This print-out should have 37 questions. Multiple-choice questions may continue on the next column or page—find all choices before answering.

001 10.0 points
Calculate the equilibrium constant at 25°C for a reaction for which \( \Delta G^0 = -4.85 \) kcal/mol.

1. 3592.86
2. 7185.72
3. 1796.43
4. -3592.86
5. 35928.6

002 10.0 points
The standard molar Gibbs free energy of formation of NO\(_2\) (g) at 298 K is 51.30 kJ \cdot mol^{-1} and that of N\(_2\)O\(_4\) (g) is 97.82 kJ \cdot mol^{-1}. What is the equilibrium constant at 25°C for the reaction

\[
2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)
\]

1. None of these
2. 0.657
3. 9.72 \times 10^9
4. 7.01 \times 10^{-9}
5. 1.02 \times 10^{-10}
6. 0.145
7. 1.00
8. 6.88

003 10.0 points
The reaction

A + B ⇌ C + 2D

has an equilibrium constant of \( 3.7 \times 10^{-3} \). Consider a reaction mixture with

\[
[A] = 2.0 \times 10^{-2} \text{ M} \quad [C] = 2.4 \times 10^{-6} \text{ M}
[B] = 1.7 \times 10^{-4} \text{ M} \quad [D] = 3.5 \times 10^{-3} \text{ M}
\]

Which of the following statements is definitely true?

1. The forward reaction can occur to a greater extent than the reverse reaction until equilibrium is established.
2. Heat will be evolved.
3. No conclusions about the system can be made without additional information.
4. The system is at equilibrium.
5. The reverse reaction can occur to a greater extent than the forward reaction until equilibrium is established.

004 10.0 points
The reaction

\[
\text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g)
\]

has an equilibrium constant of \( 4.0 \times 10^8 \) at 25°C. What will eventually happen if 44.0 moles of NH\(_3\), 0.452 moles of N\(_2\), and 0.108 moles of H\(_2\) are put in a 10.0 liter container at 25°C?

1. More NH\(_3\) will be formed.
2. More N\(_2\) and H\(_2\) will be formed.
3. Nothing; the system is at equilibrium.

005 10.0 points
\( K_c = 2.6 \times 10^8 \) at 825 K for the reaction

\[
2\text{H}_2(\text{g}) + \text{S}_2(\text{g}) \rightleftharpoons 2\text{H}_2\text{S}(\text{g})
\]

The equilibrium concentration of H\(_2\) is 0.0020 M and that of S\(_2\) is 0.0010 M. What is the equilibrium concentration of H\(_2\)S?

1. 10 M
2. 1.02 M
3. 0.10 M
4. 0.0010 M

Suppose the reaction

\[ \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2 \text{HI}(\text{g}) \]

has an equilibrium constant \( K_c = 49 \) and the initial concentration of \( \text{H}_2 \) and \( \text{I}_2 \) is 0.5 M and \( \text{HI} \) is 0.0 M. Which of the following is the correct value for the final concentration of \( \text{HI}(\text{g}) \)?

1. 0.389 M
2. 0.219 M
3. 0.778 M
4. 0.250 M
5. 0.599 M

The system

\[ \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2 \text{HI}(\text{g}) \]

is at equilibrium at a fixed temperature with a partial pressure of \( \text{H}_2 \) of 0.200 atm, a partial pressure of \( \text{I}_2 \) of 0.200 atm, and a partial pressure of \( \text{HI} \) of 0.100 atm. An additional 0.32 atm pressure of \( \text{HI} \) is admitted to the container, and it is allowed to come to equilibrium again. What is the new partial pressure of \( \text{HI} \)?

Answer in units of atm

Consider the reaction

\[ \text{Ni(CO)}_4(\text{g}) \rightarrow \text{Ni(s)} + 4 \text{CO}(\text{g}) \]

If the initial concentration of \( \text{Ni(CO)}_4(\text{g}) \) is 1.0 M, and \( x \) is the equilibrium concentration of \( \text{CO}(\text{g}) \), what is the correct equilibrium relation?

1. \( K_c = \frac{x}{1.0 - \frac{x}{4}} \)
2. \( K_c = \frac{x^4}{1.0 - \frac{x}{4}} \)
3. \( K_c = \frac{x^5}{1.0 - \frac{x}{4}} \)
4. \( K_c = \frac{4x}{1.0 - 4x} \)
5. \( K_c = \frac{x^4}{1.0 - 4x} \)

At 990°C, \( K_c = 1.6 \) for the reaction

\[ \text{H}_2(\text{g}) + \text{CO}_2(\text{g}) \rightleftharpoons \text{H}_2\text{O}(\text{g}) + \text{CO}(\text{g}) \]

How many moles of \( \text{H}_2\text{O}(\text{g}) \) are present in an equilibrium mixture resulting from the addition of 1.00 mole of \( \text{H}_2 \), 2.00 moles of \( \text{CO}_2 \), 0.75 moles of \( \text{H}_2\text{O} \), and 1.00 mole of \( \text{CO} \) to a 5.00 liter container at 990°C?

1. 1.1 mol
2. 1.4 mol
3. 1.7 mol
4. 0.80 mol
5. 1.0 mol
6. 0.60 mol

What happens to the concentration of \( \text{NO}(\text{g}) \) when the total pressure on the equilibrium reaction

\[ 3 \text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{HNO}_3(\text{aq}) + \text{NO}(\text{g}) \]

is increased (by compression)?

1. remains the same
2. Unable to determine

3. increases

4. decreases

011 10.0 points

Consider the reaction

\[ 2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g) \]

where \( \Delta H_{\text{rxn}} = -198 \text{ kJ} \). The amount of \( \text{SO}_2(g) \) at equilibrium increases when

1. the pressure is increased.

2. the volume is increased.

3. \( \text{SO}_3 \) is removed.

4. the temperature is decreased.

5. more oxygen is added.

012 10.0 points

For an exothermic reaction, what would happen to the numerical value of \( K_c \), if we increase the temperature at constant pressure?

1. \( K_c \) would increase.

2. \( K_c \) would decrease.

3. \( K_c \) would not change.

4. \( K_c \) would either increase or decrease, depending on the number of moles of gas involved.

5. \( K_c \) would either increase or decrease, depending on the concentrations.

013 10.0 points

Suppose the reaction mixture

\[ \text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g) \]

is at equilibrium at a given temperature and pressure. The pressure is then increased at constant temperature by compressing the reaction mixture, and the mixture is then allowed to reestablish equilibrium. At the new equilibrium,

1. there is more ammonia present than there was originally.

2. there is less ammonia present than there was originally.

3. there is the same amount of ammonia present as there was originally.

4. the nitrogen is used up completely.

014 10.0 points

Consider the system

\[ 2 \text{N}_2\text{O}_5(g) \rightleftharpoons 2 \text{N}_2\text{O}_4(g) + \text{O}_2(g) + \text{heat} \]

at equilibrium at 25°C. If the temperature were raised would the equilibrium be shifted to produce more \( \text{N}_2\text{O}_5 \) or more \( \text{N}_2\text{O}_4 \)?

1. more \( \text{N}_2\text{O}_5 \)

2. There would be no effect.

3. more \( \text{N}_2\text{O}_4 \)

015 10.0 points

Given the reaction

\[ 2 \text{NH}_3(g) \rightleftharpoons \text{N}_2(g) + 3 \text{H}_2(g) \]

at equilibrium, if the pressure is doubled (think of the volume of the container halving), in which direction will the reaction shift?

1. right

2. left

3. no change

016 10.0 points

The system

\[ \text{CO}_2(g) + \text{H}_2(g) \rightleftharpoons \text{H}_2\text{O}(g) + \text{CO}(g) \]
is at equilibrium at some temperature. At equilibrium a 4.00 L vessel contains 1.00 mole CO$_2$, 1.00 mole H$_2$, 2.40 moles H$_2$O, and 2.40 moles CO. How many moles of CO$_2$ must be added to the system to bring the equilibrium CO concentration to 0.677 mol/L? Answer in units of moles

017 10.0 points
The figure represents a reaction at 298 K.

Based on the figure, which of the following statements (if any) is false?

1. None of the statements is false.
2. At point B, $Q < K$.
3. For this reaction $\Delta G^\circ$ is negative.
4. At point C, the system is at equilibrium.
5. At point D, the reaction will move toward the reactants to get to equilibrium.

018 10.0 points
The following figure represents the progress of a given reaction at 298 K.

At point B on this figure, what is the relationship of $Q$ to $K$?

1. $Q = K$
2. $Q > K$
3. $Q < K$
4. Cannot be determined

019 10.0 points
Given the hypothetical reaction

$$X(g) \rightleftharpoons Y(g)$$

predict what will happen when 1.0 mol Y is placed into an evacuated container.

1. $Q$ will decrease until $Q = K$.
2. $Q$ will increase until $Q = K$.
3. $\Delta G^\circ$ will decrease until $\Delta G^\circ = 0$.
4. Nothing; the products are already formed, so no reaction occurs.

020 10.0 points
Consider the reaction:

$$\text{C}_{\text{graphite}}(s) + O_2(g) \rightleftharpoons CO_2(g)$$

$\Delta G^\circ = -400 \ \text{kJ} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$

Which of the following is a possible value of $K$ for this reaction?

1. -0.56
2. 0.56
3. $10^{-70}$
4. $10^{70}$

021 10.0 points
The hydronium ion is ______.

1. OH$^-$
2. H$_2$O$^+$
3. HO$^+$
4. H₃O⁺

A strong acid (or base) is one which

1. dissolves metals.
2. dissolves glass.
3. reacts with a salt to form water.
4. should only be used when wearing goggles and gloves.
5. dissociates completely in aqueous solution.

HCN is classified as a weak acid in water. This means that it produces

1. a relatively small fraction of the maximum number of possible hydronium ions.
2. no hydronium ions.
3. a relatively large fraction of the maximum number of possible hydronium ions.
4. 100% of the maximum number of possible hydronium ions.

An acid is strong if it

1. causes metals to corrode.
2. makes acid-base indicators change color.
3. is very concentrated.
4. ionizes completely in water.

Which of the following substances is NOT a weak acid?

1. HSO₃⁻
2. HCN
3. HCl
4. H₃PO₄
5. HF
6. H₂CO₃

Which of the following substances is a weak acid?

1. HNO₃
2. H₂SO₄
3. HI
4. HCl
5. HClO₃
6. H₂CO₃
7. HBr

In the reversible reaction

H₃O⁺ + NH₃ ⇌ H₂O + NH₄⁺,
what two substances act as acids in the Bronsted-Lowry sense?

1. some other pair
2. NH₃ and H₂O
3. H₃O⁺ and NH₄⁺
4. H₃O⁺ and H₂O
5. NH₃ and NH₄⁺

In the two reactions represented by

HCN + H₂O ⇌ CN⁻ + H₃O⁺, the two Bronsted-Lowry acids are
1. HCN and H₃O⁺.
2. H₂O and CN⁻.
3. HCN and CN⁻.
4. H₂O and H₃O⁺.
5. There is only one Bronsted-Lowry acid shown.

029 10.0 points
A water solution of sodium acetate is basic because
1. the acetate ion acts as a Bronsted-Lowry base in a reaction with water.
2. sodium acetate is only weakly ionized.
3. the acetate ion acts as a Bronsted-Lowry acid in a reaction with water.
4. the conjugate base of the acetate ion is a strong base.
5. the statement is false; a water solution of sodium acetate is acidic.

030 10.0 points
What is the conjugate acid of NO₃⁻?
1. HNO₃
2. H⁺
3. NO₃²⁻
4. NO₂⁻
5. NH₃
6. OH⁻

031 10.0 points
According to the Bronsted-Lowry concept of acids and bases, which of the following statements about a base is NOT true?

032 10.0 points
Which statement is true for the following reaction?
CCl₃COOH + H₂O ⇌ CCl₃CO⁻ + H₃O⁺
1. H₃O⁺ is the conjugate acid of CCl₃CO₂⁻.
2. CCl₃COOH is the conjugate acid of CCl₃CO₂⁻.
3. Cl₃COOH is the conjugate base of CCl₃CO₂⁻.
4. H₂O is the conjugate base of CCl₃CO₂⁻.
5. H₃O⁺ is the conjugate base of CCl₃CO₂⁻.
6. H₂O is the conjugate acid of CCl₃CO₂⁻.

033 10.0 points
According to Bronsted-Lowry Theory an acid is
1. amphoteric.
2. a proton acceptor.
3. a proton donor.
4. a soluble ionic hydroxide.

034 10.0 points
Which is NOT a conjugate base-acid pair?
1. H₂O : H₃O⁺
2. $\text{HSO}_4^- : \text{SO}_4^{2-}$
3. $\text{OH}^- : \text{H}_2\text{O}$
4. $\text{CN}^- : \text{HCN}$
5. $\text{F}^- : \text{HF}$

035 10.0 points
The conjugate base of $\text{H}_2\text{SO}_4$ is:

1. $\text{H}_3\text{O}^+$
2. $\text{SO}_4^{2-}$
3. $\text{OH}^-$
4. $\text{H}_2\text{SO}_3$
5. $\text{HSO}_4^-$
6. $\text{H}_2\text{O}$
7. $\text{H}_3\text{SO}_4^+$

036 10.0 points
A given weak acid $\text{HZ}$ has a $K_a = 3.6 \times 10^{-6}$. What is the $\text{H}_3\text{O}^+$ concentration of a solution of $\text{HZ}$ that has a concentration of 0.76 mol/L? Answer in units of mol/L

037 10.0 points
Assume that five weak acids, identified only by numbers (1, 2, 3, 4, and 5), have the following ionization constants.

<table>
<thead>
<tr>
<th>Acid</th>
<th>Ionization Constant $K_a$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>2</td>
<td>$3.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>3</td>
<td>$2.6 \times 10^{-7}$</td>
</tr>
<tr>
<td>4</td>
<td>$4.0 \times 10^{-9}$</td>
</tr>
<tr>
<td>5</td>
<td>$7.3 \times 10^{-11}$</td>
</tr>
</tbody>
</table>

The anion of which acid is the strongest base?