1. For the reaction:

$$
\mathrm{BrO}_{3}^{-}+5 \mathrm{Br}^{-}+6 \mathrm{H}+\rightarrow 3 \mathrm{Br}_{2}+3 \mathrm{H}_{2} \mathrm{O}
$$

If the value of $-\Delta\left[\mathrm{Br}^{-}\right] / \Delta \mathrm{t}=7.5 \times 10^{-2} \mathrm{~mol} \mathrm{~L}^{-1} \mathrm{~s}^{-1}$, What will be the value of $\Delta$ $\left[\mathrm{Br}_{2}\right] / \Delta \mathrm{t}$ at the same instant (in $\mathrm{mol} \mathrm{L}^{-1} \mathrm{~s}^{-1}$ )?
A) $1.25 \times 10^{-2}$
B) $1.5 \times 10^{-2}$
C) $4.5 \times 10^{-2}$
D) $1.25 \times 10^{-1}$

## SOLUTION

$-\frac{\Delta\left[\mathrm{Br}^{-}\right]}{5 \times \Delta \mathrm{t}}=+\frac{\Delta\left[\mathrm{Br}_{2}\right]}{3 \times \Delta \mathrm{t}},-\frac{\Delta\left[\mathrm{Br}^{-}\right]}{\Delta \mathrm{t}}=+\frac{\Delta\left[\mathrm{Br}_{2}\right]}{\Delta \mathrm{t}}=-\frac{3 \times \Delta\left[\mathrm{Br}^{-}\right]}{5 \times \Delta \mathrm{t}}=\frac{3 \times 7.5 \times 10^{-2}}{5}=0.045 \mathrm{~mol} \mathrm{~L}^{-1} \mathrm{~s}^{-1}$
2. Nitric oxide reacts with chlorine to form nitrosyl chloride:

$$
\mathrm{NO}+\mathbf{1} / 2 \mathrm{Cl}_{2} \rightarrow \mathrm{NOCl}
$$

From the following data, the reaction rate law (rate equation) is:

| Exper <br> iment | $[\mathrm{NO}]$ <br> $(\mathbf{M})$ | $\left[\mathrm{Cl}_{2}\right]$ <br> $(\mathbf{M})$ | Initial rate <br> $\left(\mathbf{M ~ m i n}^{-1}\right)$ |
| :---: | :---: | :---: | :---: |
| 1 | $\mathbf{0 . 2 2}$ | $\mathbf{0 . 0 6 4}$ | $\mathbf{0 . 9 6}$ |
| 2 | $\mathbf{0 . 6 6}$ | $\mathbf{0 . 0 6 4}$ | $\mathbf{8 . 6 4}$ |
| 3 | $\mathbf{0 . 2 2}$ | $\mathbf{0 . 0 3 2}$ | $\mathbf{0 . 4 8}$ |

A) Rate $=k\left[\mathrm{NO}^{2}\left[\mathrm{Cl}_{2}\right]^{2}\right.$
B) Rate $=\mathrm{k}[\mathrm{NO}]^{2}\left[\mathrm{Cl}_{2}\right]^{1 / 2}$
C) Rate $=k[\mathrm{NO}]\left[\mathrm{Cl}_{2}\right]^{1 / 2}$
D) Rate $=\mathrm{k}[\mathrm{NO}]^{2}\left[\mathrm{Cl}_{2}\right]$
$\quad$ SOLUTION
rate $=k[\mathrm{NO}]^{x}\left[\mathrm{Cl}_{2}\right]^{\mathrm{y}}$
3. At $25^{\circ} \mathrm{C}$, the rate constant for the first order decomposition of a pesticide solution is $6.4 \times 10^{-3} \mathrm{~min}^{-1}$. If the initial concentration of pesticide is $\mathbf{0 . 0 3 1 4} \mathbf{~ m o l}$ $\mathrm{L}^{-1}$. What its concentration (in $\mathbf{~ m o l ~ L} \mathrm{L}^{-1}$ ) after $\mathbf{6 2 . 0} \mathbf{~ m i n}$ at $25^{\circ} \mathrm{C}$ ?
A) $\mathbf{0 . 0 1 1}$
B) 0.0131
C) 0.0191
D) 0.0211

$$
\ln \frac{[\text { pesticide }]_{0}}{[\text { pesticide }]_{\mathrm{t}}}=\mathrm{kt}, \ln \frac{0.0314}{[\text { pesticide }]_{\mathrm{t}}}=6.4 \times 10^{-3} \times 62,[\text { pesticide }]_{\mathrm{t}}=0.0211 \mathrm{~mol} \mathrm{~L}^{-1}
$$

4. A first order reaction has a rate constant of $2.8 \times 10^{-2} \mathrm{~s}^{-1}$. How many seconds will it take for the [reactant] to decrease from $0.88 \mathrm{~mol} \mathrm{~L}^{-1}$ to $0.14 \mathrm{~mol} \mathrm{~L}^{-1}$ ?
A) 59.5
B) 65.7
C) 74.8
D) 88.6
$\ln \frac{[\text { reactant }]_{\mathrm{o}}}{[\text { reactant }]_{\mathrm{t}}}=\mathrm{kt}, \ln \frac{0.88}{0.14}=2.8 \times 10^{-2} \times \mathrm{t}, \mathrm{t}=65.65 \mathrm{~min}$
5. Increasing of which of the following would alter the value of the rate constant $(\mathrm{k})$ for the reaction?

$$
2 \mathrm{~A}+\mathrm{B} \rightarrow \text { products }
$$

A) [A] only
B) $[B]$ only
C) $[\mathrm{A}]$ and $[\mathrm{B}]$
D) temperature

## SOLUTION

According to Arrhenius equation, $\ln k=\ln A-\frac{E_{a}}{R T}$, it appears that $k$ value depends on the values of $A, E_{a}, R$, and $T$. The values of $A$ and $E_{a}$ are constant for the same reaction, and the value of $R$ is always constant. Therefore, $k$ cannot be increased unless T is increased.
6. The isomerization of cyclopropane follows first order kinetics. The rate constant at 700 K is $6.2 \times 10^{-4} \mathrm{~min}^{-1}$, and the half life at 760 K is $\mathbf{2 9 . 0} \mathbf{~ m i n}$. The activation energy for this reaction, in $\mathrm{kJ} / \mathrm{mol}$, is:
A) 269.2
B) 250.6
C) 240.8
D) 283.4

$$
\begin{aligned}
& \mathrm{k}(760 \mathrm{~K})=\frac{\ln 2}{\mathrm{t}_{0.5}}=\frac{0.693}{29}=2.39 \times 10^{-2} \\
& \ln \frac{\mathrm{k}_{1}}{\mathrm{k}_{2}}=\frac{\mathrm{E}_{\mathrm{a}}}{\mathrm{R}}\left(\frac{T_{1}-T_{2}}{T_{1} \times T_{2}}\right), \ln \frac{6.2 \times 10^{-4}}{2.39 \times 10^{-2}}=\frac{\mathrm{E}_{\mathrm{a}}}{8.314 \times 10^{-3}}\left(\frac{700-760}{700 \times 760}\right), \mathrm{E}_{\mathrm{a}}=269.2 \mathrm{~kJ}
\end{aligned}
$$

7. The unit for a third order reaction rate constant is:
A) $\mathrm{s}^{-1}$
B) $\mathrm{mol}^{-2} \mathrm{~L}^{2} \mathrm{~s}^{-1}$
C) $\mathrm{mol}^{2} \mathrm{~L}^{-2} \mathrm{~s}^{-1}$
D) $\mathrm{mol}^{3} \mathrm{~L}^{-3} \mathrm{~s}^{-1}$

$$
\text { k UNITS }=\text { mol }^{1-\mathrm{n}} \mathbf{L}^{\mathrm{n}-1} \mathrm{~s}^{-1}=\mathrm{mol}^{1-3} \mathbf{L}^{3-1} \mathrm{~s}^{-1}=\mathrm{mol}^{-2} \mathbf{L}^{2} \mathrm{~s}^{-1}
$$

8. The correct equilibrium constant expression for the following reaction is:

$$
\mathrm{Fe}_{2} \mathrm{O}_{3}(\mathrm{~s})+3 \mathrm{H}_{2}(\mathrm{~g}) \rightleftharpoons 2 \mathrm{Fe}(\mathrm{~s})+3 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g})
$$

A) $\mathrm{K}_{\mathrm{c}}=\left[\mathrm{H}_{2} \mathrm{O}\right]^{3} /\left[\mathrm{H}_{2}\right]^{3}$
B) $\mathrm{K}_{\mathrm{c}}=[\mathrm{Fe}]^{2}\left[\mathrm{H}_{2} \mathrm{O}\right]^{3} /\left[\mathrm{Fe}_{2} \mathrm{O}_{3}\right]\left[\mathrm{H}_{2}\right]^{3}$
C) $\mathrm{K}_{\mathrm{c}}=\left[\mathrm{Fe}_{2} \mathrm{O}_{3}\right]\left[\mathrm{H}_{2}\right]^{3} /[\mathrm{Fe}]^{2}\left[\mathrm{H}_{2} \mathrm{O}\right]^{3}$
D) $\mathrm{K}_{\mathrm{c}}=\left[\mathrm{H}_{2} \mathrm{O}\right] /\left[\mathrm{H}_{2}\right]$

$$
\mathrm{K}_{\mathrm{c}}=[\mathrm{Fe}]^{2}\left[\mathrm{H}_{2} \mathrm{O}\right]^{3} /\left[\mathrm{Fe}_{2} \mathrm{O}_{3}\right]\left[\mathrm{H}_{2}\right]^{3} \quad \text { SOLUTION }
$$

9. From the following equilibria, $K_{1}$ and $K_{2}$ are related by:
$\mathrm{SO}_{2}(\mathrm{~g})+\mathbf{1 / 2 \mathrm { O } _ { 2 }}(\mathrm{g}) \rightleftharpoons \mathrm{SO}_{3}(\mathrm{~g})$
$K_{1}$
$2 \mathrm{SO}_{3}(\mathrm{~g}) \rightleftharpoons 2 \mathrm{SO}_{2}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g})$
$\mathrm{K}_{2}$
A) $K_{2}=\left(\mathbf{K}_{1}\right)^{2}$
B) $\left(K_{2}\right)^{2}=K_{1}$
C) $\mathbf{K}_{2}=\left(\mathbf{K}_{1}\right)^{-2}$
D) $\mathbf{K}_{2}=\left(\mathbf{K}_{1}\right)^{-1}$

SOLUTION
From the equilibrium constants of both reactions:
$\mathrm{K}_{1}=\left[\mathrm{SO}_{3}\right] /\left[\mathrm{SO}_{2}\right]\left[\mathrm{O}_{2}\right]^{1 / 2}$
$\mathbf{K}_{2}=\left[\mathrm{SO}_{2}\right]^{2}\left[\mathrm{O}_{2}\right] /\left[\mathrm{SO}_{3}\right]^{2}$
It appears that $K_{2}=\left(K_{1}\right)^{-2}$
10. Knowing that

$$
\mathrm{NH}_{4} \mathrm{HS}(\mathrm{~s}) \rightleftharpoons \mathrm{NH}_{3}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{~S}(\mathrm{~g}) \quad \mathrm{K}_{\mathrm{c}}(295 \mathrm{~K})=1.2 \times 10^{-4}
$$

The equilibrium partial pressure of $\mathrm{NH}_{3}(\mathrm{~g})$ is:
A) 0.117
B) 0.265
C) 0.344
D) 0.424

## SOLUTION

Because this is a heterogeneous equilibrium:

$$
\mathbf{K}_{\mathrm{c}}=\left[\mathrm{NH}_{3}\right]\left[\mathrm{H}_{2} \mathrm{~S}\right] \text { and } \mathrm{K}_{\mathrm{p}}=\mathrm{P}_{\mathrm{NH}_{3}} \times \mathrm{P}_{\mathrm{H}_{2} \mathrm{~S}}
$$


11. For following reaction at equilibrium:

$$
2 \mathrm{SO}_{2}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g}) \rightleftharpoons 2 \mathrm{SO}_{3}(\mathrm{~g}) \quad \Delta \mathrm{H}_{\mathrm{rxn}}=-198 \mathrm{~kJ}
$$

Which of the following statements could be true? $\mathrm{K}_{\mathrm{p}}$ increases with:
1).decreasing temperature.
2) increasing temperature.
3) decreasing total pressure.
4) increasing total pressure.
A) 1 only
B) 1 and 4
C) 2 only
D) 2 and 3

## SOLUTION

Equilibrium constant for any reaction does not change except if its temperature changes. And for exothermic reactions equilibrium constants increases as temperature decreases.
12. $\quad 4.21$ moles of $\mathrm{S}_{2} \mathrm{Cl}_{4}$ gas are introduced in 2.0 L vessel, and at equilibrium 1.25 moles of $\mathrm{S}_{2} \mathrm{Cl}_{4}$ are found in the reaction vessel, and $\mathrm{K}_{\mathbf{c}}$ for the reaction is:
$\mathrm{S}_{2} \mathrm{Cl}_{4}(\mathrm{~g}) \rightleftharpoons \mathbf{2 S C l}_{2}(\mathrm{~g})$
A) $\mathbf{1 4 . 0}$
B) 17.0
C) 19.5
D) 21.5

$$
\begin{aligned}
& \text { SOLUTION } \\
& {\left[\mathrm{S}_{2} \mathrm{Cl}_{4}\right]_{\text {initial }}=\frac{\mathrm{n}_{\mathrm{S}_{2} \mathrm{Cl}_{4}}}{\mathrm{~V}}=\frac{4.21}{2}=\mathbf{2 . 1 0 5} \mathrm{M},\left[\mathrm{~S}_{2} \mathrm{Cl}_{4}\right]_{\text {equilibrium }}=\frac{\mathrm{n}_{\mathrm{SCl}}^{2}}{} \mathrm{~V}_{\mathrm{V}}=\frac{1.25}{2}=\mathbf{0 . 6 2 5} \mathrm{M}} \\
& 2.105-\mathrm{X}=0.625 \mathrm{M}, \mathrm{X}=1.48 \\
& {\left[\mathrm{SCl}_{2}\right]_{\text {equilibrium }}=2 \mathrm{X}=2 \times 1.48=2.96 \mathrm{M}} \\
& \mathrm{~K}_{\mathrm{c}}=\frac{\left[\mathrm{SCl}_{2}\right]^{2}}{\left[\mathrm{~S}_{2} \mathrm{C}_{4}\right]}=\frac{(2.96)^{2}}{0.625}=14.02
\end{aligned}
$$

13. If the following equilibrium mixture concentrations are $\left[\mathrm{SO}_{3}\right]=\mathbf{1 0 . 0 0} \mathbf{M}$, $\left[\mathrm{SO}_{2}\right]=0.01 \mathrm{M}$ and $\left[\mathrm{O}_{2}\right]=0.10 \mathrm{M}$ at 700 K :

$$
2 \mathrm{SO}_{2}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g}) \rightleftharpoons 2 \mathrm{SO}_{3}(\mathrm{~g}) \quad \mathrm{K}_{\mathrm{c}}(700 \mathrm{~K})=4.3 \times 10^{6}
$$

A) the reaction mixture is at equilibrium.
B) the reaction must proceed to the right to reach equilibrium.
C) the reaction must proceed to the left to reach equilibrium.
D) there is not enough information to answer.

$$
\mathrm{Q}=\frac{\left[\mathrm{SO}_{3}\right]^{2}}{\left[\mathrm{SO}_{2}\right]^{2}\left[\mathrm{O}_{2}\right]}=\frac{(10)^{2}}{(0.01)^{2} \times(0.1)}=1 \mathbf{1 0 0 \times 1 0 ^ { 7 }}
$$

## $1.00 \times 10^{-7}>4.3 \times 10^{6}$

Because $\mathrm{Q}>\mathrm{K}_{\mathrm{c}}$, the reaction must proceed to the left to reach equilibrium.
14. What is the $\mathbf{p H}$ of 1.0 L buffer solution that is 0.12 M lactic acid, $\mathrm{HC}_{3} \mathrm{H}_{5} \mathrm{O}_{3}$, and 0.10 M sodium lactate, $\mathrm{NaC}_{3} \mathrm{H}_{5} \mathrm{O}_{3}$, after the addition of 0.01 mole of gaseous HCl ? assume that this will not change the volume of the solution, and $\mathrm{K}_{\mathrm{a}}\left(\mathrm{HC}_{3} \mathrm{H}_{5} \mathrm{O}_{3}\right)=\mathbf{1 . 4 \times 1 0 ^ { - 4 }}$.
A) 3.27
B) 3.45
C) 3.69
D) 3.95

$$
\begin{aligned}
& \text { SOLUTION } \\
& {\left[\mathrm{S}_{2} \mathrm{Cl}_{4}\right]_{\text {initial }}=\frac{\mathrm{n}_{\mathrm{S}_{2} \mathrm{Cl}_{4}}}{\mathrm{~V}}=\frac{4.21}{2}=\mathbf{2 . 1 0 5} \mathrm{M},\left[\mathrm{~S}_{2} \mathrm{Cl}_{4}\right]_{\text {equilibrium }}=\frac{\mathrm{n}_{\mathrm{SCl}}^{2}}{} \mathrm{~V}_{\mathrm{H}}=\frac{1.25}{2}=\mathbf{0 . 6 2 5} \mathrm{M}} \\
& \mathrm{HC}_{3} \mathrm{H}_{5} \mathrm{O}_{3}+\mathrm{H}_{2} \mathrm{O} \quad \rightleftharpoons \quad \mathrm{C}_{3} \mathrm{H}_{5} \mathrm{O}_{3}^{-}+\mathrm{H}_{3} \mathrm{O}^{+} \\
& \text {Before: } \quad 0.2 \mathrm{M} \\
& \text { After: } \quad \mathbf{0 . 2} \mathbf{+ 0 . 0 1}=\mathbf{0 . 2 1} \mathrm{M} \\
& 0.10-0.01=0.09 \mathrm{M} \\
& \mathrm{pH}=\mathrm{pK}_{\mathrm{a}}+\log \frac{\left[\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{O}_{3}^{-}\right]}{\left[\mathrm{HC}_{3} \mathrm{H}_{5} \mathrm{O}_{3}\right]}=-\log 1.4 \times 10^{-4}+\log \frac{0.09}{0.21}=3.48589
\end{aligned}
$$

15. The conjugated acid of $\mathrm{NH}_{2}{ }^{-}$is:
A) $\mathbf{H N O}_{3}$
B) $\mathrm{HNO}_{2}$
C) $\mathrm{NH}_{4}{ }^{+}$
D) $\mathrm{NH}_{3}$

## SOLUTION

Because the conjugate acid is more than its conjugate base by one $\mathbf{H}^{+}$, the conjugated acid of $\mathrm{NH}_{2}^{-}$is $\mathrm{NH}_{3}$.
16. The pOH of $2.5 \times 10^{-3} \mathrm{M} \mathrm{Ba}(\mathrm{OH})_{2}$ solution is:
A) 5.0
B) 2.5
C) 2.3
D) 2.1

> SOLUTION
> $\left[\mathrm{OH}^{-}\right]=\mathrm{nC}_{\mathrm{b}}=2 \times 2.5 \times 10^{-3}=5 \times 10^{-3} \mathrm{M}, \mathrm{pOH}=-\log \left[\mathrm{OH}^{-}\right]=-\log 5 \times 10^{-3}=2.3$
17. The $\mathbf{p H}$ of $\mathbf{1 0 0} \mathbf{~ m l}$ of $\mathbf{0 . 0 0 2} \mathbf{~ M ~ H C l}$ solution is:
A) 0.27
B) 2.0
C) 0.2
D) 2.7

$$
\begin{gathered}
\text { SOLUTION } \\
{\left[\mathrm{H}^{+}\right]=\mathrm{nC}_{\mathrm{a}}=1 \times 0.002=0.002 \mathrm{M}, \mathrm{pH}=-\log \left[\mathrm{H}^{+}\right]=-\log 0.002=2.7}
\end{gathered}
$$

18. The $\mathbf{p H}$ of 1.6 M KOH solution is:
A) 13.8
B) 14.2
C) 12.4
D) 1.6

## SOLUTION

$\left[\mathrm{OH}^{-}\right]=\mathrm{nC}_{\mathrm{b}}=1 \times!.6=1.6 \mathrm{M}, \mathrm{pOH}=-\log \left[\mathrm{OH}^{-}\right]=-\log 1.6=-\mathbf{0 . 2 0 4}$
$\mathrm{pH} 14-\mathrm{pOH}=14-(-0.204)=14.204$
19. The pH of 0.05 M acetic acid $\left(\mathrm{K}_{\mathrm{a}}=1.8 \times 10^{-5}\right)$ solution is:
A) 3
B) 4
C) 5
D) 6

SOLUTION
$\left[\mathrm{H}^{+}\right]=\sqrt{\mathrm{C}_{\mathrm{a}} \mathrm{K}_{\mathrm{a}}}=\sqrt{0.05 \times 1.8 \times 10^{-5}}=9.487 \times 10^{-4} \mathrm{M}, \mathrm{pH}=-\log \left[\mathrm{H}^{+}\right]$
$\mathrm{pH}=-\log 9.487 \times 10^{-4}=3.02$
20. The $\mathbf{p H}$ of $\mathbf{0 . 1} \mathrm{M}$ ammonia $\left(\mathrm{K}_{\mathrm{b}}=1.8 \times 10^{-5}\right)$ solution is:
A) $\mathbf{2 . 8 7}$
B) 11.13
C) 8.94
D) $\mathbf{1 2 . 5 6}$

SOLUTION
$\left[\mathrm{OH}^{-}\right]=\sqrt{\mathrm{C}_{\mathrm{b}} \mathrm{K}_{\mathrm{b}}}=\sqrt{0.1 \times 1.8 \times 10^{-5}}=1.34 \times 10^{-3} \mathrm{M}, \mathrm{pOH}=-\log \left[\mathrm{OH}^{-}\right]$ $\mathrm{pOH}=-\log 1.34 \times 10^{-3} \times 10^{-4}=2.87, \mathrm{pH}=11.13$

