

Chapter 9

Problems

Problem 1

True or false

(a). *M* is a valid unit for a reaction rate.

(b). *Atoms/sec* is a valid unit for a reaction rate.

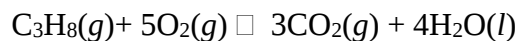
Answer

(a). **False.** Rate has units of concentration (or amount) divided by time.

(b). **True.** Rate has units of concentration (or amount) divided by time. This would be a unit useful in nuclear decay.

Problem 2

_____ in the reaction below either appears or disappears the most rapidly. This represents the combustion of propane, used for barbeques and portable stoves.

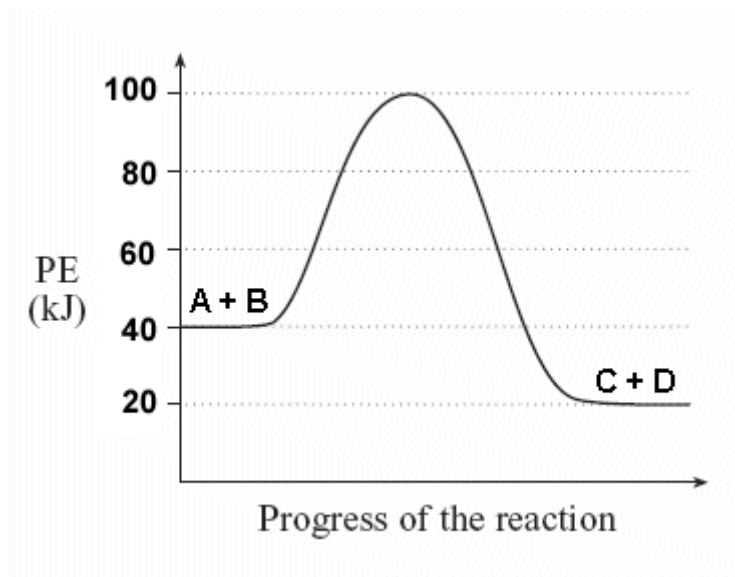


Answer

The larger the coefficient in a balanced equation, the faster the rate of disappearance or appearance of a substance, which is O_2 in this equation.

Problem 3

The reaction



(Figure courtesy of Socratic.org)

- (a). For $A + B \rightarrow C + D$, the activation energy is ____ kJ.
(b). For $C + D \rightarrow A + B$, the activation energy is ____ kJ.

Answer

- (a). The activation energy is $(100-40)\text{kJ} = 60 \text{ kJ}$.
(b). The activation energy is $(100-20)\text{kJ} = 80 \text{ kJ}$.

Problem 4

The time in days taken for pizza dough to spoil is given below as a function of temperature ($^{\circ}\text{C}$).

Time(days)	Temp($^{\circ}\text{C}$)
7	5.0
30	-8.0
90	-12.0
360	-18.0

- (Data courtesy of *The use of the Arrhenius equation in the study of deterioration and of cooking of foods. Some scientific and pedagogic aspects* Petrou, A.; Roulia, M., Tampouris, K. Chemistry Education Research and Practice, 2002, 3(1):87-97)

True or False

At a temperature of -20°C , the time taken for pizza dough to spoil is greater than 360 days.

Answer

True. As the temperature is lowered from -16°C to -20°C , the time taken for the reactions involved in the spoiling of pizza dough increases.

Problem 5

True or false

(a). An increase in temperature lowers the activation energy.

(b). A catalyst lowers the activation energy.

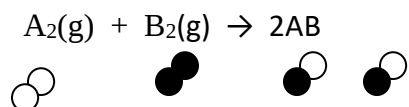
Answer

(a). False. As temperature is increased, the activation energy remains the same; however, the rate increases.

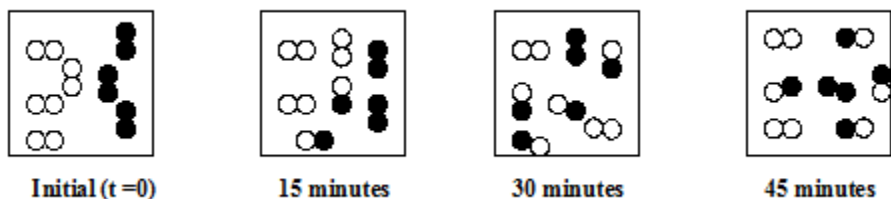
(b). True. There are several such examples in the textbook for chemical and biological systems.

Problem 6

The following diagrams represent a hypothetical reaction:



The element A is represented by open spheres (o) and the element B is represented by shaded spheres (●). These diagrams represent the system at the following times, 0, 15, 30 and 45 minutes, as indicated.



Do these figures indicate that equilibrium has been reached? Select the correct response.

*(a). Yes

(b). No

Answer

We note that for the times 30 and 45 minutes, the concentration is the same. A constant composition indicates that equilibrium has been reached.

Problem 7

What is the expression for the equilibrium constant (K_c) for the reaction:



***(a).** $K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]}$

(b). $K_c = \frac{[\text{PCl}_5]}{[\text{PCl}_3][\text{Cl}_2]}$

(c). $K_c = [\text{PCl}_3][\text{Cl}_2]$

(d). $K_c = \frac{1}{[\text{PCl}_3][\text{Cl}_2]}$

Answer

We use the law of mass action. The expression for the equilibrium constant is a quotient. The numerator contains the product of concentrations of products, raised to the power of the stoichiometric coefficients in the balanced equation. The denominator contains the product of concentrations of reactants, raised to the power of the stoichiometric coefficients in the balanced equation.

Problem 8

What is the expression for the equilibrium constant (K_c) for the reaction



(a). $K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]}$

(b). $K_c = \frac{[\text{PCl}_5]}{[\text{PCl}_3][\text{Cl}_2]}$

***(c).** $K_c = [\text{PCl}_3][\text{Cl}_2]$

(d). $K_c = \frac{1}{[\text{PCl}_3][\text{Cl}_2]}$

Answer

We use the law of mass action, **noting that this a heterogeneous system involving gases and a**

solid, and only gases are included.

Problem 9

What is the expression for the equilibrium constant (K_c) for the reaction representing the decomposition of calcium carbonate, the principal component of egg shells.



(a).
$$K_c = \frac{[\text{CaO}][\text{CO}_2]}{[\text{CaCO}_3]}$$

(b).
$$K_c = \frac{[\text{CaCO}_3]}{[\text{CaO}][\text{CO}_2]}$$

*(c).
$$K_c = [\text{CO}_2]$$

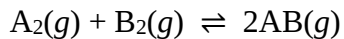
(d).
$$K_c = \frac{1}{[\text{CO}_2]}$$

Answer

We use the law of mass action, **noting that this a heterogeneous system involving gases and solids, and only gases are included.**

Problem 10

For the reaction given below, the value of the equilibrium constant at a certain temperature is 16.0.



At equilibrium, the concentrations of A_2 and B_2 are each 1.0 mol/L. What is the equilibrium concentration of AB?

- (a) 1.0 mol/L
- (b) 1.6 mol/L
- (c) 2.0 mol/L
- *(d) 4.0 mol/L
- (e) 16 mol/L

Answer

We substitute known values K_c , $[A_2]$ and $[B_2]$ to solve for $[AB]$

$$K_c = \frac{[AB]^2}{[A_2][B_2]}$$

$$16.0 = \frac{[AB]^2}{[1.0][1.0]}$$

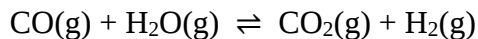
Thus,

$$[AB] = \sqrt{16.0} = 4.0$$

We note that in expressions for equilibrium constant (a unit-less quantity), we omit the units.

Problem 11

For the reaction,



At equilibrium it is found that the concentration of $\text{CO}_2\text{(g)}$ and $\text{H}_2\text{(g)}$ is 0.50 M each while that for CO and H_2O is 1.0 M each. What is the value of the equilibrium constant?

- (a) 4.0
- (b) 2.0
- (c) 1
- (d) 0.50
- *(e) 0.25

Answer

We substitute known values $[\text{CO}]$, $[\text{H}_2\text{O}]$, $[\text{CO}_2]$ and $[\text{H}_2]$ to solve for K_c .

$$K_c = \frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]} = \frac{(0.50)(0.50)}{(1.0)(1.0)} = 0.25$$

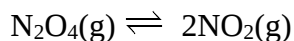
We note that in expressions for equilibrium constant (a unit-less quantity), we omit the units.

Problem 12

(From Green Facts)

Nitrogen dioxide (NO_2) is one of the nitrogen oxides (NO_x), a group of air pollutants produced from combustion processes. Epidemiological studies provide some evidence that long-term NO_2 exposure may decrease lung function and increase the risk of respiratory symptoms. (The effects are hard to isolate because a number of pollutants are present.)

In an experiment, N_2O_4 is introduced in an evacuated container such that its concentration is 3.00 M . It undergoes a reaction:



When equilibrium is achieved, the concentration of N_2O_4 is 1.00 M . Calculate the equilibrium concentration of NO_2 .

- *(a) 4.00 M
- (b) 2.00 M
- (c) 1.00 M
- (d) 0.50 M
- (e) 0.25 M

Answer

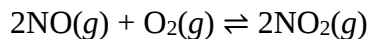
This is a problem based on stoichiometry!

	$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$	
Initial concentration	3.00 M	0
Equilibrium concentration	1.00 M	

Thus, the change in concentration of N_2O_4 is 2.00 M . For **1 molecule** of N_2O_4 , **2 molecules** of NO_2 are produced. Thus, the change in concentration of NO_2 is 4.00 M , which is also the equilibrium concentration since no NO_2 was initially present.

Problem 13

The compound nitrogen monoxide (NO) is a pollutant in automobile exhaust. It undergoes oxidation, as shown below.



At 25°C, the value of K_c for the reaction is 5.4×10^{13} .

Select the correct statement.

- *(a) The reaction mixture contains mostly NO_2
- (b) The reaction mixture contains mostly NO and O_2
- (c) The reaction mixture contains NO, O_2 and NO_2 in roughly equal concentrations

Answer

When the value of the equilibrium constant is much larger than 1, mostly products are present.

Problem 14

A qualitative test for the presence of Fe^{3+} ions in an aqueous solution is the addition of SCN^- ions, which makes the color change from orange to blood red.

The equilibrium is represented by



True or false

- (a). The addition of iron (III) nitrate to a solution at equilibrium (as described above) will cause the color to become more red.
- (b). Heating a solution at equilibrium (as described above) will cause the color to become more red.

Answer

(a). **True.** The solution becomes more red. The addition of the $\text{Fe}(\text{NO}_3)_3$ for a system at equilibrium provides Fe^{3+} ions, a reactant, which drives the equilibrium in the forward direction, or more products, based on Le Chatelier's Principle. This results in an increase in the intensity of red color.

(b). **False.** The solution becomes less red. This is an exothermic reaction. Heating the solution at equilibrium drives the equilibrium in the reverse direction, or more reactants, based on Le Chatelier's Principle. This results in a decrease in the intensity of red color.

Problem 15

As discussed in previous lessons, the production of ammonia (NH₃) from nitrogen and hydrogen, shown below, was an important breakthrough resulting in Nobel prizes in chemistry to Fritz Haber (1918) and Carl Bosch (1931). This compound is widely used in manufacturing fertilizers. Consider the following reaction at equilibrium:



The yield of ammonia can be maximized by carrying out the reaction at

- (a) A high temperature and high pressure
- (b) A high temperature and low pressure
- *(c) A low temperature and high pressure
- (d) A low temperature and low pressure

Answer

We apply Le Chatelier's Principle. For a system at equilibrium, an increase in pressure shifts the equilibrium in the direction of fewer gas molecules (products in this example). Since this is an exothermic reaction, reduction in temperature will shift the equilibrium in the direction of products.

In practice, a catalyst is also used, and an optimum temperature is used so that the reaction rate is high enough.