ExamFitter

examfitter.com · Free AP Chemistry quizzes, revision notes and worksheets

Topic 9.7: Coupled Reactions

Revision Notes · AP Chemistry

UNIT 9 · THERMODYNAMICS AND ELECTROCHEMISTRY

On ExamFitter.com: Topic 9.7 Quiz · Topic 9.7 Worksheet · Unit 9: All Topics · AP Chemistry Home

An Unfavorable Reaction Cannot Go Alone

Positive ΔG° means reactants win. A reaction with ΔG° > 0 has its equilibrium far toward reactants.

Coupling is the workaround. Run the unfavorable reaction together with a favorable second reaction, linked so the two proceed as a single overall process. The favorable partner is the driver, the unfavorable one the driven step.

The pair is judged as one process. Thermodynamics asks one question about the combined process: is its total free energy change negative?

Free Energies Add

Add the ΔG° values, signs attached.

$\Delta G^\circ(\text{overall}) = \Delta G^\circ(\text{driven}) + \Delta G^\circ(\text{driver})$

Reaction X at +45 kJ mol^{-1} coupled to reaction Y at −80 kJ mol^{-1} gives (+45) + (−80) = −35 kJ mol^{-1}.

The Hess rules carry over. Reversing a step flips the sign of its ΔG°: the reverse of an −80 kJ mol^{-1} step carries +80 kJ mol^{-1}. Doubling a step doubles its ΔG°.

Actual ΔG values add too. Away from standard conditions the same bookkeeping applies to ΔG itself: a driven step at +8 kJ mol^{-1} beside a driver at −15 kJ mol^{-1} gives a coupled total of −7 kJ mol^{-1}, still favorable.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

The Driver Must Release More Than the Step Costs

Magnitude decides, not the driver's sign alone. A driver at −20 kJ mol^{-1} coupled to a step costing +28 kJ mol^{-1} gives a total of +8 kJ mol^{-1} and the process still fails. The release must exceed the cost.

Breaking even is not enough. Steps at +10 and −10 kJ mol^{-1} sum to exactly zero. Zero means the coupled process sits at equilibrium, with no net drive either way. Coupling succeeds only when the total is strictly negative.

One Copy May Not Be Enough: Scale the Driver

Copies multiply the contribution. If one run of the driver does not release enough, run it more than once. Each extra copy adds its full ΔG° again.

n copies contribute n × ΔG°(driver)

Count up until the total turns negative. A step P → Q costs +18 kJ mol^{-1}; a driver R → S releases −12 kJ mol^{-1}. One copy gives (+18) + (−12) = +6 kJ mol^{-1}, still unfavorable. Two copies give (+18) + 2(−12) = −6 kJ mol^{-1}, favorable. The minimum is the smallest whole number of copies that makes the sum negative.

The Pair Must Share an Intermediate

Addition on paper is not coupling. Two reactions are not coupled unless they are mechanistically linked. The link is a common intermediate: a species produced by one step and consumed by the other, so it cancels when the step equations are added.

A sequence shows the cancellation.

X → Y, ΔG° = −40 kJ mol^{-1}

Y → Z, ΔG° = +25 kJ mol^{-1}

Y is made by the first step and used up by the second, so the overall equation is X → Z, with ΔG° = (−40) + (+25) = −15 kJ mol^{-1}. The favorable step pulls the unfavorable one forward through the shared Y.

No link, no drive. Reactions with a promising combined ΔG° but no shared species reach their own equilibria separately. The unfavorable reaction is never driven, however negative the sum looks.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

ATP: The Cell's Coupling Agent

One hydrolysis, one standard value. Cells run most coupling through ATP.

$ATP + H_2O \rightarrow ADP + Pi$, $\Delta G^{\circ\prime} = -30.5\ kJ\ mol^{-1}$

The prime marks the biological standard state, pH 7 rather than $[H_3O^+] = 1\ mol\ L^{-1}$, and $\Delta G^{\circ\prime}$ values add exactly as ΔG° values do.

ATP works as an intermediate, not as bottled energy. Hydrolysis drives a biosynthesis when the two reactions share species. The sum decides: glucose phosphorylation at $+13.8\ kJ\ mol^{-1}$ coupled to ATP hydrolysis gives $(+13.8) + (-30.5) = -16.7\ kJ\ mol^{-1}$ and runs.

Other carriers do the same job. Sucrose synthesis from glucose and fructose costs $+23\ kJ\ mol^{-1}$; cells couple it to UTP hydrolysis at $-30.5\ kJ\ mol^{-1}$, giving $-7.5\ kJ\ mol^{-1}$ overall. The carrier changes; the bookkeeping does not.

What Coupling Cannot Change

Each step keeps its own ΔG°. What is new is the overall process, with its own ΔG° and its own K: a negative overall ΔG° means the coupled equilibrium favors the overall products, $K > 1$.

A missing value comes from rearranging the sum. If a coupled pair totals $-12\ kJ\ mol^{-1}$ and the driven step is $+33\ kJ\ mol^{-1}$, the driver must be $(-12) - (+33) = -45\ kJ\ mol^{-1}$.

Coupling says nothing about speed. A coupled process with a negative total can still be extremely slow: free energy fixes direction, not rate. Enzymes speed a coupled process up; they do not supply its driving force, and no catalyst can make an uncoupled unfavorable reaction favorable.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

Worked Examples

Example 1: Glucose phosphorylation, equations and all. Driven step, $\Delta G^{\circ\prime}$ = +13.8 kJ mol^{-1}:

glucose + Pi → glucose-6-phosphate + H_2O

Driver, $\Delta G^{\circ\prime}$ = −30.5 kJ mol^{-1}:

ATP + H_2O → ADP + Pi

Pi is produced by the driver and consumed by the driven step, and H_2O cancels too, leaving:

glucose + ATP → glucose-6-phosphate + ADP

The free energies add: (+13.8) + (−30.5) = −16.7 kJ mol^{-1}. Negative, so the coupled phosphorylation proceeds.

Example 2: How many ATP molecules? A cell must drive the reaction below, $\Delta G^{\circ\prime}$ = +35 kJ mol^{-1}, using ATP hydrolysis at −30.5 kJ mol^{-1} each.

M → N One ATP: (+35) + (−30.5) = +4.5 kJ mol^{-1}, still positive, so one is not enough. Two ATP: (+35) + 2(−30.5) = −26 kJ mol^{-1}. The minimum is 2 ATP per molecule of M converted.

Example 3: Finding the missing driver. A coupled pair totals ΔG° = −12 kJ mol^{-1} and the driven step is +33 kJ mol^{-1}. Rearranging the sum, driver = overall − driven = (−12) − (+33) = −45 kJ mol^{-1}. Check: (+33) + (−45) = −12 kJ mol^{-1}, the stated total.

Example 4: Sucrose synthesis with UTP. Sucrose synthesis costs $\Delta G^{\circ\prime}$ = +23 kJ mol^{-1}. Coupled to UTP hydrolysis at −30.5 kJ mol^{-1}, the total is (+23) + (−30.5) = −7.5 kJ mol^{-1}. Negative, so the coupled synthesis is favorable and its overall equilibrium favors products.

Traps That Cost Marks in Topic 9.7

Adding the magnitudes instead of the signed values. +45 coupled to −80 totals −35 kJ mol^{-1}, not −125. The signs are part of the numbers; drop one and the verdict flips.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

Trusting the driver's sign alone. A negative driver is necessary but not sufficient: +28 with −20 sums to +8 and fails. Compare sizes before concluding.

Calling a zero total favorable. Equal and opposite values cancel to equilibrium. A coupled process at $\Delta G^\circ = 0$ has no net drive toward products.

Claiming the driven step's ΔG° has changed. Coupling changes the overall process only. The unfavorable step keeps its ΔG° and its K; saying otherwise loses the mark.

Forgetting the shared intermediate. A negative sum between two unlinked reactions drives nothing. If no species is shared, there is no coupling, whatever the numbers say.

Forgetting to multiply a repeated driver. Two ATP molecules contribute $2 \times (-30.5) = -61$ kJ mol^{-1}, not −30.5. Scale first, then add.

Key Relationships to Remember

- ΔG°(overall) is the sum of the steps' ΔG° values, signs attached; reverse a step and its ΔG° flips sign, scale a step and its ΔG° scales
- Overall $\Delta G^\circ < 0$: the coupled process is favorable; overall $\Delta G^\circ > 0$: it fails; overall $\Delta G^\circ = 0$: it sits at equilibrium, not driven
- The driver must release more free energy than the driven step requires: $|\Delta G^\circ(\text{driver})| > \Delta G^\circ(\text{driven})$ when one copy of each runs
- n copies of a driver contribute $n \times \Delta G^\circ(\text{driver})$; the minimum useful n is the smallest whole number making the total negative
- Coupling requires a shared intermediate, produced by one step and consumed by the other, cancelling in the overall equation
- ATP hydrolysis, $\Delta G^{\circ\prime} = -30.5$ kJ mol^{-1}, is the cell's standard driver; the prime marks the biological standard state at pH 7
- Coupling changes the overall process only: each step keeps its own ΔG° and K, while the pair has its own K, greater than 1 when the overall ΔG° is negative
- Coupling is thermodynamics, not kinetics: it never speeds a reaction up, and a catalyst can never substitute for it

© 2026 ExamFitter.com · Free AP Chemistry revision notes

Continue Revising

Topic 9.7 Quiz: Coupled Reactions

Topic 9.7 Worksheet

Unit 9: All Topics

© 2026 ExamFitter.com · Free AP Chemistry revision notes