Section 6.1: Reaction Rates
Tutorial 1 Practice, page 350

1. (a) Given: \([H_2(g)]_{t=0} = 1.00 \text{ mol/L}; \ [H_2(g)]_{t=2.6} = 0.500 \text{ mol/L}

Required: average rate of disappearance of hydrogen gas over the first 2.16 s

Analysis: Since the average rate of disappearance of a reactant will be a negative number, use the following equation:

\[
\text{rate}_A = \frac{[A]}{t}
\]

Solution: \[\text{rate}_{H_2(g)} = \left( \frac{[H_2(g)]}{t} \right) \]

\[= \left( \frac{[H_2(g)]_{t=2.6} - [H_2(g)]_{t=0}}{2.16 \text{ s} - 0 \text{ s}} \right) \]

\[= \left( \frac{0.500 \text{ mol/L} - 1.00 \text{ mol/L}}{2.16 \text{ s}} \right) \]

\[= (0.231 \text{ mol/(L} \cdot \text{s)}) \]

\[\text{rate}_{H_2(g)} = 0.231 \text{ mol/(L} \cdot \text{s)} \]

Statement: The average rate of disappearance of hydrogen gas over the first 2.16 s of the reaction is 0.231 mol/(L \cdot s).

(b) Given: \([HCl(g)]_{t=0} = 0.00 \text{ mol/L}; \ [HCl(g)]_{t=4.32} = 1.50 \text{ mol/L}

Required: average rate of appearance of hydrogen chloride gas over the first 4.32 s

Analysis: Since the average rate of appearance of a product will be a positive number, use the following equation:

\[
\text{rate}_A = \frac{[A]}{t}
\]

Solution: \[\text{rate}_{HCl(g)} = \frac{[HCl(g)]}{t} \]

\[= \frac{[HCl(g)]_{t=4.32} - [HCl(g)]_{t=0}}{4.32 \text{ s} - 0 \text{ s}} \]

\[= \frac{1.50 \text{ mol/L} - 0.00 \text{ mol/L}}{4.32 \text{ s}} \]

\[\text{rate}_{HCl(g)} = 0.347 \text{ mol/(L} \cdot \text{s)} \]

Statement: The average rate of appearance of hydrogen chloride gas over the first 4.32 s of the reaction is 0.347 mol/(L \cdot s).

(c) Given: \([Cl_2(g)]_{t=2.16} = 0.500 \text{ mol/L}; \ [Cl_2(g)]_{t=4.32} = 0.250 \text{ mol/L}

Required: average rate of disappearance of chlorine gas between 2.16 s and 4.32 s

Analysis: The average rate of disappearance will be a negative number, so use the following equation:

\[
\text{rate}_A = \frac{[A]}{t}
\]
Solution: \( \text{rate}_{\text{Cl}_2(g)} = \left( \frac{[\text{Cl}_2(g)]}{t} \right) \)

\[ = \left( \frac{[\text{Cl}_2(g)]_{t=4.32 \text{ s}} - [\text{Cl}_2(g)]_{t=2.16 \text{ s}}}{4.32 \text{ s} - 2.16 \text{ s}} \right) \]

\[ = \left( \frac{0.250 \text{ mol/L} - 0.500 \text{ mol/L}}{2.16 \text{ s}} \right) \]

\[ = -0.116 \text{ mol/(L \cdot s)} \]

\[ \text{rate}_{\text{Cl}_2(g)} = 0.116 \text{ mol/(L \cdot s)} \]

Statement: The average rate of disappearance of chlorine gas between 2.16 s and 4.32 s is 0.116 mol/(L \times s).

(d) Given: \([\text{H}_2(g)]_{t=2.16 \text{ s}} = 0.500 \text{ mol/L}; [\text{H}_2(g)]_{t=4.32 \text{ s}} = 0.250 \text{ mol/L}\)

Required: average rate of disappearance of hydrogen gas between 2.16 s and 4.32 s

Analysis: The average rate of disappearance will be a negative number, so use the following equation:

\[ \text{rate}_A = \frac{[A]}{t} \]

Solution: \( \text{rate}_{\text{H}_2(g)} = \left( \frac{[\text{H}_2(g)]}{t} \right) \)

\[ = \left( \frac{[\text{H}_2(g)]_{t=4.32 \text{ s}} - [\text{H}_2(g)]_{t=2.16 \text{ s}}}{4.32 \text{ s} - 2.16 \text{ s}} \right) \]

\[ = \left( \frac{0.250 \text{ mol/L} - 0.500 \text{ mol/L}}{2.16 \text{ s}} \right) \]

\[ = -(-0.116 \text{ mol/(L \cdot s)}) \]

\[ \text{rate}_{\text{H}_2(g)} = 0.116 \text{ mol/(L \cdot s)} \]

Statement: The average rate of disappearance of hydrogen gas between 2.16 s and 4.32 s is 0.116 mol/(L \times s).

Tutorial 2 Practice, pages 352–353

1. Given: Figure 6

Required: average rate of appearance of oxygen gas between 5 s and 10 s

Analysis: The average rate of reaction is the slope of the secant line between \( t = 5 \text{ s} \) and \( t = 10 \text{ s} \).

\[ \text{rate} = \frac{y}{x} \]

Solution: Step 1. From the graph, interpolate the concentrations of oxygen gas at 5 s and 10 s:

\([\text{O}_2(g)]_{t=5 \text{ s}} = 0.13 \text{ mol/L}; [\text{O}_2(g)]_{t=10 \text{ s}} = 0.15 \text{ mol/L}\)
Step 2. Calculate the slope of the secant line.

\[
\text{rate}_{O_2(g)} = \frac{y}{x} = \frac{0.15 \text{ mol/L} - 0.13 \text{ mol/L}}{10 \text{ s} - 5 \text{ s}}
\]

\[
\text{rate}_{O_2(g)} = 4 \times 10^{-3} \text{ mol/(L \cdot s)}
\]

**Statement:** The average rate of appearance of oxygen gas between 5 s and 10 s is \(4 \times 10^{-3} \text{ mol/(L \cdot s)}\).

**Tutorial 3 Practice, pages 356–357**

1. **Given:** Figure 10

   **Required:** instantaneous rate of appearance of oxygen gas at 4 s

   **Analysis:** In Figure 10, a tangent to the oxygen gas concentration curve is drawn at 4 s. This tangent line is the hypotenuse of a right triangle; \(\Delta y\) is the change in concentration, \([O_2(g)]_{t=4 \text{ s}}\), and \(\Delta x\) is the change in time, \(\Delta t\). Determine \([O_2(g)]_{t=4 \text{ s}}\) and \(\Delta t\). Then, substitute these values for \(\Delta y\) and \(\Delta x\) in the slope formula to determine the instantaneous rate of appearance of oxygen gas at 4 s.

   **Solution:** Determine \([O_2(g)]_{t=4 \text{ s}}\) and \(\Delta t\).

   \[ [O_2(g)]_{t=4 \text{ s}} = 0.135 \text{ mol/L} \quad 0.085 \text{ mol/L} \quad t = 7.3 \text{ s} \quad 0.7 \text{ s} \]

   \[ [O_2(g)]_{t=4 \text{ s}} = 0.05 \text{ mol/L} \quad t = 6.6 \text{ s} \]

   Use the slope formula to determine the instantaneous rate.

   \[
   \text{rate}_{\text{instantaneous at } t=4 \text{ s}} = \frac{\Delta y}{\Delta x} \quad \text{slope of the tangent line at 4 s}
   \]

   \[
   = \frac{[O_2(g)]_{t=4 \text{ s}}}{t} = \frac{0.05 \text{ mol/L}}{6.6 \text{ s}}
   \]

   \[
   \text{rate}_{\text{instantaneous at } t=4 \text{ s}} = 8 \times 10^{-3} \text{ mol/(L \cdot s)}
   \]

   **Statement:** The instantaneous rate of appearance of oxygen gas at 4 s is \(8 \times 10^{-3} \text{ mol/(L \cdot s)}\).
2. (a) Graphs will be curves of best fit and may vary. Sample graph:

(b) Answers may vary, as graphs, tangent lines, and points used in calculations may vary. Sample answer:

**Given:** Graph in (a)

**Required:** instantaneous rate of appearance of hydrogen gas at 60 s, 150 s, and 210 s

**Analysis:** Draw tangents to the curve at \( t = 60 \) s and \( t = 150 \) s. Each tangent line is the hypotenuse of a right triangle. \( \Delta y \) is the change in volume, and \( \Delta x \) is the change in time. Substitute these values for \( \Delta y \) and \( \Delta x \) in the slope formula to get the instantaneous rate of appearance of hydrogen gas at 60 s and 150 s. At \( t = 210 \) s, \( \Delta y = 0 \), because at this point, the curve is a horizontal line.
Solution: To calculate the instantaneous rate at $t = 60$ s, use the points (14 s, 1.5 mL) and (105 s, 6.3 mL) on the tangent to the curve at 60 s.

$$\text{rate}_{\text{instantaneous at } t=60 \text{ s}} = \text{slope of the tangent at 60 s}$$

$$= \frac{y}{x} \text{ at 60 s}$$

$$= \frac{6.3 \text{ mL} - 1.5 \text{ mL}}{105 \text{ s} - 14 \text{ s}}$$

$$= 0.053 \text{ mL/s}$$

To calculate the instantaneous rate at $t = 150$ s, use the points (60 s, 4.8 mL) and (180 s, 8.5 mL) on the tangent to the curve at 150 s.

$$\text{rate}_{\text{instantaneous at } t=150 \text{ s}} = \text{slope of the tangent at 150 s}$$

$$= \frac{y}{x} \text{ at 150 s}$$

$$= \frac{8.5 \text{ mL} - 4.8 \text{ mL}}{180 \text{ s} - 60 \text{ s}}$$

$$= 0.031 \text{ mL/s}$$

To calculate the instantaneous rate at $t = 210$ s, use the points (170 s, 8.2 mL) and (220 s, 8.7 mL) on the tangent to the curve at 210 s.

$$\text{rate}_{\text{instantaneous at } t=210 \text{ s}} = \text{slope of the tangent at 210 s}$$

$$= \frac{y}{x} \text{ at 210 s}$$

$$= \frac{8.7 \text{ mL} - 8.2 \text{ mL}}{220 \text{ s} - 170 \text{ s}}$$

$$= 0.010 \text{ mL/s}$$

Statement: The instantaneous rate of appearance of hydrogen gas at is 0.053 mL/s at 60 s, 0.031 mL/s at 150 s, and 0.010 mL/s at 210 s. (c) The rate of appearance of hydrogen gas is faster at 60 s than at 200 s. This is indicated by the decreasing slope of the graph over time.

Tutorial 4 Practice, page 360

1. Given: $N_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g)$

Required: stoichiometric rate relationships

Analysis: Rate relationships are proportional to the stoichiometric relationships in the chemical equation.

Solution:

(a) $\text{H}_2(g) : \text{NH}_3(g) = 3:2$

(b) $N_2(g) : \text{H}_2(g) = 1:3$

(c) $N_2(g) : \text{NH}_3(g) = 1:2$
2. Given: \(4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g)\); instantaneous rate of consumption of 
\(\text{NH}_3(g), \frac{[\text{NH}_3(g)]}{t} = 1.8 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}\)

**Required:** (a) rate of consumption of \(\text{O}_2(g)\)
(b) rate of appearance of \(\text{H}_2\text{O}(g)\)

**Analysis:** Scale the rates by the inverse of their coefficients in the balanced chemical equation. Then, substitute the given rate and solve for the required rates.

**Solution:**
\[
\frac{1}{4} \left( \frac{[\text{NH}_3(g)]}{t} \right) = \frac{1}{5} \left( \frac{[\text{O}_2(g)]}{t} \right) = \frac{1}{6} \left( \frac{[\text{H}_2\text{O}(g)]}{t} \right) 
\]

(a) 
\[
\frac{1}{5} \left( \frac{[\text{O}_2(g)]}{t} \right) = \frac{1}{4} \left( \frac{[\text{NH}_3(g)]}{t} \right) 
\]

\[
\frac{[\text{O}_2(g)]}{t} = \frac{5}{4} (1.8 \times 10^{-2} \text{ mol/(L} \cdot \text{s)})
\]

\[
\frac{[\text{O}_2(g)]}{t} = 2.3 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}
\]

(b) 
\[
\frac{1}{6} \left( \frac{[\text{H}_2\text{O}(g)]}{t} \right) = \frac{1}{4} \left( \frac{[\text{NH}_3(g)]}{t} \right) 
\]

\[
\frac{[\text{H}_2\text{O}(g)]}{t} = \frac{6}{4} (1.8 \times 10^{-2} \text{ mol/(L} \cdot \text{s)})
\]

\[
\frac{[\text{H}_2\text{O}(g)]}{t} = 2.7 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}
\]

**Statement:** (a) The rate of consumption of \(\text{O}_2(g)\) is \(2.3 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}\).
(b) The rate of appearance of \(\text{H}_2\text{O}(g)\) is \(2.7 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}\).

3. Given: \(aA + bB \rightarrow cC\)

\[
\frac{1}{a} \left( \frac{A}{t} \right) = \frac{1}{b} \left( \frac{B}{t} \right) = \frac{1}{c} \left( \frac{C}{t} \right) 
\]

\[
\frac{A}{t} = 0.0080 \text{ mol/(L} \cdot \text{s); } \frac{B}{t} = 0.0120 \text{ mol/(L} \cdot \text{s); } \frac{C}{t} = 0.0160 \text{ mol/(L} \cdot \text{s)}
\]

**Required:** \(a, b, c\)

**Analysis:** \(a : b : c = 0.0080 : 0.0120 : 0.0160\)

**Solution:**
\[
\frac{a}{b} : \frac{b}{c} = \frac{0.0080}{0.004} : \frac{0.0120}{0.004} : \frac{0.0160}{0.004}
\]

\[
a : b : c = 2 : 3 : 4
\]

**Statement:** The values of the coefficients of \(A, B, \text{ and } C\) are \(a = 2, b = 3, \text{ and } c = 4\).
Section 6.1 Questions, page 361

1. (a) Given: \([O_2(g)]_{t=0} = 0.200 \text{ mol/L}; [O_2(g)]_{t=40} = 0.000 \text{ mol/L}\)

Required: average rate of disappearance of oxygen gas over the first 40 s

Analysis: Since the average rate of disappearance of a reactant will be a negative number, use the equation

\[
\text{rate}_A = \frac{[A]}{t}
\]

Solution: \[
\text{rate}_{O_2(g)} = \frac{[O_2(g)]}{t}
\]

\[
= \frac{[O_2(g)]_{t=40} - [O_2(g)]_{t=0}}{40 \text{ s} - 0 \text{ s}}
\]

\[
= \frac{0.000 \text{ mol/L} - 0.200 \text{ mol/L}}{40 \text{ s}}
\]

\[
= \left( 5 \times 10^{-3} \text{ mol/}(L \cdot s) \right)
\]

rate_{O_2(g)} = 5 \times 10^{-3} \text{ mol/}(L \cdot s)

Statement: The average rate of disappearance of oxygen gas over the first 40 s of the reaction is

\[
5 \times 10^{-3} \text{ mol/}(L \cdot s).
\]

2. Given: \(\text{MnO}_4^{-}(aq) + 5 \text{Fe}^{2+}(aq) + 8 \text{H}^{+}(aq) \rightarrow \text{Mn}^{2+}(aq) + 5 \text{Fe}^{3+}(aq) + 4 \text{H}_2\text{O}(l)\)

instantaneous rate of consumption of \(\text{MnO}_4^{-}(aq)\), \[
\frac{[\text{MnO}_4^{-}(aq)]}{t} = 4.0 \times 10^{-2} \text{ mol/}(L \cdot s)
\]

Required: rate of consumption of \(\text{Fe}^{2+}(aq)\) and \(\text{H}^{+}(aq)\); rate of appearance of \(\text{Mn}^{2+}(aq)\), \(\text{Fe}^{3+}(aq)\), and \(\text{H}_2\text{O}(l)\)

Analysis: Scale the rates by the inverse of their coefficients in the balanced chemical equation. Then, substitute the given rate and solve for the required rates.

Solution: \[
\frac{[\text{MnO}_4^{-}(aq)]}{t} = \frac{1}{5} \left( \frac{[\text{Fe}^{2+}(aq)]}{t} \right) = \frac{1}{8} \left( \frac{[\text{H}^{+}(aq)]}{t} \right)
\]

\[
= \frac{[\text{Mn}^{2+}(aq)]}{t} = \frac{1}{5} \left( \frac{[\text{Fe}^{3+}(aq)]}{t} \right) = \frac{1}{4} \left( \frac{[\text{H}_2\text{O}(l)]}{t} \right)
\]

Rate of consumption of \(\text{Fe}^{2+}(aq)\): \[
\frac{[\text{Fe}^{2+}(aq)]}{t} = \frac{[\text{MnO}_4^{-}(aq)]}{t}
\]

\[
= 5 \left( \frac{[\text{MnO}_4^{-}(aq)]}{t} \right)
\]

\[
= 5(4.0 \times 10^{-2} \text{ mol/}(L \cdot s))
\]

\[
\frac{[\text{Fe}^{2+}(aq)]}{t} = 0.20 \text{ mol/}(L \cdot s)
\]
Rate of consumption of H\(^+\)(aq): \[ \frac{1}{8} \left( \frac{[H^+ (aq)]}{t} \right) = \frac{[MnO_4^- (aq)]}{t} \]

\[ \frac{[H^+ (aq)]}{t} = 8 \left( \frac{[MnO_4^- (aq)]}{t} \right) \]

\[ = 8(4.0 \times 10^{-2} \text{ mol/(L \cdot s)}) \]

\[ \frac{[H^+ (aq)]}{t} = 0.32 \text{ mol/(L \cdot s)} \]

Rate of appearance of Mn\(^{2+}\)(aq): \[ \frac{[Mn^{2+} (aq)]}{t} = \frac{[MnO_4^- (aq)]}{t} \]

\[ \frac{[Mn^{2+} (aq)]}{t} = 4.0 \times 10^{-2} \text{ mol/(L \cdot s)} \]

Rate of appearance of Fe\(^{3+}\)(aq): \[ \frac{1}{5} \left( \frac{[Fe^{3+} (aq)]}{t} \right) = \frac{[MnO_4^- (aq)]}{t} \]

\[ \frac{[Fe^{3+} (aq)]}{t} = 5 \left( \frac{[MnO_4^- (aq)]}{t} \right) \]

\[ = 5(4.0 \times 10^{-2} \text{ mol/(L \cdot s)}) \]

\[ \frac{[Fe^{3+} (aq)]}{t} = 0.20 \text{ mol/(L \cdot s)} \]

Rate of appearance of H\(_2\)O(l): \[ \frac{1}{4} \left( \frac{[H_2O (l)]}{t} \right) = \frac{[MnO_4^- (aq)]}{t} \]

\[ \frac{[H_2O (l)]}{t} = 4 \left( \frac{[MnO_4^- (aq)]}{t} \right) \]

\[ = 4(4.0 \times 10^{-2} \text{ mol/(L \cdot s)}) \]

\[ \frac{[H_2O (l)]}{t} = 0.16 \text{ mol/(L \cdot s)} \]

**Statement:** The rate of consumption of Fe\(^{2+}\)(aq) is 0.20 mol/(L \cdot s), and of H\(^+\)(aq), 0.32 mol/(L \cdot s). The rate of appearance of Mn\(^{2+}\)(aq) is 0.040 mol/(L \cdot s); of Fe\(^{3+}\)(aq), 0.20 mol/(L \cdot s); and of H\(_2\)O(l), 0.16 mol/(L \cdot s).

3. (a) **Given:** 4 NH\(_3\)(g) + 5 O\(_2\)(g) \rightarrow 4 NO(g) + 6 H\(_2\)O(g); instantaneous rate of consumption of NH\(_3\)(g) at 10 s is 2.0 \times 10^{-2} \text{ mol/(L \cdot s)}

**Required:** (i) rate of consumption of oxygen gas at 10 s 
(ii) rate of appearance of water vapour at 10 s

**Analysis:** Scale the rates by the inverse of their coefficients in the balanced chemical equation. Then, substitute the given rate and solve for the required rates.
Solution: \[4\ \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g)\]

\[
\frac{1}{4} \left( \frac{[\text{NH}_3(g)]}{t} \right) = \frac{1}{5} \left( \frac{[\text{O}_2(g)]}{t} \right) = \frac{1}{6} \left( \frac{[\text{H}_2\text{O}(g)]}{t} \right)
\]

(i) \[
\frac{[\text{O}_2(g)]}{t} = \frac{5}{4} (2.0 \times 10^{-2} \text{ mol/(L \cdot s)})
\]

(ii) \[
\frac{[\text{H}_2\text{O}(g)]}{t} = \frac{6}{4} (2.0 \times 10^{-2} \text{ mol/(L \cdot s)})
\]

Statement: (i) The rate of consumption of oxygen gas at 10 s is \(2.5 \times 10^{-2} \text{ mol/(L \cdot s)}\).
(ii) The rate of appearance of water vapour at 10 s is \(3.0 \times 10^{-2} \text{ mol/(L \cdot s)}\).

(b) The instantaneous rates of consumption of ammonia gas and appearance of nitrogen monoxide gas are related by their stoichiometric ratios in the chemical reaction.

4. (a) Given: \(2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g)\)

\[
\frac{[\text{O}_2(g)]}{t} = 2.0 \times 10^{-3} \text{ mol/(L \cdot s)}
\]

Required: rate of the reaction expressed with respect to nitrogen dioxide gas formation; rate of formation of nitrogen dioxide gas

Analysis: The expression for the reaction rate in terms of \(\text{NO}_2(g)\) formation is

\[
\text{rate} = \frac{[\text{NO}_2(g)]}{t}
\]

Scale the rate by the inverse of its coefficient in the balanced chemical equation. Then, substitute the given rate and solve for the required rate.

Solution: Step 1. \[
\frac{1}{2} \left( \frac{[\text{NO}_2(g)]}{t} \right) = \left( \frac{[\text{O}_2(g)]}{t} \right)
\]

\[
\frac{[\text{NO}_2(g)]}{t} = 2 \left( \frac{[\text{O}_2(g)]}{t} \right)
\]

\[
= 2(2.0 \times 10^{-3} \text{ mol/(L \cdot s)}) = 4.0 \times 10^{-3} \text{ mol/(L \cdot s)}
\]

Statement: The expression for the reaction rate in terms of nitrogen dioxide formation is

\[
\text{rate} = \frac{[\text{NO}_2(g)]}{t}, \text{ and the rate of } \text{NO}_2(g) \text{ formation is } 4.0 \times 10^{-2} \text{ mol/(L \cdot s)}.\]
(b) The two reaction rates have different signs because oxygen gas is being consumed and nitrogen dioxide gas is being formed. Since the concentration of a reactant decreases over time, \( \Delta [O_2(g)] \) is a negative quantity, and since the concentration of a product increases with reaction progress, \( \Delta [NO_2(g)] \) is positive.

5. (a) In general, the reaction of acid with carbonate compound yields water, carbon dioxide, and an ionic compound.

\[
H_2SO_4(aq) + 2 NaHCO_3(aq) \rightarrow 2 H_2O(l) + CO_2(g) + Na_2SO_4(aq)
\]

(b) Given: \( H_2SO_4(aq) + 2 NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2 CO_2(g) + 2 H_2O(l) \);

0.038 mol \( NaHCO_3 \) reacts in 20 s

**Required:** (i) grams of sodium hydrogen carbonate consumed per second; (ii) moles of sulfuric acid consumed per second; (iii) moles of carbon dioxide gas formed per second

**Analysis:** Since the change in mass for a time interval is given, rather than the change concentration, use the following equation:

\[
\text{rate} = \frac{\text{amount reacted}}{\text{produced}}
\]

Scale the rates by the inverse of their coefficients in the balanced chemical equation.

rate of consumption of \( H_2SO_4(aq) \) = \( \frac{1}{2} \) (rate of consumption of \( NaHCO_3(aq) \))

\[= \frac{1}{2} \text{(rate of formation of } CO_2(g) \text{)}\]

Then, substitute the given rate and solve for the required rates.

For (i), first convert the amount 0.038 mol \( NaHCO_3 \) to mass in grams:

\[
M_{NaHCO_3} = M_{Na} + M_{H} + M_{C} + 3M_{O}
\]

\[= 22.99 \text{ g/mol} + 1.01 \text{ g/mol} + 12.01 \text{ g/mol} + 3(16.00 \text{ g/mol})
\]

\[M_{NaHCO_3} = 84.01 \text{ g/mol}
\]

\[
m_{NaHCO_3} = (0.038 \text{ mol}) \left( \frac{84.01 \text{ g}}{1.00 \text{ mol}} \right)
\]

\[m_{NaHCO_3} = 3.192 \text{ g} \text{ (two extra digits carried)}
\]

**Solution:** (i) rate of consumption of \( NaHCO_3(aq) \) = \( \frac{\text{amount } NaHCO_3(aq) \text{ reacted}}{t} \)

\[= \frac{3.192 \text{ g}}{20 \text{ s}}
\]

rate of consumption of \( NaHCO_3(aq) \) = \( 2 \times 10^{-1} \) g/s
(ii) rate of consumption of $\text{H}_2\text{SO}_4\text{(aq)} = \frac{1}{2}$ (rate of consumption of $\text{NaHCO}_3\text{(aq)}$) \\
\hspace{1cm} = \frac{1}{2} \left( \frac{\text{amount NaHCO}_3\text{(aq)} \text{ reacted}}{t} \right) \\
\hspace{1cm} = \frac{1}{2} \left( \frac{0.038 \text{ mol}}{20 \text{ s}} \right) \\
\hspace{1cm} \text{rate of consumption of } \text{H}_2\text{SO}_4\text{(aq)} = 1 \times 10^{-3} \text{ mol / s} \\
(iii) \frac{1}{2} \left( \text{rate of formation of } \text{CO}_2\text{(aq)} \right) = \frac{1}{2} \left( \text{rate of consumption of } \text{NaHCO}_3\text{(aq)} \right) \\
\hspace{1cm} = \frac{0.038 \text{ mol}}{20 \text{ s}} \\
\hspace{1cm} \text{rate of formation of } \text{CO}_2\text{(aq)} = 2 \times 10^{-3} \text{ mol / s} \\
\text{Statement: In this reaction, (i) } 2 \times 10^{-1} \text{ g of sodium hydrogen carbonate is consumed per second; (ii) } 1 \times 10^{-3} \text{ mol sulfuric acid is consumed per second; and, (iii) } 2 \times 10^{-3} \text{ mol of carbon dioxide gas is formed per second.}