9.7 Coupled Reactions

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS coupled reaction • state function • ATP hydrolysis ATP • extraction • electrolysis • drive

Objective

Build the skills to answer exam questions on **coupled reactions** : adding ΔG° values so a favored reaction drives an unfavored one.

You must be able to:

- add equations and their ΔG° values (free energy is a state function)
- explain **coupling** : a shared species links an unfavored step to a strongly favored one
- use ATP hydrolysis as the coupling reaction in living cells
- explain that electricity or light can drive a reaction with $\Delta G^\circ > 0$

1 Key knowledge and worked examples

Making an unfavored step happen

idea	rule
add	add the equations; add their ΔG° values
coupling	the overall ΔG° must be negative; a species made in one step is used in the other
in cells	$\mathrm{ATP} + \mathrm{H_2O} \rightarrow \mathrm{ADP} + \mathrm{P_i}$, $\Delta G^\circ \approx -30.5$ kJ/mol, drives many steps
metal extraction	carbon (giving CO or $\mathrm{CO_2}$) removes $\mathrm{O_2}$ from metal oxides
outside energy	electrolysis (electricity) and photosynthesis (light) drive $\Delta G^\circ > 0$ reactions

Worked example: copper oxide and carbon. $\mathrm{CuO(s)} \rightarrow \mathrm{Cu(s)} + \frac{1}{2}\mathrm{O_2(g)}$, $\Delta G^\circ = +129.7$ kJ/mol; $\mathrm{C(s)} + \frac{1}{2}\mathrm{O_2(g)} \rightarrow \mathrm{CO(g)}$, $\Delta G^\circ = -137.2$ kJ/mol.

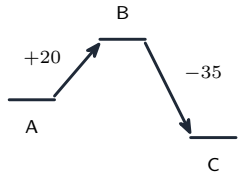
1. Add: $\mathrm{CuO} + \mathrm{C} \rightarrow \mathrm{Cu} + \mathrm{CO}$; the $\frac{1}{2}\mathrm{O_2}$ cancels.
2. $\Delta G^\circ = 129.7 - 137.2 = -7.5$ **kJ/mol**: the coupled reaction is favored.

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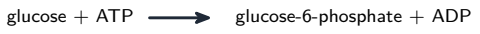
Answer shapes: write both equations, cancel the shared species, add the ΔG° values.

2 Practice

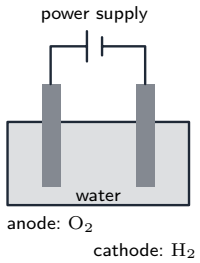
2.1 Step 1, A $\to$ B, has $\Delta G^\circ = +20$ kJ/mol. Step 2, B $\to$ C, has $\Delta G^\circ = -35$ kJ/mol. Find ΔG° for A $\to$ C, and state whether it is favored. [2]



2.2 In cells, glucose + P_i $\to$ glucose-6-phosphate has $\Delta G^\circ = +13.8$ kJ/mol. It is coupled to ATP $\to$ ADP + P_i, $\Delta G^\circ = -30.5$ kJ/mol. Find ΔG° for the coupled reaction. [2]



2.3 Splitting water into hydrogen and oxygen is not thermodynamically favored. Explain how electrolysis makes it happen. [2]



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3 Exam-style questions

3.1 Zinc is made from zinc oxide by heating it with carbon. The table gives approximate values of ΔG°.

(a) Write the overall equation and calculate ΔG° at 298 K. State whether the reaction is favored at 298 K. [3]

reaction	ΔG° at 298 K	ΔG° at 1200 K
$\mathrm{ZnO(s) \rightarrow Zn + \frac{1}{2}O_2(g)}$	$+320.5$	$+210$
$\mathrm{C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)}$	-137.2	-218

values in kJ/mol

(b) Calculate ΔG° at 1200 K. Explain why ΔG° for $\mathrm{C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)}$ becomes more negative at higher temperature. [3]

(c) Explain what "coupling" means for these two reactions. [2]

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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

Each answer shows the steps, then the **result**.

2.1

$+20 + (-35) = \mathbf{-15\ kJ/mol}$; favored

2.2

$13.8 + (-30.5) = \mathbf{-16.7\ kJ/mol}$

2.3

the power supply provides electrical energy; this outside energy drives the unfavored reaction

3.1

(a) $ZnO(s) + C(s) \rightarrow Zn + CO(g)$; $320.5 + (-137.2) = \mathbf{+183.3\ kJ/mol}$; **not favored**

(b) $210 + (-218) = \mathbf{-8\ kJ/mol}$; $\frac{1}{2}$ mol of gas becomes 1 mol of gas, so $\Delta S^\circ > 0$; so $-T\Delta S^\circ$ becomes more negative as T rises

(c) the O_2 made in the first reaction is used in the second; the large negative ΔG° of the second makes the sum negative, which drives the first

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