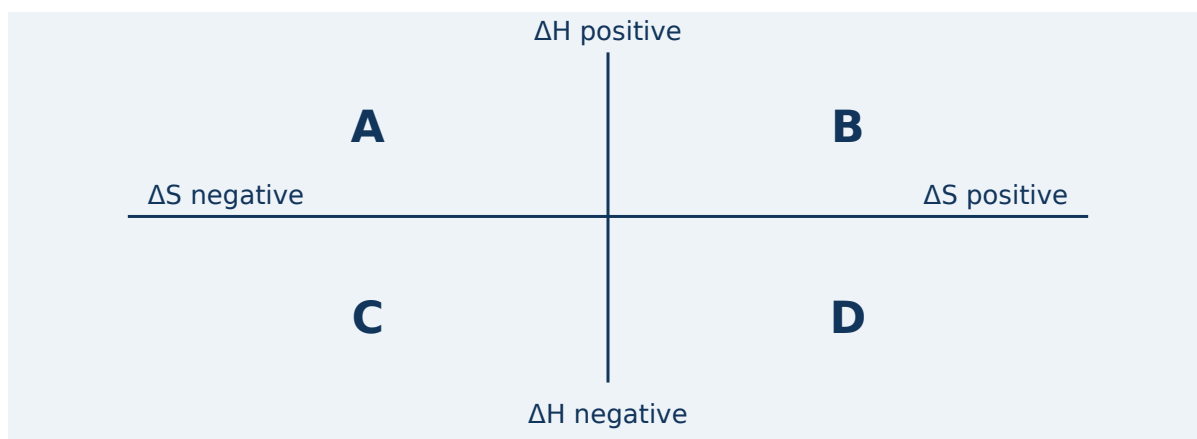
Aarav in Pune is given $\Delta H = -40.0 \text{ kJ}$ and $\Delta S = -100 \text{ J/K}$ for a reaction at 298 K. Calculate ΔG and state whether the reaction is spontaneous.

Problem 5 Endothermic but spontaneous (easy)

A process has $\Delta H = +50.0 \text{ kJ}$ and $\Delta S = +150 \text{ J/K}$. Calculate ΔG at 400 K and decide whether it is spontaneous.

Problem 6 Four cases (easy)

The diagram shows four regions A to D for the possible signs of ΔH and ΔS .



1. State the region where a reaction is spontaneous at all temperatures.
2. State the region where it is spontaneous only at high temperature.
3. State the region where it is spontaneous only at low temperature.

Problem 7 Entropy of methane combustion (medium)

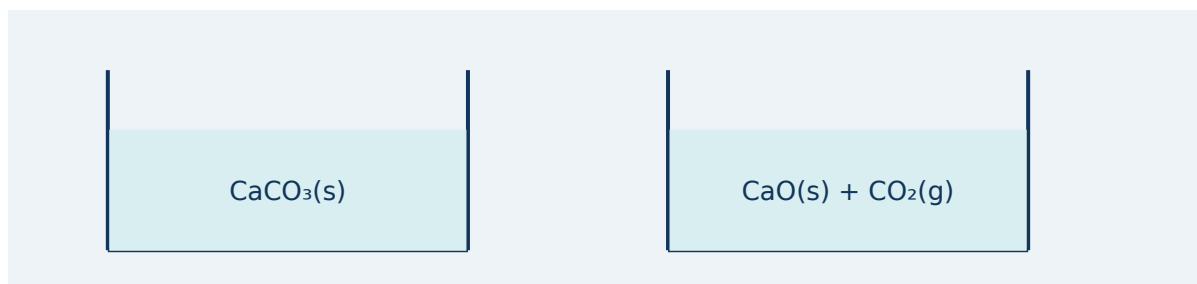
Chiamaka in Lagos studies $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$. S° values ($\text{J}/(\text{mol}\cdot\text{K})$): CH_4 186.3, O_2 205.1, CO_2 213.8, $\text{H}_2\text{O}(\text{g})$ 188.8.

1. Calculate ΔS° .
2. Explain why the value is so small although the reaction releases so much heat.

Problem 8 Decomposition of limestone (medium)

$\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ has $\Delta H^\circ = +178.3 \text{ kJ}$. S° ($\text{J}/(\text{mol}\cdot\text{K})$): CaCO_3 92.9, CaO 39.8, CO_2 213.8.

1. Calculate ΔS° .
2. Calculate ΔG° at 298 K.
3. Calculate the temperature above which the decomposition is spontaneous.



Reactant and products.

Problem 9 Free energy of formation (medium)

Use ΔG°_f values (kJ/mol): $\text{CaCO}_3(\text{s}) -1128.8$, $\text{CaO}(\text{s}) -603.3$, $\text{CO}_2(\text{g}) -394.4$. Calculate ΔG° for $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ and compare it with the value from $\Delta H^\circ - T\Delta S^\circ$.

Problem 10 Melting of ice (medium)

For melting, $\Delta H = +6.01 \text{ kJ/mol}$ and $\Delta S = +22.0 \text{ J/(mol}\cdot\text{K)}$.

1. Calculate the melting temperature.
2. Calculate ΔG at 263 K and at 283 K.
3. State which temperature favours melting.

Problem 11 Boiling of ethanol (medium)

Ethanol boils at 351 K (78 °C) with $\Delta H(\text{vap}) = 38.6 \text{ kJ/mol}$. At the boiling point $\Delta G = 0$ for the phase change.

1. Calculate $\Delta S(\text{vap})$ in $\text{J/(mol}\cdot\text{K)}$.
2. Explain why $\Delta S(\text{vap})$ is positive.

Problem 12 K from ΔG° (medium)

A reaction has $\Delta G^\circ = -20.0 \text{ kJ}$ at 298 K. Calculate K.

Problem 13 ΔG° from K (medium)

Wanjiru in Nairobi measures $K = 1.0 \times 10^{-5}$ at 298 K for a reaction. Calculate ΔG° and comment on the sign.

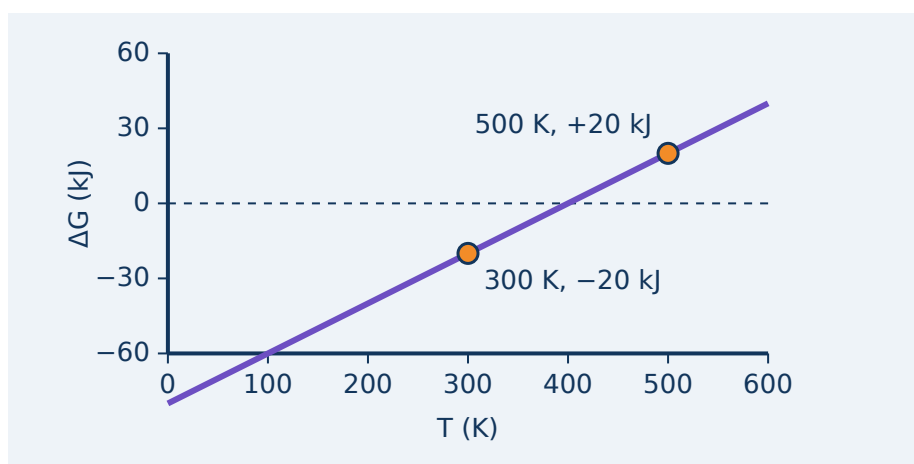
Problem 14 Free energy away from standard state (medium)

A reaction has $\Delta G^\circ = +10.0 \text{ kJ}$ at 298 K. Bilal in Lahore sets up a mixture with $Q = 1.0 \times 10^{-3}$.

1. Calculate ΔG .
2. State the direction in which the reaction proceeds.

Problem 15 Reading a ΔG against T line (medium)

Mei in Singapore measures $\Delta G = -20 \text{ kJ}$ at 300 K and $\Delta G = +20 \text{ kJ}$ at 500 K.



Two points on a ΔG against T line.

1. Calculate the slope and hence ΔS .
2. Calculate ΔH .
3. Calculate the temperature at which $\Delta G = 0$.

Problem 16 Making sulfur trioxide (hard)

Consider $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$. ΔH_f° (kJ/mol): SO_2 -296.8 , SO_3 -395.7 . S° (J/(mol·K)): SO_2 248.2 , O_2 205.1 , SO_3 256.8 .

1. Calculate ΔH° and ΔS° .
2. Calculate ΔG° at 298 K.
3. Calculate the temperature above which the reaction is not spontaneous under standard conditions.

Problem 17 Temperature and the equilibrium constant (hard)

Using the data of "Making sulfur trioxide", Kofi in Accra considers the industrial temperature 800 K.

1. Calculate ΔG° at 800 K.
2. Calculate K at 800 K.
3. Explain why plants nevertheless use about 700 to 800 K.

Problem 18 Coupled reactions (hard)

In a cell, glucose + Pi $\rightarrow$ glucose-6-phosphate has $\Delta G^\circ = +13.8$ kJ, and $\text{ATP} \rightarrow \text{ADP} + \text{Pi}$ has $\Delta G^\circ = -30.5$ kJ at 298 K.

1. Add the two reactions and calculate ΔG° for the coupled reaction.
2. Calculate K for the coupled reaction.
3. Explain why coupling lets the first reaction proceed.

Problem 19 Instant cold pack (hard)

Diego in Texas notices that dissolving $\text{NH}_4\text{NO}_3(\text{s})$ in water makes the pack cold. $\Delta H = +25.7$ kJ/mol and $\Delta S = +108.7$ J/(mol·K).

1. Calculate ΔG at 298 K.
2. Explain why the process is spontaneous although it absorbs heat.
3. Calculate the temperature below which dissolving would not be spontaneous.

Problem 20 Entropy of the universe (hard)

The ammonia reaction $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$ has $\Delta H^\circ = -92.2$ kJ and $\Delta S^\circ(\text{system}) = -198.7$ J/(mol·K) at 298 K.

1. Calculate $\Delta S(\text{surroundings}) = -\Delta H/T$.
2. Calculate $\Delta S(\text{universe})$.
3. Show that $\Delta S(\text{universe}) = -\Delta G/T$ and explain what its sign means.