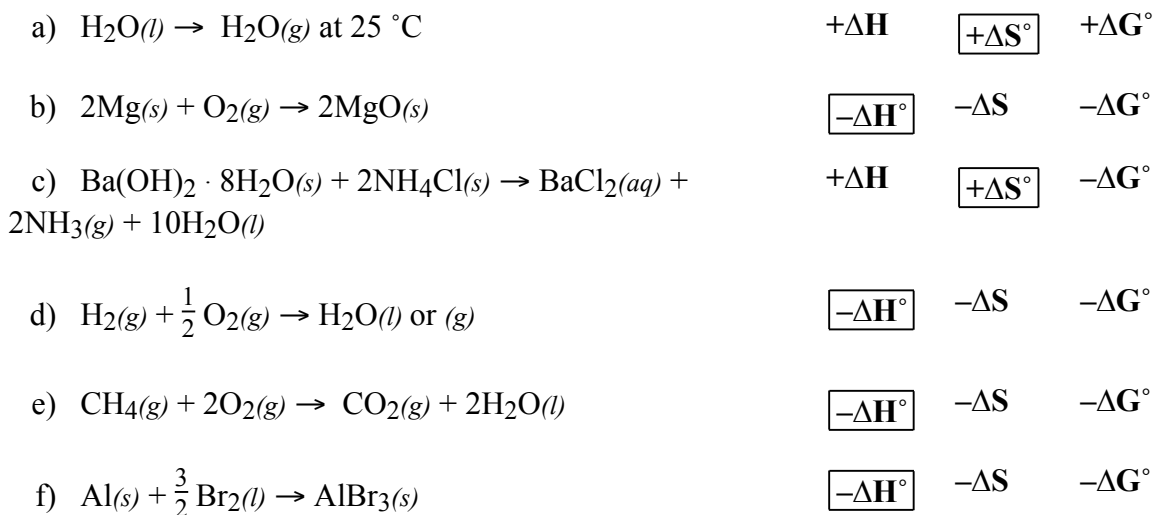


Spontaneity and Free Energy DCI

Name _____ Section _____

1. Summarize the signs (+ or -) of $\Delta H^\circ_{\text{rxn}}$ and $\Delta S^\circ_{\text{rxn}}$ for each of the following reactions (refer to the previous DCI activities on page 91 and 95).



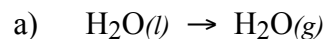
2. Circle which driving forces account for the spontaneity of each of the previous reactions

The driving force has a box around it in Q1.

3. In which reactions do the driving forces oppose each other?

Reaction a), b) c), d), e) and f)

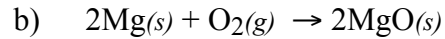
4. The net driving force for a chemical reaction is called the free energy ($\Delta G^\circ_{\text{rxn}}$) for the reaction. It is the energy that is free to drive the reaction rather than oppose another driving force. It can be calculated from free energies of formation (ΔG°_f) in the same way as enthalpies of formation. Calculate ($\Delta G^\circ_{\text{rxn}}$) for the reactions in Q1.



$$\Delta G^\circ_{\text{rxn}} = \sum m \Delta G^\circ_f(\text{products}) - \sum n \Delta G^\circ_f(\text{reactants})$$

$$\Delta G^\circ_{\text{rxn}} = \Delta G^\circ_f(\text{H}_2\text{O}(g)) - \Delta G^\circ_f(\text{H}_2\text{O}(l))$$

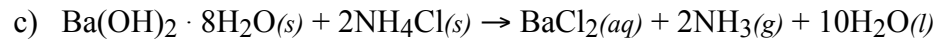
$$\Delta G^\circ_{\text{rxn}} = -229 \text{ kJ mol}^{-1} - (-237 \text{ kJ mol}^{-1}) = +8 \text{ kJ mol}^{-1}$$



$$\Delta G_{\text{rxn}}^{\circ} = \Sigma m \Delta G_{\text{f}}^{\circ}(\text{products}) - \Sigma n \Delta G_{\text{f}}^{\circ}(\text{reactants})$$

$$\Delta G_{\text{rxn}}^{\circ} = 2\Delta G_{\text{f}}^{\circ}(\text{MgO}(s)) - [2\Delta G_{\text{f}}^{\circ}(\text{Mg}(s)) + \Delta G_{\text{f}}^{\circ}(\text{O}_2(g))]$$

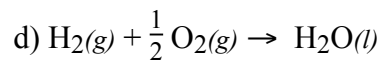
$$\Delta G_{\text{rxn}}^{\circ} = 2 \cdot -569 \text{ kJ mol}^{-1} - [2 \cdot 0 \text{ kJ mol}^{-1} + 0 \text{ kJ mol}^{-1}] = -1038 \text{ kJ mol}^{-1}$$



$$\Delta G_{\text{rxn}}^{\circ} = \Sigma m \Delta G_{\text{f}}^{\circ}(\text{products}) - \Sigma n \Delta G_{\text{f}}^{\circ}(\text{reactants})$$

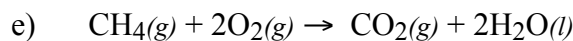
$$\Delta G_{\text{rxn}}^{\circ} = [\Delta G_{\text{f}}^{\circ}(\text{BaCl}_2(aq)) + 2\Delta G_{\text{f}}^{\circ}(\text{NH}_3(g)) + 10\Delta G_{\text{f}}^{\circ}(\text{H}_2\text{O}(l))] - [\Delta G_{\text{f}}^{\circ}(\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(s)) - 2\Delta G_{\text{f}}^{\circ}(\text{NH}_4\text{Cl}(g))]$$

$$\Delta G_{\text{rxn}}^{\circ} = -823 \text{ kJ mol}^{-1} + 2 \cdot -17 \text{ kJ mol}^{-1} + 10 \cdot -237 \text{ kJ mol}^{-1} - [-2793 \text{ kJ mol}^{-1} + 2 \cdot -201 \text{ kJ mol}^{-1}] = -32 \text{ kJ mol}^{-1}$$



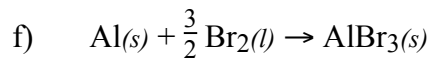
$$\Delta G_{\text{rxn}}^{\circ} = \Sigma(mS^{\circ}(\text{products})) - \Sigma(nS^{\circ}(\text{reactants}))$$

$$\Delta G_{\text{rxn}}^{\circ} = -237 \text{ kJ mol}^{-1}$$



$$\Delta G_{\text{rxn}}^{\circ} = \Sigma(mS^{\circ}(\text{products})) - \Sigma(nS^{\circ}(\text{reactants}))$$

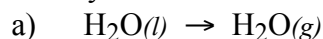
$$\Delta G_{\text{rxn}}^{\circ} = -817 \text{ kJ mol}^{-1}$$



$$\Delta G_{\text{rxn}}^{\circ} = \Sigma(mS^{\circ}(\text{products})) - \Sigma(nS^{\circ}(\text{reactants}))$$

$$\Delta G_{\text{rxn}}^{\circ} = -505 \text{ kJ mol}^{-1}$$

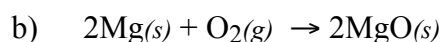
5. Another way to calculate the free energy is to combine the two driving forces of enthalpy and entropy to recognize contribution of each to compensate for any way the oppose each other. The equation for doing this (called the Gibbs free energy equation) is: $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. Calculate the free energy of the equations in Question 1 using this equation, and compare your results with the values you determined from free energies of formation.



$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

$$\Delta G^\circ_{\text{rxn}} = \Delta G^\circ_{\text{f}}(\text{H}_2\text{O}(g)) - \Delta G^\circ_{\text{f}}(\text{H}_2\text{O}(l))$$

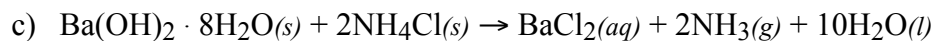
$$\Delta G^\circ_{\text{rxn}} = -229 \text{ kJ mol}^{-1} - (-237 \text{ kJ mol}^{-1}) = +8 \text{ kJ mol}^{-1}$$



$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

$$\Delta G^\circ_{\text{rxn}} = 2\Delta G^\circ_{\text{f}}(\text{MgO}(s)) - [2\Delta G^\circ_{\text{f}}(\text{Mg}(s)) + \Delta G^\circ_{\text{f}}(\text{O}_2(g))]$$

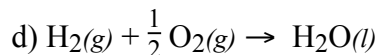
$$\Delta G^\circ_{\text{rxn}} = 2 \cdot -569 \text{ kJ mol}^{-1} - [2 \cdot 0 \text{ kJ mol}^{-1} + 0 \text{ kJ mol}^{-1}] = -1038 \text{ kJ mol}^{-1}$$



$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

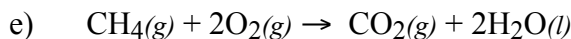
$$\Delta G^\circ_{\text{rxn}} = [\Delta G^\circ_{\text{f}}(\text{BaCl}_2(aq)) + 2\Delta G^\circ_{\text{f}}(\text{NH}_3(g)) + 10\Delta G^\circ_{\text{f}}(\text{H}_2\text{O}(l))] - [\Delta G^\circ_{\text{f}}(\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(s)) + 2\Delta G^\circ_{\text{f}}(\text{NH}_4\text{Cl}(s))]$$

$$\Delta G^\circ_{\text{rxn}} = -823 \text{ kJ mol}^{-1} + 2 \cdot -17 \text{ kJ mol}^{-1} + 10 \cdot -237 \text{ kJ mol}^{-1} - [-2793 \text{ kJ mol}^{-1} + 2 \cdot -201 \text{ kJ mol}^{-1}] = -32 \text{ kJ mol}^{-1}$$



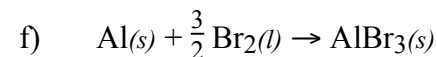
$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

$$\Delta G^\circ_{\text{rxn}} = -237 \text{ kJ mol}^{-1}$$



$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

$$\Delta G^\circ_{\text{rxn}} = -817 \text{ kJ mol}^{-1}$$



$$\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$$

$$\Delta G^\circ_{\text{rxn}} = -505 \text{ kJ mol}^{-1}$$

6. Use your data from question 1 to complete the blank cells for $\Delta G^\circ_{\text{rxn}}$ when the driving forces drive in the same direction. What does the sign for $\Delta G^\circ_{\text{rxn}}$ signify for the spontaneity of the reaction?

Sign of $\Delta H^\circ_{\text{rxn}}$ (25 °C)	Sign of $\Delta S^\circ_{\text{rxn}}$ (25 °C)	Sign of $\Delta G^\circ_{\text{rxn}}$ (25 °C)	Sign of $\Delta G^\circ_{\text{rxn}}$ at high T	Sign of $\Delta G^\circ_{\text{rxn}}$ at low T
-	+	-	-	-
+	-	+	+	+
-	-	- or +	+	-
+	+	+ or -	-	+

7. Predict whether the entropy of the system increases, remains constant or decreases when the following processes occur. Explain your reasoning.
- Ice melts at 0 °C.
 $\text{H}_2\text{O}(s) \rightarrow \text{H}_2\text{O}(l)$ Since the products are more random compared to the reactant, because a liquid phase is more random compared to a solid phase, the phase change leads to greater randomness and ΔS is positive.
 - A precipitate forms in aqueous solution.
 $\text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl}(s)$ The products are less random compared to the reactant, because a solid phase is less random compared to ions dissolved and distributed in water, a precipitation leads to lower randomness and ΔS is negative.
 - A solid dissolves in water.
 $\text{C}_6\text{H}_{12}\text{O}_6(s) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq)$ When a solid dissolves in water the substance is distributed through out the solution so there is much greater randomness when the solid has dissolved compared to the solid phase where particles can not move.
 - A gas condenses to a liquid.
 $\text{N}_2(g) \rightarrow \text{N}_2(l)$ The products are less random compared to the reactant, because a liquid phase is less random compared to the gas phase, the phase change leads to lower randomness and ΔS is negative.

Substance and State	ΔH_f° (kJ/mol)	Substance and State	ΔH_f° (kJ/mol)
C(s) (graphite)	0	HCl(g)	-92.3
C(s) (diamond)	2	HBr(g)	-36.4
CO(g)	-110.5	HI(g)	26.5
CO ₂ (g)	-393.5	I ₂ (g)	62.25
CH ₄ (g)	-75	O ₂ (g)	0
CH ₃ OH(g)	-201	O(g)	249
CH ₃ OH(l)	-239	O ₃ (g)	143
H ₂ CO(g)	-116		
CCl ₄ (l)	-135.4	N ₂ (g)	0
HCOOH(g)	-363	NH ₃ (g)	-46
HCN(g)	135.1	NH ₃ (aq)	-80
CS ₂ (g)	117.4	NH ₄ ⁺ (aq)	-132
CS ₂ (l)	89.7	NH ₄ Cl(s)	-314.4
C ₂ H ₂ (g)	227	N ₂ H ₄ (l)	50.6
C ₂ H ₄ (g)	52	NO(g)	90.25
CH ₃ CHO(g)	-166	NO ₂ (g)	33.18
C ₂ H ₅ OH(l)	-278	N ₂ O(g)	82.0
C ₂ H ₅ O ₂ N(g)	-533	N ₂ O ₄ (g)	9.16
C ₂ H ₆ (g)	-84.7	N ₂ O ₄ (l)	20
C ₃ H ₆ (g)	20.9	HNO ₃ (aq)	-207.36
C ₃ H ₈ (g)	-104	HNO ₃ (l)	-174.10
C ₄ H ₁₀ (g)	-126	NH ₄ ClO ₄ (s)	-295
C ₈ H ₁₈ (l)	-208		
CH ₂ = CHCN(l)	152		
CH ₃ COOH(l)	-484	S ₂ Cl ₂ (g)	-18
C ₆ H ₁₂ O ₆ (s)	-1275	SO ₂ (g)	-296.83
		H ₂ S(g)	-20.6
Cl ₂ (g)	0	SOCl ₂ (g)	-213
Cl ₂ (aq)	-23		
Cl ⁻ (aq)	-167.5	SiCl ₄ (g)	-657
		SiO ₂ (s)	-910.94
H ₂ (g)	0	SiF ₄ (g)	-1614.9
H(g)	217		
H ⁺ (aq)	0	Ba(OH) ₂ ·8H ₂ O(s)	-3342
OH ⁻ (aq)	-230	BaCl ₂ (aq)	-872
H ₂ O(l)	-286	AlBr ₃ (s)	-526
H ₂ O(g)	-242	ZnS(s)	-206