**Name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**AP Chemistry**

**Thermodynamics Practice Problems**

**Multiple Choice**

*Identify the letter of the choice that best completes the statement or answers the question.. You may refer to your formula sheet and periodic table. Calculator use is not permitted for MC.*

\_\_\_\_ 1.

3 C2H2*(g)*  C6H6*(g)*

What is the standard enthalpy change, *H*°, for the reaction represented above? (*H*°*f* of C2H2*(g)* is 230 kJ mol-1; *H*°*f* of C6H6*(g)* is 83 kJ mol-1.)

|  |  |  |  |
| --- | --- | --- | --- |
| a. | –607 kJ | c. | –19 kJ |
| b. | –147 kJ | d. | +19 kJ |

\_\_\_\_ 2.

*X(s)*  *X(l)*

Which of the following is true for any substance undergoing the process represented above at its normal melting point?

|  |  |  |  |
| --- | --- | --- | --- |
| a. | *S* < 0 | c. | *H* = *T**S* |
| b. | *H* = 0 | d. | *T**S* = 0 |

\_\_\_\_ 3. N2*(g)* + 3 H2*(g)*  2 NH3*(g)*

The reaction indicated above is thermodynamically spontaneous (favorable) at 298 K, but becomes nonspontaneous (not thermodynamically favorable) at higher temperatures. Which of the following is true at 298 K?

|  |  |
| --- | --- |
| a. | *G*,*H*, and *S* are all positive. |
| b. | *G*, *H*. and *S* are all negative. |
| c. | *G* and *H* are negative, but *S* is positive. |
| d. | *G* and *S* are negative, but *H* is positive. |

\_\_\_\_ 4. Which of the following must be true for a reaction that proceeds spontaneously (i.e., is thermodynamically favorable) from initial standard state conditions?

|  |  |  |  |
| --- | --- | --- | --- |
| a. | *G* > 0 and Keq > 1 | c. | *G* < 0 and Keq > 1 |
| b. | *G* > 0 and Keq < 1 | d. | *G* < 0 and Keq < 1 |

\_\_\_\_ 5. One statement of the first law of thermodynamics is that

|  |  |
| --- | --- |
| a. | the amount of work done on a system is dependent of pathway. |
| b. | the total work done on a system must equal the heat absorbed by the system. |
| c. | the heat flow in or out of a system is independent of pathway. |
| d. | the total energy flow in or out of a system is equal to the sum of the heat transferred to or from the system and the work done by or on the system. |

\_\_\_\_ 6. Calculate *E* for the system in which 16 J of work is done on a gas by the surroundings and the gas absorbs 51 J of heat?

|  |  |  |  |
| --- | --- | --- | --- |
| a. | -67 J | c. | +35 J |
| b. | -35 J | d. | +67 J |

\_\_\_\_ 7. Calculate *E* for the system in which a gas absorbs 31 J of heat and does 18 J of work on the surroundings?

|  |  |  |  |
| --- | --- | --- | --- |
| a. | -49 J | c. | +13 J |
| b. | -13 J | d. | +31 J |

\_\_\_\_ 8. All of the following statements concerning entropy are true EXCEPT

|  |  |
| --- | --- |
| a. | entropy values for substances are greater than or equal to zero. |
| b. | entropy is a state function. |
| c. | a positive change in entropy denotes a change toward greater disorder. |
| d. | entropy is zero for elements under standard conditions. |

\_\_\_\_ 9. Predict the signs of *H* and *S* for the condensation of steam at 85 C.

|  |  |  |  |
| --- | --- | --- | --- |
| a. | *H* < 0 and *S* < 0 | c. | *H* > 0 and *S* < 0 |
| b. | *H* < 0 and *S* > 0 | d. | *H* > 0 and *S* > 0 |

\_\_\_\_ 10. Thermodynamics can be used to determine all of the following EXCEPT

|  |  |
| --- | --- |
| a. | the rate of reaction. |
| b. | the extent to which a reaction occurs. |
| c. | the direction in which a reaction is spontaneous. |
| d. | the temperature at which a reaction is spontaneous. |

\_\_\_\_ 11. H2*(g)* +  O2*(g)*  H2O*(l)* Hf = x

2 Na*(s)* +  O2*(g)*  Na2O*(s)* Hf = y

Na*(s)* + O2*(g)* +  H2*(g)*  NaOH*(s)* Hf = z

Based on the information above, what is the standard enthalpy change for the following reaction?

Na2O*(s)* + H2O*(l)*  2 NaOH*(s)*

|  |  |  |  |
| --- | --- | --- | --- |
| a. | x + y + z | c. | x + y – 2z |
| b. | x + y – z | d. | 2z – x – y |

\_\_\_\_ 12. 125 g of copper forms a welded layer on the bottom of a skillet. Which of the following correctly calculates the amount of heat in kJ needed to raise the temperature of the copper layer from 25oC to 300oC? The specific heat of copper is 0.387 J/g K.

|  |  |  |  |
| --- | --- | --- | --- |
| a. | (125)(0.387)(275)/1000 | c. | (125)(0.387)(300)/1000 |
| b. | (125)(0.387)(25)/1000 | d. | (125)(0.387)(25)(300)/1000 |

**Free Response Questions**

**Show all your work. You may refer to your formula sheet and periodic table. Keep your calculator handy!**

13. **2001 B**

2 NO*(g)* + O2*(g)*  2 NO2*(g)*

*H*°= -114.1 kJ, *S*°= -146.5 J K-1

The reaction represented above is one that contributes significantly to the formation of photochemical smog.

(a) Calculate the quantity of heat released when 73.1 g of NO*(g)* is converted to NO2*(g)*.

(b) For the reaction at 25C, the value of the standard free-energy change, *G*, is -70.4 kJ.

(i) Calculate the value of the equilibrium constant, *Keq*, for the reaction at 25C.

(ii) Indicate whether the value of *G* would become more negative, less negative, or remain unchanged as the temperature is increased. Justify your answer.

(c) Use the data in the table below to calculate the value of the standard molar entropy, S, for O2*(g)* at 25C.

|  |  |
| --- | --- |
|  | Standard Molar Entropy, *S* (J K-1 mol-1) |
| NO*(g)* | 210.8 |
| NO2*(g)* | 240.1 |

14. Answer the following questions using the information related to reactions X, Y, and Z in the table below. (2009A)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reaction | Equation |  |  |  |
| X | C(*s*) + H2O(*g*) CO(*g*) + H2(*g*) | +131 kJ mol-1 | +134 J mol-1 K-1 | +91 kJ mol-1 |
| Y | CO2(*g*) + H2(*g*) CO(*g*) + H2O(*g*) | +41 kJ mol-1 | +42 J mol-1 K-1 | +29 kJ mol-1 |
| Z | 2 CO(*g*) C(*s*) + CO2(*g*) | ? | ? | ? |

(a) For reaction X, write the expression for the equilibrium constant, *Kp*. (1 pt)

(b) For reaction X, will the equilibrium constant, *Kp*, increase, decrease, or remain the same if the temperature rises above 298 K ? Justify your answer. (1 pt)

(c) For reaction Y at 298 K, is the value of *Kp* greater than 1, less than 1, or equal to 1? Justify your answer. (1 pt)

(d) For reaction Y at 298 K, which is larger: the total bond energy of the reactants or the total bond energy of the products? Explain. (1 pt)

(e) Is the following statement true or false? Justify your answer.

“On the basis of the data in the table, it can be predicted that reaction Y will occur more rapidly than reaction X will occur.”

(f) Consider reaction Z at 298 K.

(i) Is *S*° for the reaction positive, negative, or zero? Justify your answer. (1 pt)

(ii) Determine the value of *H* ° for the reaction. (1 pt)

(iii) A sealed glass reaction vessel contains only CO(*g*) and a small amount of C(*s*). If a reaction occurs and the temperature is held constant at 298 K, will the pressure in the reaction vessel increase, decrease, or remain the same over time? Explain. (1 pt)

**Thermodynamics Practice Problems**

**Answer Section**

**MULTIPLE CHOICE**

1. ANS: A PTS: 1

2. ANS: C PTS: 1

3. ANS: B PTS: 1

4. ANS: C PTS: 1

5. ANS: D PTS: 1 OBJ: 6.4 The First Law of Thermodynamics

6. ANS: D PTS: 1 OBJ: 6.4 The First Law of Thermodynamics

7. ANS: C PTS: 1 OBJ: 6.4 The First Law of Thermodynamics

8. ANS: D PTS: 1 OBJ: 19.4 Entropy and the Second Law of Thermodynamics

9. ANS: A PTS: 1 OBJ: 19.6 Gibbs Free Energy

10. ANS: A PTS: 1 OBJ: 19.7 G | K | and Product Favorability

11. ANS: D PTS: 1

12. ANS: A PTS: 1

**PROBLEM**

13. ANS:

(a) 73.1 g   = 139 kJ

(b) (i) *Keq* = e–*G*/RT = e–(–70400/(8.31)(298)) = 2.221012

(ii) less negative; *G* = *H* – T*S*; as temperature increases, –T*S* becomes a larger positive value causing an increase in *G* (less negative).

(c) *S* = *S*(products) – *S*(reactants)

-146.5 = [(2)(240.1)] – [(210.8)(2)+ *S*oxygen] J/K

*S*oxygen = +205.1 J/K

PTS: 1

14. ANS:

*Kp =* 

*Kp* will increase.

If the temperature is increased for an endothermic reaction *(* 298 *H* Ä .. = +131 kJ mol-1), then by Le Chatelier’s principle the reaction will shift towardproducts, thereby absorbing energy. With greater concentrations of products at equilibrium, the value of *Kp* will increase.

**OR**

Because *G* Ä ..= - *RT* ln *Kp* = 298 *H* Ä .. - *T* 298 *S* Ä .. , then ln *Kp* = - 298 *HRT*

An increase in *T* for a positive 298 *H* Ä .. results in an increase in ln *Kp* and thus an increase in *Kp* .

c *Kp* for reaction Y is less than 1. For reaction Y, 298 *G* Ä .. = +29 kJ mol-1, a positive number. Because .. *G* Ä = - *RT* ln *K* and .. *G* Ä is positive, then ln *Kp* must be negative. This is true when *Kp* is less than 1.

**OR**

A positive .. *G* Ä results in a nonspontaneous reaction under standard conditions. This favors reactants over products as equilibrium is approached starting from standard conditions,

resulting in a *Kp* less than 1.

d) The total bond energy of the reactants is larger. Reaction Y is endothermic ( 298 *H* Ä .. = + 41 kJ mol-1 > 0), so there is a net input of energy as the reaction occurs. Thus, the total energy required to break the bonds in the reactants must be greater the total energy released when the bonds are formed in the products.

e) The statement is false. Thermodynamic data for an overall reaction have no bearing on how slowly or rapidly the reaction occurs.

f) i) Ä*S*° for reaction Z is negative.

In reaction Z, two moles of gas with relatively high entropy

are converted into one mole of solid and one mole of gas, a net

loss of one mole of gas and thus a net loss in entropy.

**OR**

Reaction Z can be obtained by reversing reactions X and Y and adding them together. Thus Ä*S*° for reaction Z is the sum

of two negative numbers and must itself be negative.

ii) dd the values of the negatives of 298 *H* Ä .. for reactions X and Y :

-131 kJ mol-1 + (-41 kJ mol-1) = -**172 kJ mol**-

iii) The pressure in the flask decreases.The reaction would proceed to the right, forming more C(*s*) and CO2(*g*). Because two moles of CO(*g*) would be consumed for every mole of CO2(*g*) that is produced, the total number of moles of gas in the flask would decrease, thereby causing the pressure in the flask to decrease.

PTS: 1