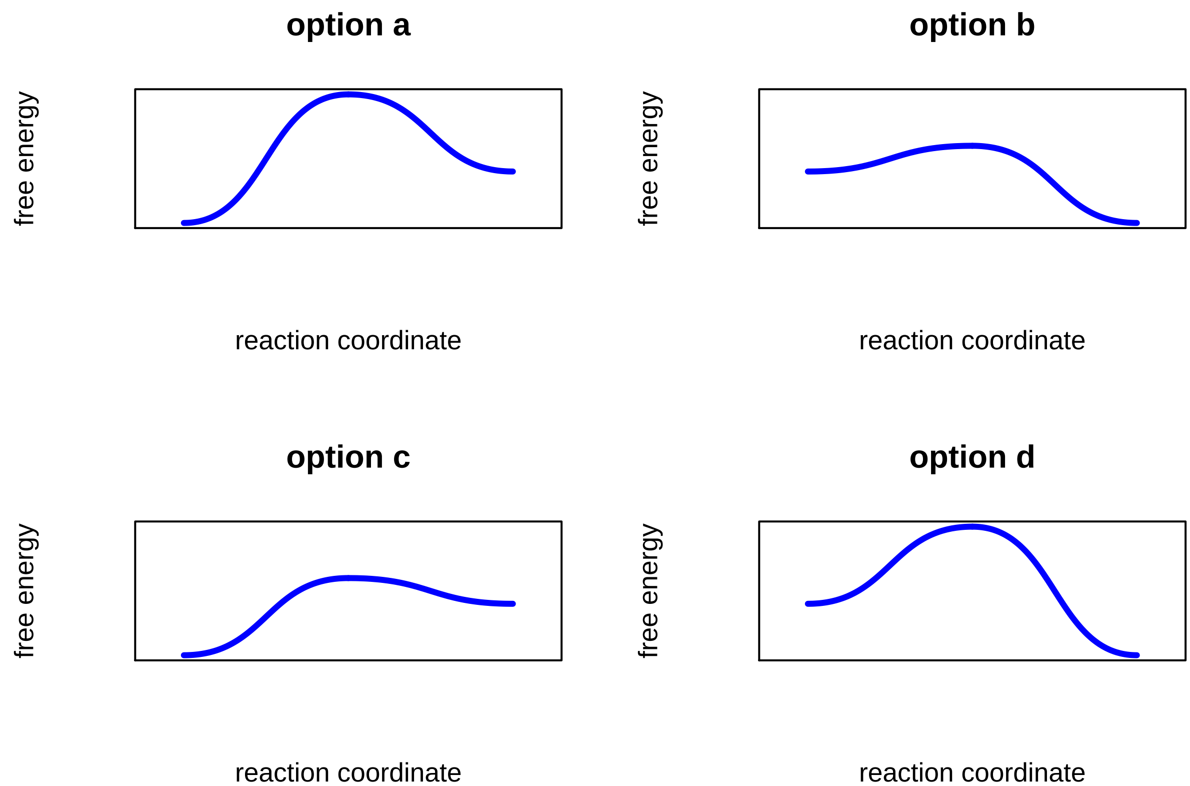
Unit Exam: Thermodynamics

On the following pages are six problems that consider the thermodynamics of chemical or biochemical systems. Read each problem carefully and consider how you will approach it before you put pen or pencil to paper. If you are unsure how to answer a problem, then move on to another; working on a new problem may suggest an approach to the one that is more troublesome. If a problem requires a written response, be sure that you answer in complete sentences and that you directly and clearly address the question. No brain dumps allowed! Generous partial credit is available, but only if you include sufficient work for evaluation and that work is relevant to the question.

Problem	Points	Maximum	Problem	Points	Maximum
1		13	4		24
2		13	5		20
3		13	6		17
			Total		100

A few constants and equations are provided on a separate sheet; other information is included within individual problems. A periodic table also is available.

Figure to Accompany Problem 1



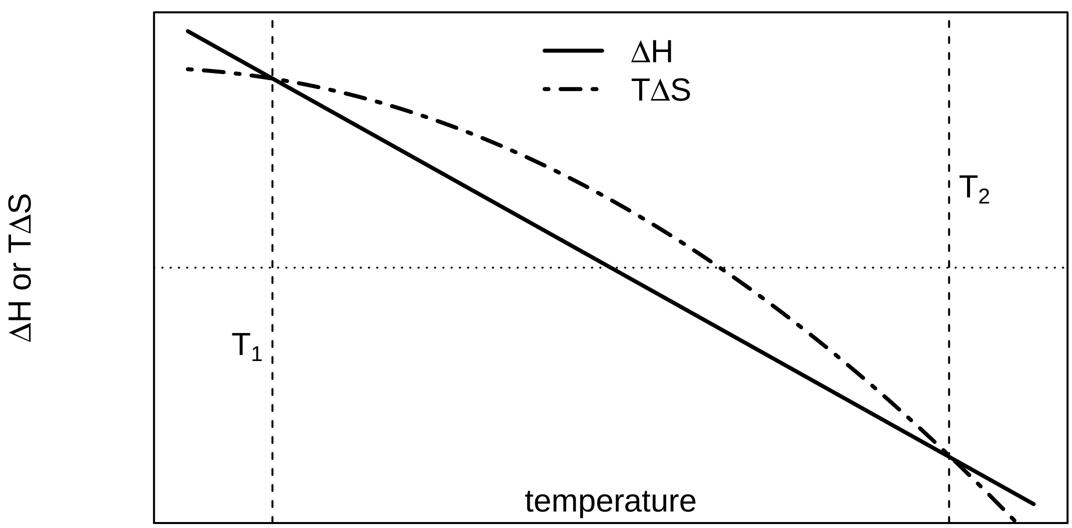
Part A: Three Problems With Short Written Answers and/or With Short Calculations

Problem 1. A supersaturated solution exists when more of a solid is dissolved in solution than is thermodynamically allowed. A supersaturated solution may remain stable for some time, but if a particle of dust falls into the solution, solid will rapidly precipitate. The figure on the exam's cover sheet shows four reaction energy diagrams. Although unmarked, the *y*-axis has the same scale in all four diagrams. One of the diagrams shows the supersaturated solution before the dust particle falls into the solution and one shows the supersaturated solution immediately after the dust particle falls into the solution. Fill in the blanks in the statement below and provide a 1–2 sentence explanation of your reasoning.

Diagram _________ shows the system before the dust particle falls into the solution.

Diagram _________ shows the system immediately after the dust particle falls into the solution.

Problem 2. The folding of a protein from its unfolded state (unfolded $\longrightarrow$ folded) depends on its values for ΔH° and $T\Delta S^\circ$. The figure below shows how ΔH° and $T\Delta S^\circ$ for a typical protein change as a function of temperature. Note that the curves cross each other at temperatures T_1 and T_2. The horizontal dotted line shows where the values of ΔH° and $T\Delta S^\circ$ are zero.



For what temperatures is protein folding favorable? The possible answers are (a) for all $T < T_1$, (b) for all $T > T_1$, (c) for all $T_1 < T < T_2$, (d) for all $T < T_2$, (e) for all $T > T_2$, (f) for all temperatures, and (g) at no temperatures. Enter your choice in the blank below and provide a 1–3 sentence explanation of your reasoning.

Option _________ describes the temperatures for which protein folding is favorable.

Problem 3. Consider the following set of molecules or ions:

$N_2(g)$ $H_2O(l)$ $FeO(s)$ $SO_2(g)$ $Fe_2O_3(s)$ $CH_3COOH(l)$

Arrange these species in order of their entropy, placing the species with the largest entropy on the left and the species with the smallest entropy on the right. Assume you have one mole of each species. Explain how you arrived at this order in 2–3 sentences.

largest > > > > > smallest

Part B: Three Problems With More Involved Calculations

Problem 4. Copper has two common oxide ores: CuO and Cu_2O. Given the following thermodynamic data

species	ΔH_f° (kJ/mol$_{rxn}$)	ΔG_f° (kJ/mol$_{rxn}$)	S° (J/K • mol$_{rxn}$)
$Cu(s)$	0	0	33.3
$CuO(s)$	–155.2	–127.2	43.5
$Cu_2O(s)$	–168.6	–146.0	93.1
$O_2(s)$	0	0	205

and assuming that each species is in its standard state and that the greatest expense in extracting Cu(s) from an ore is the energy needed to heat the oxide, which ore will you choose? The reactions of interest are

$$4\,CuO(s) \longrightarrow 4\,Cu(s) + 2\,O_2(g) \qquad 2\,Cu_2O(s) \longrightarrow 4\,Cu(s) + O_2(g)$$

Clearly state the oxide you will use and any restrictions you must place on temperature so your reaction is thermodynamically favorable. In addition to your calculations, explain the reason for your decision in 2–4 sentences.

Problem 5. One way to determine the specific heat of a metal is to measure the mass of ice that melts when a sample of the metal at a high temperature cools to the temperature of ice. For example, the following data was determined in one experiment:

mass of metal: 4.35 g

initial temperature of metal: 95.7°C

final temperature of metal and ice: 0°C

mass of liquid water collected: 0.316 g

It will help to know that the heat of formation for $H_2O(l)$ is -285.8 kJ/mol$_{rxn}$ and the heat of formation of $H_2O(s)$ is -291.9 kJ/mol$_{rxn}$. What is the specific heat of the metal?

Problem 6. Consider the following set of standard state reduction reactions and potentials for the halogens

halogen	reduction reaction	$E°$ (V)
fluorine	$F_2(g) + 2e^- \longrightarrow 2\,F^-(aq)$	+2.87
chlorine	$Cl_2(g) + 2e^- \longrightarrow 2\,Cl^-(aq)$	+1.36
bromine	$Br_2(l) + 2e^- \longrightarrow 2\,Br^-(aq)$	+1.07
iodine	$I_2(s) + 2e^- \longrightarrow 2\,I^-(aq)$	+0.53

Identify the oxidation-reduction reaction between an elemental form of a halogen, such as $Br_2(l)$, and an anionic form of a halogen, such as $I^-(aq)$, that is the most favorable and determine its value for $\Delta G°$? Clearly identify the reaction by writing it in the general form of $X_2 + 2\,Y^- \longrightarrow 2\,X^- + Y_2$. In addition to your calculations, explain the reason for your decision in 1–2 sentences.