Rates of Reaction

Consider the decomposition of dinitrogen pentoxide:

$$\underset{\text{dinitrogen pentoxide}}{2\,N_2O_5} \rightarrow \underset{\text{nitrogen dioxide}}{4\,NO_2} + \underset{\text{oxygen}}{O_2}$$

Suppose the average rate of change in N_2O_5 concentration per second was determined to be -1.36×10^{-3} M⁄s at a particular moment:

$$\frac{\Delta[N_2O_5]}{\Delta t} = -1.36 \times 10^{-3}\ \text{M/s}$$

Since 4 mol NO_2 are produced for every 2 mol of N_2O_5 used, the average rate of formation of NO_2 would be:

$$\frac{\Delta[NO_2]}{\Delta t} = \left(\frac{4}{2}\right)(1.36 \times 10^{-3}\ \text{M/s}) = 2.72 \times 10^{-3}\ \text{M/s}$$

Since 1 mol O_2 is produced for every 2 mol N_2O_5 that react, the average rate of formation of O_2 would be:

$$\frac{\Delta[O_2]}{\Delta t} = \left(\frac{1}{2}\right)(1.36 \times 10^{-3}\ \text{M/s}) = 6.80 \times 10^{-4}\ \text{M/s}$$

The average rate of reaction could also be written:

$$-\frac{1}{2}\frac{\Delta[N2O5]}{\Delta t} = \frac{1}{4}\frac{\Delta[NO2]}{\Delta t} = \frac{\Delta[O2]}{\Delta t} = 6.80 \times 10^{-4}\ \text{M/s}$$

Note: The units M⁄s could also be written as $\frac{mol}{L \cdot s}$, mol $L^{-1}s^{-1}$ or M s^{-1}.

In general, for the reaction:

$$aA + bB \rightarrow cC + dD$$

the rate of reaction is defined by:

$$\text{rate} = -\frac{1}{a}\frac{\Delta A}{\Delta t} = -\frac{1}{b}\frac{\Delta B}{\Delta t} = \frac{1}{c}\frac{\Delta C}{\Delta t} = \frac{1}{d}\frac{\Delta D}{\Delta t}$$

Note the use of a negative sign denotes a decrease in the concentration of a reactant with time, and a positive sign denotes the increase in the concentration of a product with time.

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EXERCISES

A. Consider the reaction:

$$N_{2\,(g)} + 3\,H_{2\,(g)} \rightarrow 2\,NH_{3\,(g)}$$

Fill in the blanks:

1) For every molecule of N_2 that reacts, ______ molecules of H_2 react.
   (#)
2) Hydrogen is disappearing __________ __ as fast as the nitrogen.
   (how many times ?)
3) For every molecule of N_2 that reacts, ______ molecules of NH_3 are formed.
   (#)
4) The rate at which NH_3 is formed is __________ __ as fast as the rate at which the N_2 disappears.
   (how many times ?)

B. Consider the following equation:

$$4\,NH_{3\,(g)} + 5\,O_{2\,(g)} \rightarrow 4\,NO_{(g)} + 6\,H_2O_{(g)}$$

Suppose that at a particular moment, the ammonia is reacting at a rate of 0.24 mol $L^{-1}s^{-1}$.

1) Write the rate expression for this reaction.
2) What is the rate at which oxygen is reacting?
3) What is the rate at which NO is being formed?
4) What is the rate at which H_2O is being formed?

SOLUTIONS

A. (1) three (2) three times (3) two (4) twice

B. (1) $-\frac{1}{4}\frac{\Delta[NH_3]}{\Delta t} = -\frac{1}{5}\frac{\Delta[O_2]}{\Delta t} = \frac{1}{4}\frac{\Delta[NO]}{\Delta t} = \frac{1}{6}\frac{\Delta[H_2O]}{\Delta t}$ (2) 0.30 M/s (3) 0.24 M/s (4) 0.36 M/s