Select the expression below that does not define the rate of the reaction $2 \text{N}_2\text{O}_5(g) \rightarrow 4 \text{NO}_2(g) + \text{O}_2(g)$.

A. 
$$\text{Rate} = - \frac{1}{2} \frac{\Delta[\text{N}_2\text{O}_5]}{\Delta t}$$

B. 
$$\text{Rate} = \frac{1}{4} \frac{\Delta[\text{NO}_2]}{\Delta t}$$

C. 
$$\text{Rate} = \frac{\Delta[\text{O}_2]}{\Delta t}$$

D. 
$$\text{Rate} = \frac{\Delta[\text{O}_2]}{\Delta t}$$
Question #: 2

For the reaction \( \text{P}_4(g) + 6 \text{H}_2(g) \rightarrow 4 \text{PH}_3(g) \),

\[ \frac{\Delta[\text{H}_2]}{\Delta t} = -0.66 \text{ M/s} \]

Under the same conditions, the reaction rate is \( \frac{1}{\text{M/s}} \). Report your answer to the correct number of significant figures. Do NOT include units in your answer.

1. \__________

Question #: 3

The gas-phase decomposition of NOBr according to the chemical equation below is second order in NOBr. Which of the expressions below could be the rate constant for this reaction?

\[ 2 \text{NOBr}(g) \rightarrow 2 \text{NO}(g) + \text{Br}_2(g) \]

A. \( 0.80 \ \text{M}^{-1}\text{s}^{-1} \)
B. \( 2.8 \times 10^{-3} \ \text{s}^{-1} \)
C. \( 8.1 \times 10^2 \ \text{M}\text{s}^{-1} \)
D. \( 6.8 \ \text{M}^{-1}\text{s}^{-2} \)
Question #: 4

The table below shows data collected for the reaction:

\[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]

The reaction order with respect to NO is 1.
The reaction order with respect to O\(_2\) is 2.
The overall order of the reaction is 3.

Give a numerical answer for each blank.

<table>
<thead>
<tr>
<th>[NO] (M)</th>
<th>[O(_2)] (M)</th>
<th>Initial Rate of formation of [NO(_2)] (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.0055</td>
<td>0.0855</td>
</tr>
<tr>
<td>0.30</td>
<td>0.0110</td>
<td>0.171</td>
</tr>
<tr>
<td>0.90</td>
<td>0.0110</td>
<td>1.542</td>
</tr>
</tbody>
</table>

1. _________
2. _________
3. _________

Question #: 5

The decomposition of azomethane, CH\(_3\)N\(_2\)CH\(_3\), at 300 °C follows first-order kinetics with a rate constant of \(k = 2.55 \times 10^{-3}\) s\(^{-1}\). How long does it take for the concentration of azomethane to decrease from 0.254 M to 0.0406 M?

\[ \text{CH}_3\text{N}_2\text{CH}_3(g) \rightarrow \text{N}_2(g) + \text{C}_2\text{H}_6(g) \]

A. 110. minutes  
B. 760. minutes  
C. 12.0 minutes  
D. 3.00 minutes
Which plot shows $1/[A]$ vs. time for the second-order conversion of reactant A to products?

A.

![Plot A](image)

B.

![Plot B](image)

C.
Question #: 7

The half-life for the first-order decomposition of N₂O₅ is 24 minutes. How long does it take for the N₂O₅ concentration to decrease from 0.80 M to 0.20 M? [Hint: Think before you calculate.]

N₂O₅(g) → 2 NO₂(g) + ½O₂(g)

A. 12 min  
B. 48 min  
C. 24 min  
D. 96 min

Question #: 8

The second-order rate constant for the decomposition of nitrous oxide to nitrogen and oxygen is 0.011 M⁻¹·s⁻¹ at 923 K and 0.24 M⁻¹·s⁻¹ at 1023 K. The activation energy for this reaction is __1__ kJ/mol. Report your answer with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. __________

Question #: 9

According to the collision model, reaction rates increase with increasing temperature mainly because

A. the frequency factor (A in the Arrhenius equation) increases strongly with increasing temperature.  
B. at higher temperature, a larger fraction of intermolecular collisions occurs with the proper orientation to form products.  
C. at higher temperature, a larger fraction of intermolecular collisions occurs with sufficient energy to form products by overcoming the activation energy barrier.  
D. the activation energy (Eₐ in the Arrhenius equation) decreases with increasing temperature.
Question #: 10

The hydrolysis of SiCl(CH$_3$)$_3$

SiCl(CH$_3$)$_3$ + OH$^-$ → SiOH(CH$_3$)$_3$ + Cl$^-$

is described by the following two-step reaction mechanism. The species labeled Q is a(n) __________ in this mechanism.

1. __________

Question #: 11

The rate law for the reaction

2 NO(g) + Cl$_2$(g) → 2 NOCl(g)

is

\[ \text{rate} = k[\text{NO}][\text{Cl}_2]. \]

If the proposed mechanism below is correct, what are the relative rates of the two steps?

Step 1: NO(g) + Cl$_2$(g) ⇌ NOCl$_2$(g)
Step 2: NOCl$_2$(g) + NO(g) → 2 NOCl(g)

A. Step 1 is faster than Step 2.
B. Step 2 is faster than Step 1.
C. Step 1 and Step 2 proceed at equal rates.
**Question #**: 12

The figure below shows the oxidation of CO\((g)\) to CO\(_2\)(g) on a palladium surface according to the equation

\[
2 \text{CO}(g) + \text{O}_2(g) \rightarrow 2 \text{CO}_2(g).
\]

The palladium surface acts as a(n) _________.

A. enzyme  
B. homogeneous catalyst  
C. heterogeneous catalyst  
D. reaction intermediate

---

**Question #**: 13

Select the **two true** statements about this equilibrium reaction. \(K_P = 1.52\) at 700 °C.

\[
\text{COCl}_2(g) \rightleftharpoons \text{CO}(g) + \text{Cl}_2(g)
\]

A. Pure COCl\(_2\) reactant will be converted completely to CO and Cl\(_2\) above 700 °C.  
B. At equilibrium, the rate of formation of CO is equal to the rate of consumption of COCl\(_2\).  
C. Starting with pure COCl\(_2\) reactant, the total pressure of the system will rise as it approaches equilibrium.  
D. At equilibrium, \(k_f = k_r\).
Question #: 14

At 1300 K, NiO(s) is reduced to Ni(s) by CO(g). Select the two statements or equations that are true about this system.

\[ \text{NiO}(s) + \text{CO}(g) \rightleftharpoons \text{Ni}(s) + \text{CO}_2(g) \quad K_P = 100 \]

A. \((P_{\text{CO}})/100 = P_{\text{CO}_2}\) at equilibrium.
B. At equilibrium, rate of the forward reaction = rate of the reverse reaction.
C. Starting with only NiO(s) and CO(g), the rate of formation of \(\text{CO}_2(g)\) will be fast initially, then decrease to a slower, constant rate.
D. Adding more Ni(s) to the system at equilibrium will increase \(P_{\text{CO}_2}\).

Question #: 15

At a certain temperature, the reactions below have the equilibrium constants shown.

\[ \text{S}(s) + \text{O}_2(g) \rightleftharpoons \text{SO}_2(g) \quad K_{c1} = 4.2 \times 10^{26} \]
\[ 2 \text{S}(s) + 3 \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g) \quad K_{c2} = 9.8 \times 10^{64} \]

What is the equilibrium constant for the reaction below at that temperature?

\[ 2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g) \quad K_{c3} = \frac{1}{\text{?}} \]

Report your answer with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. __________
Question #: 16

Given
\[ \text{CH}_3\text{OH}(g) \rightleftharpoons \text{CO}(g) + 2 \text{H}_2(g) \quad K_c = 3.85 \times 10^{-2} \text{ at 780 °C (1053 K)} \]

what is the value of \( K_p \) at 780 °C (1053 K)?

A. 288  
B. 26.0  
C. 0.358  
D. 3.85 \times 10^{-2}

---

Question #: 17

At high temperatures, magnesium sulfite decomposes to magnesium oxide according to the equation
\[ \text{MgSO}_3(s) \rightleftharpoons \text{MgO}(s) + \text{SO}_2(g) \]
What is the \( K_P \) expression for this reaction?

A. \[ K_P = P_{\text{SO}_2} \]  
B. \[ K_P = \frac{P_{\text{MgO}} \cdot P_{\text{SO}_2}}{P_{\text{MgSO}_3}} \]  
C. \[ K_P = (P_{\text{SO}_2})^{-1} \]  
D. \[ K_P = P_{\text{MgO}} \cdot P_{\text{SO}_2} \]
Question #: 18

Initially, 0.60 moles of NOCl(g) are added to a 2.0 L reaction vessel. At equilibrium, the concentration of NO is 0.099 M. What is $K_c$ for the reaction at this temperature?

$$2 \text{NOCl}(g) \rightleftharpoons 2 \text{NO}(g) + \text{Cl}_2(g) \quad K_c = \underline{1}$$

Report your answer with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. __________

Question #: 19

Consider the diagram below displaying the equilibrium constant ($K$) and the reaction quotient ($Q$) at the same temperature for the reaction $A \rightleftharpoons B$.

Which of the following statements is true?

A. When $[A] = 0.3 \text{ M}$ and $[B] = 0.7 \text{ M}$, the reaction proceeds to the right (more $B$ forms).
B. When $[A] = 0.7 \text{ M}$ and $[B] = 0.3 \text{ M}$, the reaction proceeds to the right (more $B$ forms).
C. When $[A] = 0.5 \text{ M}$ and $[B] = 0.5 \text{ M}$, the reaction is at equilibrium.

A. __________
B. __________
C. __________
Question #: 20

When a 184-gram sample of dolomite, CaMg(CO$_3$)$_2$(s), is heated quickly to 910 K in a 0.50-liter closed container, the pressure rises to 1.2 ×10$^2$ atm. Under these conditions, the reaction quotient is __1__ and the pressure in the container __2__ [increases, decreases, remains constant] as the system approaches equilibrium.

\[
\text{CaMg(CO}_3\text{)}_2(\text{s}) \rightleftharpoons \text{CaO(}\text{s}\text{)} + \text{MgO(}\text{s}\text{)} + 2 \text{CO}_2(\text{g}) \quad K_P = 2.5 \times 10^4 \text{ at 900 K}
\]

For answer 1, report your answer with **two** significant figures. Do **NOT** include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2. Fill in the correct word or phrase for answer 2.

1. __________
2. __________

---

Question #: 21

TiCl$_4$ is usually prepared by the chlorination of TiO$_2$ according to the equation

\[
\text{TiO}_2(\text{s}) + 2 \text{Cl}_2(\text{g}) \rightleftharpoons \text{TiCl}_4(\text{g}) + \text{O}_2(\text{g}) \quad K_P = 5.4 \times 10^{15} \text{ at 498 K.}
\]

Excess TiO$_2$(s) reacts with Cl$_2$(g) in a sealed container. At equilibrium,

\[
P_{\text{TiCl}_4} = 3.0 \text{ atm}
\]

\[
P_{\text{Cl}_2} = \ __1\  \text{ atm}
\]

\[
P_{\text{O}_2} = \ __2\  \text{ atm}
\]

Report your answers with **two** significant figures. Do **NOT** include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. __________
2. __________
Question #: 22

A sample of pure HI(g) with initial pressure 0.33 atm decomposes in a sealed container at 246 K according to:

\[ 2 \text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \quad K_P = 0.020 \]

At equilibrium,

\[ P_{\text{HI}} = 1 \text{ atm} \]
\[ P_{\text{H}_2} = 2 \text{ atm} \]
\[ P_{\text{I}_2} = 3 \text{ atm} \]

Report your answers with two significant figures. Do NOT include units in your answer.

1. 
2. 
3. 

Question #: 23

A gas-tight syringe is filled with a mixture of colorless \( \text{H}_2(g) \), red-brown \( \text{Br}_2(g) \) and colorless \( \text{HBr}(g) \) at equilibrium.

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

The volume of the syringe is compressed from 80 mL to 40 mL, and the gas mixture darkens. After a minute, the system returns to equilibrium. The color of the gas in the syringe is ______ at equilibrium.

A. darker than "Before."
B. the same as "Before."
C. intermediate between "Before" and "After."
D. the same as "After."
E. lighter than "After."
Question #: 24

At high temperature, methane (CH\(_4\)) decomposes to carbon (graphite) and hydrogen in a fixed-volume container according to the following reaction equation.

\[
\text{CH}_4(g) \rightleftharpoons \text{C(graphite)} + 2\text{H}_2(g) \quad \Delta H = 74.9 \text{ kJ/mol}
\]

Heat is added to the system at equilibrium (i.e., the temperature is raised). Select the two statements that are true in order for the system to return to equilibrium.

A. More CH\(_4\)(g) decomposes.
B. No more C(graphite) is produced, because C(graphite) does not appear in the equilibrium constant expression.
C. The partial pressure of H\(_2\)(g) increases.
D. Raising the temperature does not alter the equilibrium pressures.

Question #: 25

Phosphine dissolves in water according to this reaction equation.

\[
\text{PH}_3(g) + \text{H}_2\text{O(l)} \rightarrow \text{PH}_4^+(aq) + \text{OH}^-(aq)
\]

In this reaction, PH\(_3\) acts as a(n) ______.

A. Brønsted-Lowry base
B. Arrhenius base
C. Arrhenius acid
D. Brønsted-Lowry acid

Question #: 26

Which two responses identify and classify the Brønsted-Lowry conjugate acid-base pairs in this reaction? (C\(_5\)H\(_5\)N is pyridine.)

\[
\text{C}_5\text{H}_5\text{N}(aq) + \text{H}_2\text{O(l)} \rightleftharpoons \text{C}_5\text{H}_5\text{NH}^+(aq) + \text{OH}^-(aq)
\]

A. H\(_2\)O, acid; OH\(^-\), conjugate base
B. OH\(^-\), base; H\(_3\)O\(^+\), conjugate acid
C. C\(_5\)H\(_5\)N, base; H\(_2\)O, conjugate acid
D. C\(_5\)H\(_5\)NH\(^+\), acid; C\(_5\)H\(_5\)N, conjugate base
**Question #**: 27

Four compounds with the pH of a 0.020-molar aqueous solution of each are listed below. Which is the **strongest acid**?

A. $\text{F}_3\text{CSO}_3\text{H}$, pH = 1.70  
B. $\text{CH}_3\text{NH}_3\text{Cl}$, pH = 6.17  
C. $\text{H}_2\text{SO}_3$, pH = 1.75  
D. $\text{HClO}_2$, pH = 1.83

**Question #**: 28

1. ___ is the **strongest acid** and 2. ___ is the **strongest conjugate base** listed in the table below.  
Answer with the **letter only** ($\text{A}–\text{F}$) of each species as it appears in the table.

<table>
<thead>
<tr>
<th>Acid</th>
<th>$K_a$</th>
<th>Conjugate Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. phenol</td>
<td>$1.3 \times 10^{-10}$</td>
<td>D. phenolate ion</td>
</tr>
<tr>
<td>B. hypochlorous acid</td>
<td>$3.2 \times 10^{-8}$</td>
<td>E. hypochlorite ion</td>
</tr>
<tr>
<td>C. anilinium ion</td>
<td>$2.5 \times 10^{-5}$</td>
<td>F. aniline</td>
</tr>
</tbody>
</table>

1. _________  
2. _________

**Question #**: 29

Which of these descriptions does **not** characterize the same solution at 25 °C as the other three?

A. pH = 5.27  
B. pOH = 8.73  
C. $[\text{OH}^-] = 1.9 \times 10^{-9}$  
D. $[\text{H}_3\text{O}^+] < [\text{OH}^-]$
Question #: 30

The autoionization constant of water is given at three temperatures in the table. In pure water, at which temperature is $[\text{H}_3\text{O}]^+$ the largest?

<table>
<thead>
<tr>
<th>°C</th>
<th>$K_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$5.1 \times 10^{-13}$</td>
</tr>
<tr>
<td>50</td>
<td>$5.5 \times 10^{-14}$</td>
</tr>
<tr>
<td>0</td>
<td>$1.1 \times 10^{-15}$</td>
</tr>
</tbody>
</table>

A. 100 °C  
B. 50 °C  
C. 0 °C  
D. $[\text{H}_3\text{O}]^+ = 1.0 \times 10^{-7}$ M at all temperatures.
Question #: 1

Select the expression below that does **not** define the rate of the reaction

\[ 2 \text{N}_2\text{O}_5(g) \rightarrow 4 \text{NO}_2(g) + \text{O}_2(g). \]

A. 

\[
\text{Rate} = -\frac{1}{2} \frac{\Delta[\text{N}_2\text{O}_5]}{\Delta t}
\]

B. 

\[
\text{Rate} = \frac{1}{4} \frac{\Delta[\text{NO}_2]}{\Delta t}
\]

✓C.
For the reaction $P_4(g) + 6 \text{H}_2(g) \rightarrow 4 \text{PH}_3(g)$, the reaction rate is $1 \text{M/s}$.

Under the same conditions, the reaction rate is $1 \text{M/s}$. Report your answer to the correct number of significant figures. Do NOT include units in your answer.

1. $0.11 | .11 | 1.1E-1 | +0.11 | .11 | +1.1E-1$

The gas-phase decomposition of NOBr according to the chemical equation below is second order in NOBr. Which of the expressions below could be the rate constant for this reaction?

$2 \text{NOBr}(g) \rightarrow 2 \text{NO}(g) + \text{Br}_2(g)$

✓A. $0.80 \text{M}^{-1} \cdot \text{s}^{-1}$
B. $2.8 \times 10^{-3} \text{M}^{-1} \cdot \text{s}^{-1}$
C. $8.1 \times 10^2 \text{M} \cdot \text{s}^{-1}$
D. $6.8 \text{M}^{-1} \cdot \text{s}^{-2}$

Question #: 4
The table below shows data collected for the reaction:

\[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]

The reaction order with respect to NO is \(1\).
The reaction order with respect to \( \text{O}_2 \) is \(2\).
The overall order of the reaction is \(3\).

Give a numerical answer for each blank.

<table>
<thead>
<tr>
<th>[NO] (M)</th>
<th>[O(_2)] (M)</th>
<th>Initial Rate of formation of [NO(_2)] (M/s)</th>
</tr>
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<tbody>
<tr>
<td>0.30</td>
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<td>0.171</td>
</tr>
<tr>
<td>0.90</td>
<td>0.0110</td>
<td>1.542</td>
</tr>
</tbody>
</table>

1. 2|two|second|2nd|
2. 1|one|first|1st|
3. 3|three|third|thrid|3rd|

**Question #5**

The decomposition of azomethane, \( \text{CH}_3\text{N}_2\text{CH}_3 \), at 300 °C follows first-order kinetics with a rate constant of \( k = 2.55 \times 10^{-3} \text{ s}^{-1} \). How long does it take for the concentration of azomethane to decrease from 0.254 M to 0.0406 M?

\[ \text{CH}_3\text{N}_2\text{CH}_3(g) \rightarrow \text{N}_2(g) + \text{C}_2\text{H}_6(g) \]

A. 110. minutes
B. 760. minutes
C. 12.0 minutes
D. 3.00 minutes

**Question #6**

Which plot shows 1/[A] vs. time for the second-order conversion of reactant A to products?
B.

1/ [A] vs time

Time, sec.

C.

1/ [A] vs time

Time, sec.
The half-life for the first-order decomposition of $\text{N}_2\text{O}_5$ is 24 minutes. How long does it take for the $\text{N}_2\text{O}_5$ concentration to decrease from 0.80 M to 0.20 M? [Hint: Think before you calculate.]

$\text{N}_2\text{O}_5(g) \rightarrow 2\text{NO}_2(g) + \frac{1}{2}\text{O}_2(g)$

A. 12 min
Question #: 8

The second-order rate constant for the decomposition of nitrous oxide to nitrogen and oxygen

\[ 2 \text{N}_2\text{O}(g) \rightarrow 2 \text{N}_2(g) + \text{O}_2(g) \]

is 0.011 M\(^{-1}\)\(\cdot\)s\(^{-1}\) at 923 K and 0.24 M\(^{-1}\)\(\cdot\)s\(^{-1}\) at 1023 K. The activation energy for this reaction is \(1\) kJ/mol. Report your answer with **two** significant figures. Do **NOT** include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E\(-2\).

\[ 1.240/2.4E2] \]

Question #: 9

According to the collision model, reaction rates increase with increasing temperature mainly because

A. the frequency factor (A in the Arrhenius equation) increases strongly with increasing temperature.
B. at higher temperature, a larger fraction of intermolecular collisions occurs with the proper orientation to form products.
✓ C. at higher temperature, a larger fraction of intermolecular collisions occurs with sufficient energy to form products by overcoming the activation energy barrier.
D. the activation energy (\(E_a\) in the Arrhenius equation) decreases with increasing temperature.

Question #: 10

The hydrolysis of SiCl(CH\(_3\))\(_3\)

\[ \text{SiCl(CH}_3\text{)}_3 + \text{OH}^- \rightarrow \text{SiOH(CH}_3\text{)}_3 + \text{Cl}^- \]

is described by the following two-step reaction mechanism. The species labeled \(Q\) is a(n) \(1\) in this mechanism.
The rate law for the reaction

\[ 2 \text{NO}(g) + \text{Cl}_2(g) \rightarrow 2 \text{NOCl}(g) \]

is

\[ \text{rate} = k[\text{NO}][\text{Cl}_2]. \]

If the proposed mechanism below is correct, what are the relative rates of the two steps?

Step 1: \( \text{NO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{NOCl}_2(g) \)
Step 2: \( \text{NOCl}_2(g) + \text{NO}(g) \rightarrow 2 \text{NOCl}(g) \)

A. Step 1 is faster than Step 2.
✓B. Step 2 is faster than Step 1.
C. Step 1 and Step 2 proceed at equal rates.

The figure below shows the oxidation of CO\(_2\)(g) to CO\(_2\)(g) on a palladium surface according to the equation

\[ 2 \text{CO}(g) + \text{O}_2(g) \rightarrow 2 \text{CO}_2(g). \]

The palladium surface acts as a(n) __________.
A. enzyme
B. homogeneous catalyst
✓C. heterogeneous catalyst
D. reaction intermediate

Question #: 13

Select the two true statements about this equilibrium reaction. $K_p = 1.52$ at 700 °C.

\[
\begin{align*}
&k_f \\
\text{COCl}_2(g) &\rightleftharpoons &\text{CO}(g) + \text{Cl}_2(g) \\
&k_r
\end{align*}
\]

A. Pure COCl$_2$ reactant will be converted completely to CO and Cl$_2$ above 700 °C.
✓B. At equilibrium, the rate of formation of CO is equal to the rate of consumption of COCl$_2$.
✓C. Starting with pure COCl$_2$ reactant, the total pressure of the system will rise as it approaches equilibrium.
D. At equilibrium, $k_f = k_r$.

Question #: 14

At 1300 K, NiO(s) is reduced to Ni(s) by CO(g). Select the two statements or equations that are true about this system.

$\text{NiO}(s) + \text{CO}(g) \rightleftharpoons \text{Ni}(s) + \text{CO}_2(g) \quad K_P = 100$
A. \( \left( \frac{P_{\text{CO}}}{100} \right) = P_{\text{CO}_2} \) at equilibrium.
✓B. At equilibrium, rate of the forward reaction = rate of the reverse reaction.
✓C. Starting with only NiO(s) and CO(g), the rate of formation of CO\(_2\)(g) will be fast initially, then decrease to a slower, constant rate.
D. Adding more Ni(s) to the system at equilibrium will increase \( P_{\text{CO}_2} \).

---

**Question #**: 15

At a certain temperature, the reactions below have the equilibrium constants shown.
\[ \text{S}(s) + O_2(g) \rightleftharpoons \text{SO}_2(g) \quad K_{c1} = 4.2 \times 10^{26} \]
\[ 2 \text{S}(s) + 3 O_2(g) \rightleftharpoons 2 \text{SO}_3(g) \quad K_{c2} = 9.8 \times 10^{64} \]
What is the equilibrium constant for the reaction below at that temperature?
\[ 2 \text{SO}_2(g) + O_2(g) \rightleftharpoons 2 \text{SO}_3(g) \quad K_{c3} = \]
Report your answer with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. 5.6E11

---

**Question #**: 16
Given

\[ \text{CH}_3\text{OH}(g) \rightleftharpoons \text{CO}(g) + 2 \text{H}_2(g) \quad K_c = 3.85 \times 10^{-2} \text{ at } 780 \, ^\circ\text{C} \text{ (1053 K)} \]

what is the value of \( K_p \) at 780 \(^\circ\text{C}\) \(\text{(1053 K)}\)?

✓ A. 288
B. 26.0
C. 0.358
D. 3.85 \times 10^{-2}

Question #: 17

At high temperatures, magnesium sulfite decomposes to magnesium oxide according to the equation

\[ \text{MgSO}_3(s) \rightleftharpoons \text{MgO}(s) + \text{SO}_2(g) \]

What is the \( K_P \) expression for this reaction?

✓ A. \( K_P = P_{\text{SO}_2} \)
B. \( K_P = \frac{P_{\text{MgO}} \cdot P_{\text{SO}_2}}{P_{\text{MgSO}_3}} \)
C. \( K_P = (P_{\text{SO}_2})^{-1} \)
D. \( K_P = P_{\text{MgO}} \cdot P_{\text{SO}_2} \)

Question #: 18

Initially, 0.60 moles of NOCl\((g)\) are added to a 2.0 L reaction vessel. At equilibrium, the concentration of NO is 0.099 M. What is \( K_c \) for the reaction at this temperature?
\[ 2 \text{ NOCl}(g) \rightleftharpoons 2 \text{ NO}(g) + \text{ Cl}_2(g) \quad K_c = 1 \]

Report your answer with **two** significant figures. Do **NOT** include units in your answer. Report your answer in scientific notation with the format \(2.2 \times 10^2\) or \(2.2 \times 10^{-2}\).

1. \(0.012\|1.2 \times 10^{-2}\|1.2 \times 10^{-2}\|1.2 \times 10^{-2}\)

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**Question #: 19**

Consider the diagram below displaying the equilibrium constant \((K)\) and the reaction quotient \((Q)\) at the same temperature for the reaction \(A \rightleftharpoons B\). Which of the following statements is **true**?

A. When \([A] = 0.3 \text{ M}\) and \([B] = 0.7 \text{ M}\), the reaction proceeds to the right (more \(B\) forms).
✓ B. When \([A] = 0.7 \text{ M}\) and \([B] = 0.3 \text{ M}\), the reaction proceeds to the right (more \(B\) forms).
C. When \([A] = 0.5 \text{ M}\) and \([B] = 0.5 \text{ M}\), the reaction is at equilibrium.

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**Question #: 20**

When a 184-gram sample of dolomite, \(\text{CaMg(CO}_3\text{)}_2\)(s), is heated quickly to 910 K in a 0.50-liter closed container, the pressure rises to \(1.2 \times 10^2\) atm. Under these conditions, the reaction quotient is **1** and the pressure in the container **2** [increases, decreases, remains constant] as the system approaches equilibrium.
CaMg(CO3)2(s)

CaO(s) + MgO(s) + 2 CO2(g) \quad K_p = 2.5 \times 10^4 \text{ at } 900 \text{ K}

For answer 1, report your answer with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. 1.4E4|1.4 E4|
2. increases|increase|rise|rises|

Question #: 21

TiCl4 is usually prepared by the chlorination of TiO2 according to the equation

\[ \text{TiO}_2(s) + 2 \text{Cl}_2(g) \rightleftharpoons \text{TiCl}_4(g) + \text{O}_2(g) \quad K_p = 5.4 \times 10^{15} \text{ at } 498 \text{ K.} \]

Excess TiO2(s) reacts with Cl2(g) in a sealed container. At equilibrium,

\begin{align*}
    P_{\text{TiCl}_4} &= 3.0 \text{ atm} \\
    P_{\text{Cl}_2} &= 1 \text{ atm} \\
    P_{\text{O}_2} &= 2 \text{ atm}
\end{align*}

Report your answers with two significant figures. Do NOT include units in your answer. Report your answer in scientific notation with the format 2.2E2 or 2.2E-2.

1. 4.1E-8|4.0E-8|4.2E-8|
2. 3.0|3.0E0|

Question #: 22

A sample of pure HI(g) with initial pressure 0.33 atm decomposes in a sealed container at 246 K according to:

\[ 2 \text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \quad K_p = 0.020 \]

At equilibrium,

\begin{align*}
    P_{\text{HI}} &= 1 \text{ atm} \\
    P_{\text{H}_2} &= 2 \text{ atm} \\
    P_{\text{I}_2} &= 3 \text{ atm}
\end{align*}
Question #: 23

A gas-tight syringe is filled with a mixture of colorless \( \text{H}_2(g) \), red-brown \( \text{Br}_2(g) \) and colorless \( \text{HBr}(g) \) at equilibrium.

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

The volume of the syringe is compressed from 80 mL to 40 mL, and the gas mixture darkens. After a minute, the system returns to equilibrium. The color of the gas in the syringe is ______ at equilibrium.

- A. darker than "Before."
- B. the same as "Before."
- C. intermediate between "Before" and "After."
- D. the same as "After."
- E. lighter than "After."

Question #: 24
At high temperature, methane (CH$_4$) decomposes to carbon (graphite) and hydrogen in a fixed-volume container according to the following reaction equation.

\[ \text{CH}_4(g) \rightleftharpoons \text{C(graphite)} + 2 \text{H}_2(g) \quad \Delta H = 74.9 \text{ kJ/mol} \]

Heat is added to the system at equilibrium (i.e., the temperature is raised). Select the two statements that are true in order for the system to return to equilibrium.

✓ A. More CH$_4(g)$ decomposes.
B. No more C(graphite) is produced, because C(graphite) does not appear in the equilibrium constant expression.
✓ C. The partial pressure of H$_2(g)$ increases.
D. Raising the temperature does not alter the equilibrium pressures.

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Question #: 25

Phosphine dissolves in water according to this reaction equation.

\[ \text{PH}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{PH}_4^+(aq) + \text{OH}^-(aq) \]

In this reaction, PH$_3$ acts as a(n) ______.

✓ A. Brønsted-Lowry base
B. Arrhenius base
C. Arrhenius acid
D. Brønsted-Lowry acid

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Question #: 26

Which two responses identify and classify the Brønsted-Lowry conjugate acid-base pairs in this reaction? (C$_{5}$H$_{5}$N is pyridine.)

\[ \text{C}_5\text{H}_5\text{N}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_5\text{H}_5\text{NH}^+(aq) + \text{OH}^-(aq) \]

✓ A. H$_2$O, acid; OH$^-$, conjugate base
B. OH$^-$, base; H$_3$O$^+$, conjugate acid
C. C$_5$H$_5$N, base; H$_2$O, conjugate acid
D. C$_5$H$_5$NH$^+$, acid; C$_5$H$_5$N, conjugate base

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Question #: 27
Four compounds with the pH of a 0.020-molar aqueous solution of each are listed below. Which is the **strongest acid**?

✓ A. $\text{F}_3\text{CSO}_3\text{H}$, pH = 1.70  
   B. $\text{CH}_3\text{NH}_3\text{Cl}$, pH = 6.17  
   C. $\text{H}_2\text{SO}_3$, pH = 1.75  
   D. $\text{HClO}_2$, pH = 1.83

**Question #: 28**

1 is the **strongest acid** and 2 is the **strongest conjugate base** listed in the table below.

Answer with the **letter only** (A–F) of each species as it appears in the table.

<table>
<thead>
<tr>
<th>Acid</th>
<th>$K_a$</th>
<th>Conjugate Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. phenol</td>
<td>$1.3 \times 10^{-10}$</td>
<td>D. phenolate ion</td>
</tr>
<tr>
<td>B. hypochlorous acid</td>
<td>$3.2 \times 10^{-8}$</td>
<td>E. hypochlorite ion</td>
</tr>
<tr>
<td>C. anilinium ion</td>
<td>$2.5 \times 10^{-5}$</td>
<td>F. aniline</td>
</tr>
</tbody>
</table>

1. C|c|C.|c.|  
2. D|d|D.|d.|  

**Question #: 29**

Which of these descriptions does **not** characterize the same solution at 25 °C as the other three?

A. pH = 5.27  
   B. pOH = 8.73  
   C. $[\text{OH}^-] = 1.9 \times 10^{-9}$  
   ✓ D. $[\text{H}_3\text{O}^+] < [\text{OH}^-]$  

**Question #: 30**
The autoionization constant of water is given at three temperatures in the table. In pure water, at which temperature is $[\text{H}_3\text{O}]^+$ the largest?

<table>
<thead>
<tr>
<th>°C</th>
<th>$K_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$5.1 \times 10^{-13}$</td>
</tr>
<tr>
<td>50</td>
<td>$5.5 \times 10^{-14}$</td>
</tr>
<tr>
<td>0</td>
<td>$1.1 \times 10^{-15}$</td>
</tr>
</tbody>
</table>

✓A. 100 °C  
B. 50 °C  
C. 0 °C  
D. $[\text{H}_3\text{O}]^+ = 1.0 \times 10^{-7}$ M at all temperatures.