

KEY

Thermodynamics Make-Up Test

1. Which one of the following processes produces an increase in the entropy of the system? Mark all that apply.

- evaporation of liquid hexane into gaseous hexane
 melting solid lead into liquid lead
 dissolution of LiBr(s) in water
 precipitation of AgCl(s) from Ag⁺(aq) and Cl⁻(aq) ions in solution
 mixing of two gases into one container

2. The normal boiling point of water is 100.0 °C and its molar enthalpy of vaporization is 40.67 kJ/mol. What is the change in entropy in the system in J/K when 39.3 grams of steam at 1 atm condenses to a liquid at the normal boiling point?

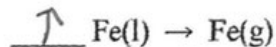
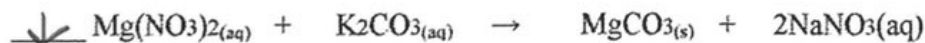
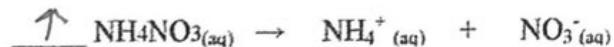
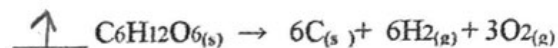
$$\Delta S = \frac{\Delta H}{T} = \frac{40.67 \text{ kJ}}{373 \text{ K}} = .109 \frac{\text{kJ}}{\text{mol} \cdot \text{K}}$$

$$\frac{39.3 \text{ g H}_2\text{O} / 1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O} / 1 \text{ mol} \cdot \text{K}} \cdot .109 \text{ kJ} = .238$$

$$\Delta S = -238 \frac{\text{J}}{\text{K}}$$

3. Indicate whether the entropy increases or decreases in each of the following reactions.

I = increase, D = decrease



4. Given the following table of thermodynamic data,

| Substance | ΔH_f° (kJ/mol) | S° (J/mol·K) |
|--------------------------|-----------------------------|---------------------|
| $\text{PCl}_3(\text{g})$ | -288.07 | 311.7 |
| $\text{PCl}_3(\text{l})$ | -319.6 | 217 |

$$\text{PCl}_3(\text{l}) \rightleftharpoons \text{PCl}_3(\text{g})$$

$$\Delta H = [-288.07] - [-319.6] = (+)$$

$$\Delta S = [311.7] - [217] = (+)$$

complete the following sentence. The vaporization of $\text{PCl}_3(\text{l})$ is _____.

- nonspontaneous at low temperature and spontaneous at high temperature
- spontaneous at low temperature and nonspontaneous at high temperature
- spontaneous at all temperatures
- nonspontaneous at all temperatures
- not enough information given to draw a conclusion

$$\Delta G = \Delta H - T\Delta S$$

$$(+)-(+)(+)$$

$$\downarrow$$

$$(+) (-)$$

5. For the reaction $\text{C}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$

$\Delta H^\circ = 121.3 \text{ kJ/mol}$ and $\Delta S^\circ = 133.6 \text{ J/K}\cdot\text{mol}$ at 298 K. At temperatures greater than _____ °C this reaction is spontaneous under standard conditions.

$$T = \frac{\Delta H}{\Delta S} = \frac{121.3 \text{ kJ/mol}}{0.1336 \text{ kJ/mol}\cdot\text{K}} = 907.9 \text{ K}$$

$$-273$$

$$\underline{635^\circ\text{C}}$$

6. For a given reaction with $\Delta S = -60.6 \text{ J/K}\cdot\text{mol}$, the $\Delta G = 0$ at 355 K. The value of ΔH must be _____ kJ/mol, assuming ΔH and ΔS do not vary with temperature.

$$\Delta H = \Delta G + T\Delta S$$

$$= 0 + (355 \text{ K})(-0.0606 \text{ kJ/mol}\cdot\text{K})$$

$$= -21.5 \text{ kJ/mol}$$

7. If ΔG° for a reaction is greater than zero, then _____.

- $K = 0$ nonspontaneous
- $K > 1$ $\Delta G = (+)$
- $K = 1$ $K < 1$
- $K < 1$
- more information is needed.

8. The equilibrium constant for a reaction is 0.35 at 25°C. What is the value of ΔG° (kJ/mol) at this temperature?

$$\begin{aligned}\Delta G &= -RT \ln K \\ &= (-8.314 \text{ J/mol K})(298 \text{ K})(\ln 0.35) \\ &= 2601 \text{ J/mol} = 2.6 \text{ kJ/mol}\end{aligned}$$

9. True or False The melting of a substance at its melting point is an isothermal process.

10. Which one of the following is always positive when a spontaneous process occurs?

- $\Delta S_{\text{surroundings}}$
- $\Delta H_{\text{universe}}$
- $\Delta H_{\text{surroundings}}$
- $\Delta S_{\text{universe}}$
- ΔS_{system}

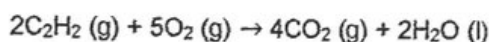
11. Consider a pure crystalline solid that is heated from absolute zero to a temperature above the boiling point of the liquid. Which of the following processes produces the greatest increase in the entropy of the substance?

- vaporizing the liquid
- melting the solid
- heating the gas
- heating the solid
- heating the liquid

12. ΔS is positive for the reaction _____.

- $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
- $\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{O}(\text{s})$
- $\text{CaO}(\text{s}) + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s})$
- $2\text{SO}_3(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g})$
- $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$

13. The combustion of acetylene in the presence of excess oxygen yields carbon dioxide and water:



The value of ΔS° for this reaction is _____ J/K·mol.

Table missing

$$\Delta S = [4(213.6) + 2(69.91)] - [2(200.8) + 5(205.0)]$$
$$944.22 \quad - \quad 1426.6$$
$$-432.38 \text{ J/K}\cdot\text{mol}$$

14. For a given reaction with $\Delta H = -26.2 \text{ kJ/mol}$, the $\Delta G = 0$ at 378 K. The value of ΔS must be _____ J/K·mol, assuming that ΔH and ΔS do not vary with temperature.

Remove this or #6 - too similar

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta H = T\Delta S$$

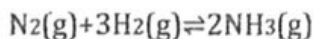
$$\Delta S = \frac{\Delta H}{T} = \frac{-26.2 \text{ kJ/mol}}{378} = -.0693$$
$$-69.3 \text{ J/mol}\cdot\text{K}$$

15. For the reaction $\text{C}_2\text{H}_6(\text{g}) \rightarrow \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g})$

ΔH° is +137 kJ/mol and ΔS° is +120 J/K·mol. This reaction is _____.

- spontaneous only at high temperature
- nonspontaneous at all temperatures
- spontaneous at all temperatures
- spontaneous only at low temperature

16. The equilibrium constant for the following reaction is 3.5×10^8 at 25°C .



The value of ΔG° for this reaction is _____ kJ/mol.

$$\begin{aligned} \Delta G &= -RT \ln K \\ &= (-8.314)(298)(\ln 3.5 \times 10^8) \\ &= -48742 \\ &= -49 \text{ kJ/mol} \end{aligned}$$

17. $\text{NaNO}_3(\text{s}) \rightarrow \text{Na}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$

In a coffee cup calorimeter, 1.35 grams of solid NaNO_3 is mixed with 65.00 grams of water at an initial temperature of 25.00°C . After dissolution of the salt, the final temperature of the calorimeter contents is 22.34°C . Assuming the solution has the same specific heat capacity as water and assuming no heat is lost to the calorimeter, calculate the enthalpy change for the dissolution of NaNO_3 in units of kJ/mol.

$$q = mc\Delta T = (66.35\text{g})(4.184\text{J/g}^\circ\text{C})(2.66^\circ\text{C}) = 738\text{J}$$

absorbed
by rxn

$$\frac{738\text{J}}{1.35\text{g NaNO}_3} \times \frac{85.00\text{g NaNO}_3}{1 \text{ mol NaNO}_3} \times \frac{1 \text{ kJ}}{1000\text{J}} = 46.5 \text{ kJ/mol}$$

$$\Delta H = +46.5 \text{ kJ/mol}$$

65.00
1.35
66.35g

25.00
- 22.34
2.66

endo. process

18. The value of ΔE for a system that performs 114 kJ of work on its surroundings and gains 66 kJ of heat is _____ kJ.

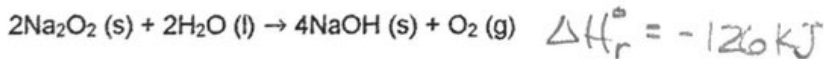
$$\Delta E = q + w = +66 + (-114 \text{ kJ}) = -48 \text{ kJ}$$

19. Calculate the work (kJ) done during a reaction in which the internal volume expands from 13 L to 48 L against an outside pressure of 4.6 atm.

work done on the surr $w = (-)$

$$w = -P\Delta V = (-4.6 \text{ atm})(35 \text{ L}) = -161 \text{ L}\cdot\text{atm} \times \frac{101.3 \text{ J}}{1 \text{ L}\cdot\text{atm}} = -16300 \text{ J} = -163 \text{ kJ}$$

20. The value of ΔH° for the reaction below is -126 kJ. The amount of heat that is released by the reaction of 40.0 g of Na_2O_2 with water is _____ kJ.



$$\frac{40.0\text{g Na}_2\text{O}_2}{1} \times \frac{1 \text{ mol Na}_2\text{O}_2}{77.98\text{g Na}_2\text{O}_2} \times \frac{-126 \text{ kJ}}{2 \text{ mol Na}_2\text{O}_2} = 32.3 \text{ kJ heat released}$$

Remove this or #8 similar

21. A sample of aluminum metal absorbs 12.5 J of heat, upon which the temperature of the sample increases from 23.2 °C to 30.5 °C. Since the specific heat capacity of aluminum is 0.90 J/g-K, the mass of the sample is _____ g.

$$q_r = mc\Delta T$$

$$m = \frac{q_r}{c\Delta T} = \frac{12.5 \text{ J}}{(0.90 \text{ J/gK})(7.3 \text{ K})} = 1.9 \text{ g}$$

22. A 4.50-g sample of copper metal at 25.0 °C is heated by the addition of 165 J of energy. The final temperature of the copper is _____ °C. The specific heat capacity of copper is 0.38 J/g-K.

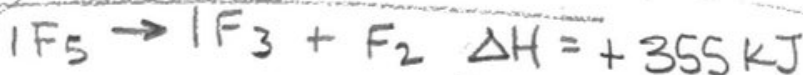
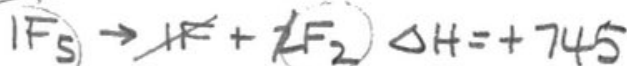
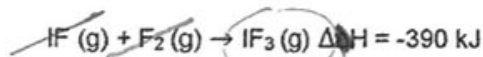
$$q_r = mc\Delta T$$

$$\Delta T = \frac{q_r}{mc} = \frac{165 \text{ J}}{(4.50 \text{ g})(0.38 \text{ J/gK})} = 96.5 \text{ K} = 96.5 \text{ }^\circ\text{C}$$

$$T_i + \Delta T = T_f$$

$$25.0 \text{ }^\circ\text{C} + 96.5 \text{ }^\circ\text{C} = 121.5 \text{ }^\circ\text{C}$$

23. Calculate ΔH for the reaction $\text{IF}_5(\text{g}) \rightarrow \text{IF}_3(\text{g}) + \text{F}_2(\text{g})$ given the data below:



24. For which one of the following reactions is $\Delta H^\circ_{\text{rxn}}$ equal to the heat of formation of the product? Mark all that apply.

- $\text{P}(\text{g}) + 4\text{H}(\text{g}) + \text{Br}(\text{g}) \rightarrow \text{PH}_4\text{Br}(\text{l})$
- $(1/2)\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{NO}_2(\text{g})$
- $12\text{C}(\text{g}) + 11\text{H}_2(\text{g}) + 11\text{O}(\text{g}) \rightarrow \text{C}_6\text{H}_{22}\text{O}_{11}(\text{g})$
- $6\text{C}(\text{s}) + 6\text{H}(\text{g}) \rightarrow \text{C}_6\text{H}_6(\text{l})$
- $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$

25. Consider the reaction: $\text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \rightarrow \text{NH}_4\text{Cl}(\text{s})$

Given the following table of thermodynamic data at 298 K:

| Substance | ΔH_f° (kJ/mol) | S° (J/K·mol) |
|----------------------------------|-----------------------------|---------------------|
| $\text{NH}_3(\text{g})$ | -46.19 | 192.5 |
| $\text{HCl}(\text{g})$ | -92.30 | 186.69 |
| $\text{NH}_4\text{Cl}(\text{s})$ | -314.4 | 94.6 |

The value of K for the reaction at 25 °C is _____.

$$\Delta H = [-314.4] - [-46.19 - 92.30] = -175.51 \text{ kJ}$$

$$\Delta S = [94.6] - [192.5 + 186.69] = -284.59 \text{ J} = -0.285 \text{ kJ}$$

$$\Delta G = -175.51 - (298)(-0.285) = -90.58 \text{ kJ}$$

$$\Delta G = -RT \ln K$$

$$\ln K = \frac{-90580 \text{ J/mol}}{(-8.314 \text{ J/mol}\cdot\text{K})(298 \text{ K})} = 36.6$$

$$K = 7.55 \times 10^{15}$$