

Thermodynamics

AP Problems

Practice Exercises

Multiple-Choice

For the first four problems below, one or more of the following responses will apply; each response may be used more than once or not at all in these questions.

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| I. ΔG° | 2. Which of these cannot be determined? |
| II. ΔS° | (A) I and III |
| III. ΔH° | (B) II |
| IV. ΔG | (C) I, II, and IV |
| V. H | (D) I, III, and IV |
| 1. Which of these must be negative for a reaction to be spontaneous? | (E) V |
| (A) I | 3. Which of these are extensive values? |
| (B) III | (A) I and III |
| (C) I, II, and IV | (B) II |
| (D) IV | (C) I, II, and IV |
| (E) I, III, and V | (D) IV, and V |
| | (E) I, III, and V |

4. If _____ is negative and _____ is positive, a reaction will never be spontaneous.
- (A) II, III
(B) III, IV
(C) I, II
(D) IV, III
(E) I, V
5. When 0.400 g of CH_4 is burned in excess oxygen in a bomb calorimeter that has a heat capacity of $3245 \text{ J } ^\circ\text{C}^{-1}$, a temperature increase of 6.795°C is observed. What is the value of q_v ?
- (A) 220 kJ mol^{-1}
(B) -882 kJ
(C) 477 kJ
(D) -22.05 kJ
(E) 8.820 kJ g^{-1}
6. Using the data in question 1, determine ΔH° for the combustion of methane.
- (A) $-22.05 \text{ kJ mol}^{-1}$
(B) -882 kJ
(C) $+22.05 \text{ kJ}$
(D) -8.820 kJ g^{-1}
(E) This value cannot be determined because w is not known.
7. Which of the following describes a system that CANNOT be spontaneous?
- (A) ΔH° is positive, and ΔS° is negative.
(B) ΔH° is positive, and ΔS° is positive.
(C) ΔH° is negative, and ΔS° is negative.
(D) ΔH° is negative, and ΔS° is positive.
(E) ΔH° is 0.00, and ΔS° is positive.
8. Which of the following explains the fact that, when KCl is dissolved, water condenses on the outside of the beaker?
- (A) ΔH° is positive, and ΔS° is negative.
(B) ΔH° is positive, and ΔS° is positive.
(C) ΔH° is negative, and ΔS° is negative.
(D) ΔH° is negative, and ΔS° is positive.
(E) ΔH° is 0.00, and ΔS° is negative.
9. The reaction with the greatest expected entropy decrease is
- (A) $\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)$
(B) $\text{CH}_4(\ell) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)$
(C) $\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(\ell)$
(D) $\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(s) + 2\text{H}_2\text{O}(g)$
(E) $\text{CH}_4(\ell) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(\ell)$
10. Water boils at 100°C with a molar heat of vaporization of $+43.9 \text{ kJ}$. What is the entropy change when
- $$\text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(\ell)$$
- at 100°C ?
- (A) Problem cannot be solved; ΔG° must also be known.
(B) Problem cannot be solved; this is not a chemical reaction.
(C) -439 J K^{-1}
(D) $+0.439 \text{ J K}^{-1}$
(E) -118 J K^{-1}

11. The Dulong and Petit law says that the molar specific heat of solid elements is approximately $25 \text{ J mol}^{-1} \text{ K}^{-1}$. This suggests that
- the heat absorbed depends only on the number of atoms
 - the heat absorbed depends on the volume change with temperature
 - the heat absorbed can be calculated from the first law of thermodynamics
 - potential energy and heat energy are inversely related
 - This law is an oddity since it does not apply to elements that are liquids or gases.
12. A gas is allowed to expand from an initial volume of 5.00 L and pressure of 3.00 atm to a volume of 15.0 L and pressure of 1.00 atm. What is the value of w ?
- +30.0 L atm
 - +10.0 L atm
 - 45.0 L atm
 - +15.0 L atm
 - 10.0 L atm
13. In question 8 the units of work are given as L atm. To convert L atm to the metric unit of joules, we need to know
- Avogadro's constant and Planck's constant
 - the universal gas law constant in units of $\text{L atm mol}^{-1} \text{ K}^{-1}$
 - the universal gas law constant in units of $\text{J mol}^{-1} \text{ K}^{-1}$
 - both B and C
 - A, B, and C
14. Which of the following is the LEAST probable for a combustion reaction?
- ΔG° is a large negative number.
 - ΔS° is a large negative number.
 - ΔH° is a large negative number.
 - K_{eq} is a large positive number.
 - Q , the reaction quotient, is a small number.
15. Of the following, which can be precisely determined for a chemical substance?
- entropy, S
 - enthalpy, H
 - free energy, G
 - internal energy, E
 - all of these
16. The heat of formation of $\text{CH}_3\text{OH}(\ell) = -238.6 \text{ kJ mol}^{-1}$, of $\text{CO}_2(\text{g}) = -393.5 \text{ kJ mol}^{-1}$, and of $\text{H}_2\text{O}(\text{g}) = -241.8 \text{ kJ mol}^{-1}$. What is ΔH° for the heat of combustion of methanol?
- 396.7 kJ
 - 1277 kJ
 - 638.5 kJ
 - +396.7 kJ
 - This value cannot be calculated without the heat of formation for $\text{O}_2(\text{g})$.
17. The rate of reaction will be large if
- ΔG° is a large negative number
 - ΔS° is a large negative number
 - ΔH° is a large negative number
 - K_{eq} is a large positive number
 - None of the above can be used to estimate reaction rates.

18. Given the following thermochemical data:



determine the heat of the reaction



- (A) 171.07 kJ
 (B) -55.21 kJ
 (C) -171.07 kJ
 (D) +55.21 kJ
 (E) -85.54 kJ
19. Which of the following can change the value of ΔG° for a chemical reaction?
- (A) changes in the total pressure
 (B) changes in the pressures of the reactants
 (C) changes in the concentrations of the reactants
 (D) changes in the temperature in $^\circ\text{C}$
 (E) the presence of a catalyst
20. At what temperature is $K_{\text{eq}} = 1.00$ if $\Delta S^\circ = 22.6 \text{ J K}^{-1}$ and $\Delta H^\circ = 15.3 \text{ kJ}$ for a chemical reaction?
- (A) 404°C
 (B) 677°C
 (C) 0.67°C
 (D) 1477°C
 (E) 1204°C
21. The standard heat of formation of $\text{SO}_3(g)$ is -396 kJ mol^{-1} . The standard entropies of $\text{S}(s)$, $\text{O}_2(g)$, and $\text{SO}_3(g)$ are 31.8, 205.0, and $256 \text{ J mol}^{-1} \text{ K}^{-1}$, respectively. Calculate the free energy for the decomposition of SO_3 in the reaction
- $$2\text{SO}_3(g) \rightarrow 2\text{S}(s) + 3\text{O}_2(g)$$
- at 25°C .
- (A) +396 kJ
 (B) -446 kJ
 (C) +346 kJ
 (D) -346 kJ
 (E) +742 kJ
22. The reaction
- $$2\text{C}_6\text{H}_6(\ell) + 15\text{O}_2(g) \rightarrow 12\text{CO}_2(g) + 6\text{H}_2\text{O}(\ell)$$
- is expected to have
- (A) a positive ΔH and a negative ΔS
 (B) a negative ΔH and a negative ΔS
 (C) a positive ΔH and a positive ΔS
 (D) a negative ΔH and a negative ΔS
 (E) These predictions cannot be made.

23. The evaporation of any liquid is expected to have
- (A) a positive ΔH and a negative ΔS
 - (B) a negative ΔH and a negative ΔS
 - (C) a positive ΔH and a positive ΔS
 - (D) a positive ΔH and a negative ΔS
 - (E) These predictions cannot be made.
24. Which of the following is most likely to be true?
- (A) No products are formed in a nonspontaneous reaction.
 - (B) A positive ΔG° indicates a spontaneous reaction.
 - (C) A positive ΔS° always means that the reaction is spontaneous.
 - (D) A spontaneous reaction always goes to completion.
 - (E) Combustion of organic compounds has a negative ΔH° .

See Appendix 1 for explanations of answers.

Free-Response

Answer the following questions using the concepts of thermodynamics and equilibrium and the methods for solving problems.

- (a) What parameters define whether or not a given reaction is spontaneous? Based on those parameters, what does it mean to say a reaction is spontaneous?
- (b) What is the difference between E , ΔE , and ΔE° ?
- (c) Tables of thermodynamic data list heat of formation, ΔH_f° , standard free energy, ΔG_{298}° , and entropy, S° . Why don't entropy values have a delta symbol, Δ ? What other difference does a table of entropy values have?

(d) The value of K_c for the reaction $2\text{NO} + \text{O}_2 \rightleftharpoons \text{N}_2\text{O}_4$ is 36 at a certain temperature. Calculate K for the following reactions.

