Section 76 – Chemical Reaction Rates

76-1. What is the difference between average rate, initial rate, and instantaneous rate?

Solution

The instantaneous rate is the rate of a reaction at any particular point in time, a period of time that is so short that the concentrations of reactants and products change by a negligible amount. The initial rate is the instantaneous rate of reaction as it starts (as product just begins to form). Average rate is the average of the instantaneous rates over a time period.

76-2. Ozone decomposes to oxygen according to the equation $2O_3(g) \longrightarrow 3O_2(g).$ Write the equation that relates the rate expressions for this reaction in terms of the disappearance of O_3 and the formation of oxygen.

Solution

Write the rate of change with a negative sign for substances decreasing in concentration (reactants) and a positive sign for those substances being formed (products). Multiply each term by the reciprocal of its coefficient:

$$\text{rate} = -\frac{[O_3]}{\Delta t} = \frac{2}{3}\frac{\Delta[O_2]}{\Delta t}$$

76-3. In the nuclear industry, chlorine trifluoride is used to prepare uranium hexafluoride, a volatile compound of uranium used in the separation of uranium isotopes. Chlorine trifluoride is prepared by the reaction $Cl_2(g) + 3F_2(g) \longrightarrow 2ClF_3(g).$ Write the equation that relates the rate expressions for this reaction in terms of the disappearance of Cl_2 and F_2 and the formation of ClF_3.

Solution

Write the rate of change with a negative sign for substances decreasing in concentration (reactants) and a positive sign for those substances being formed (products). Multiply each term by the reciprocal of its coefficient:

$$\text{rate} = +\frac{1}{2}\frac{\Delta[ClF_3]}{\Delta t} = -\frac{\Delta[Cl_2]}{\Delta t} = -\frac{1}{3}\frac{\Delta[F_2]}{\Delta t}$$

76-4. A study of the rate of dimerization of C_4H_6 gave the data shown in the table:

$$2C_4H_6 \longrightarrow C_8H_{12}$$

Time (s)	$[C_4H_6]$ (*M*)
0	1.00×10^{-2}
1600	5.04×10^{-3}
3200	3.37×10^{-3}
4800	2.53×10^{-3}
6200	2.08×10^{-3}

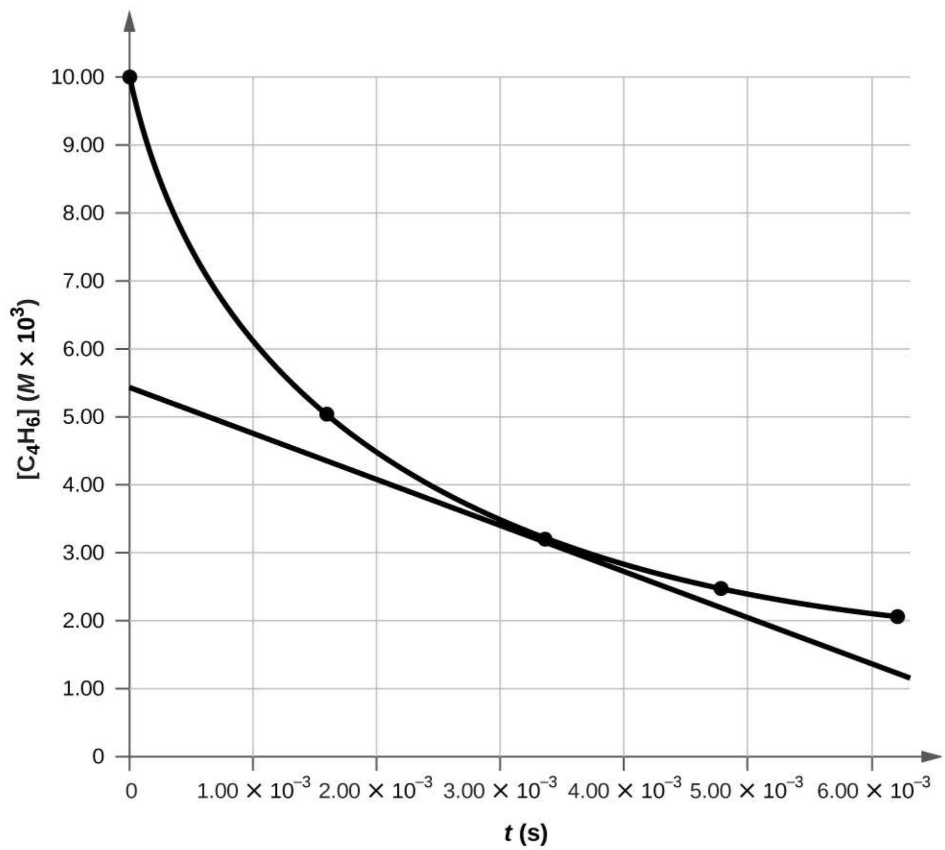
(a) Determine the average rate of dimerization between 0 s and 1600 s, and between 1600 s and 3200 s.

(b) Estimate the instantaneous rate of dimerization at 3200 s from a graph of time versus $[C_4H_6]$. What are the units of this rate?

(c) Determine the average rate of formation of C_8H_{12} at 1600 s and the instantaneous rate of formation at 3200 s from the rates found in parts (a) and (b).

Solution

Plot the concentration of C_4H_6 against time and determine the various slopes required:



(a) $\text{rate} = -\dfrac{5.04 \times 10^{-3}\ M - 1.00 \times 10^{-2}\ M}{1600\ \text{s} - 0\ \text{s}} = 3.10 \times 10^{-6}\ M\ \text{s}^{-1}$

$\text{rate} = -\dfrac{3.37 \times 10^{-3}\ M - 5.04 \times 10^{-3}\ M}{3200\ \text{s} - 1600\ \text{s}} = 1.04 \times 10^{-6}\ M\ \text{s}^{-1}$;

(b) from the approximate points on tangent line in the figure at 3200 s:

$\text{rate} = -\dfrac{2.50 \times 10^{-3}\ M - 4.50 \times 10^{-3}\ M}{4.30 \times 10^{3}\ \text{s} - 1.7 \times 10^{3}\ \text{s}} = 7.7 \times 10^{-7}\ M\ \text{s}^{-1}$;

(c) average rate = $\dfrac{3.10 \times 10^{-6}\ M - 0\ M}{2} = 1.55 \times 10^{-6}\ M\ \text{s}^{-1}$

Instantaneous rate = $\dfrac{7.7 \times 10^{-7}}{2} = 3.8 \times 10^{-7}\ M\,\text{s}^{-1}$

somewhat different values may be obtained depending upon the slope of the drawn line.

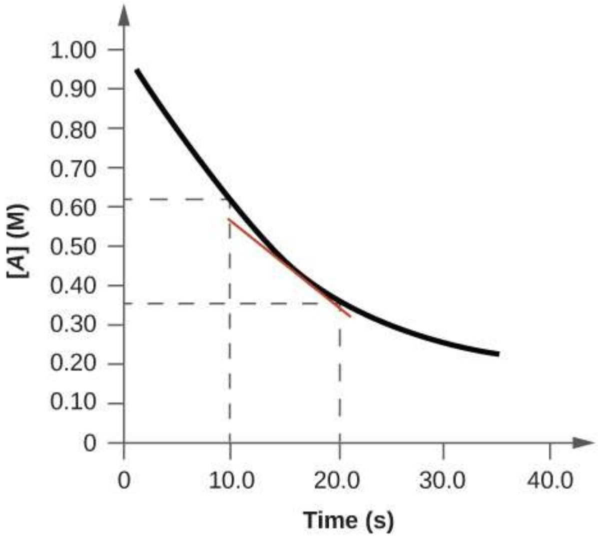
76-5. A study of the rate of the reaction represented as $2A \longrightarrow B$ gave the following data:

Time (s)	0.0	5.0	10.0	15.0	20.0	25.0	35.0
[*A*] (*M*)	1.00	0.775	0.625	0.465	0.360	0.285	0.230

(a) Determine the average rate of disappearance of *A* between 0.0 s and 10.0 s, and between 10.0 s and 20.0 s.
(b) Estimate the instantaneous rate of disappearance of *A* at 15.0 s from a graph of time versus [*A*]. What are the units of this rate?
(c) Use the rates found in parts (a) and (b) to determine the average rate of formation of *B* between 0.00 s and 10.0 s, and the instantaneous rate of formation of *B* at 15.0 s.

Solution

Plot the concentration against time and determine the required slopes:



(a) Average rates are computed directly from the reaction's rate expression and the specified concentration/time data:

average rate, $0 - 10\text{ s} = -\dfrac{0.625\ M - 1.00\ M}{10.0\text{ s} - 0.00\text{ s}} = 0.0375\text{ mol L}^{-1}\text{ s}^{-1}$

average rate, $10 - 20\text{ s} = -\dfrac{0.360\ M - 0.625\ M}{20.0\text{ s} - 10.0\text{ s}} = 0.0265\text{ mol L}^{-1}\text{ s}^{-1}$;

(b) The instantaneous rate is estimated as the slope of a line tangent to the curve at 15 s. Such a line is drawn in the plot, and two concentration/time data pairs are used to estimate the line's slope:

instantaneous rate, $15\text{ s} = -\dfrac{0.35\ M - 0.58\ M}{20.0\text{ s} - 10.0\text{ s}} = 0.023\text{ mol L}^{-1}\text{ s}^{-1}$;

(c) To derive rates for the formation of *B* from the previously calculated rates for the disappearance of *A*, we consider the stoichiometry of the reaction, namely, *B* will be produced at one-half the rate of the disappearance of *A*:

$$\text{rate} = -\frac{1}{2}\frac{\Delta[\text{A}]}{\Delta t} = \frac{\Delta[\text{B}]}{\Delta t}$$

average rate for B formation = $\dfrac{0.0375\text{ mol L}^{-1}\text{ s}^{-1}}{2} = 0.0188\text{ mol L}^{-1}\text{ s}^{-1}$

instantaneous rate for B formation = $\dfrac{0.023\text{ mol L}^{-1}\text{ s}^{-1}}{2} = 0.0120\text{ mol L}^{-1}\text{ s}^{-1}$

76-6. Consider the following reaction in aqueous solution:

$$5\text{Br}^-(aq) + \text{BrO}_3^-(aq) + 6\text{H}^+(aq) \longrightarrow 3\text{Br}_2(aq) + 3\text{H}_2\text{O}(l)$$

If the rate of disappearance of $\text{Br}^-(aq)$ at a particular moment during the reaction is 3.5×10^{-4} mol L^{-1} s^{-1}, what is the rate of appearance of $\text{Br}_2(aq)$ at that moment?

Solution

$$\frac{3}{5}(3.5 \times 10^{-4} \text{ mol L}^{-1} \text{ s}^{-1}) = 2.1 \times 10^{-4} \text{ mol L}^{-1} \text{ s}^{-1}$$