## Section 6.1: Reaction Rates
**Tutorial 1 Practice, page 350**

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

$$rate_A = -\frac{D[A]}{Dt}$$

**Solution:**
$$rate_{H_2(g)} = -\left(\frac{D[H_2(g)]}{Dt}\right)$$
$$= -\left(\frac{[H_2(g)]_{t=2.6\,s} - [H_2(g)]_{t=0\,s}}{2.16\text{ s} - 0\text{ s}}\right)$$
$$= -\left(\frac{0.500\text{ mol/L} - 1.00\text{ mol/L}}{2.16\text{ s}}\right)$$
$$= -(-0.231\text{ mol/(L}\cdot\text{s}))$$
$$rate_{H_2(g)} = 0.231\text{ mol/(L}\cdot\text{s})$$

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

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

$$rate_A = \frac{D[A]}{Dt}$$

**Solution:**
$$rate_{HCl(g)} = \frac{D[HCl(g)]}{Dt}$$
$$= \frac{[HCl(g)]_{t=4.32\,s} - [HCl(g)]_{t=0\,s}}{4.32\text{ s} - 0\text{ s}}$$
$$= \frac{1.50\text{ mol/L} - 0.00\text{ mol/L}}{4.32\text{ s}}$$
$$rate_{HCl(g)} = 0.347\text{ mol/(L}\cdot\text{s})$$

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

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

$$rate_A = -\frac{D[A]}{Dt}$$

**Solution:** $\text{rate}_{Cl_2(g)} = -\left( \dfrac{D[Cl_2(g)]}{Dt} \right)$

$\qquad\qquad\quad = -\left( \dfrac{[Cl_2(g)]_{t=4.32\,s} - [Cl_2(g)]_{t=2.16\,s}}{4.32\,s - 2.16\,s} \right)$

$\qquad\qquad\quad = -\left( \dfrac{0.250\ mol/L - 0.500\ mol/L}{2.16\,s} \right)$

$\qquad\qquad\quad = -(-0.116\ mol/(L \cdot s))$

$\qquad \text{rate}_{Cl_2(g)} = 0.116\ mol/(L \cdot s)$

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

**(d) Given:** $[H_2(g)]_{t=2.16\,s} = 0.500$ mol/L; $[H_2(g)]_{t=4.32\,s} = 0.250$ 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:

$\text{rate}_A = -\dfrac{D[A]}{Dt}$

**Solution:** $\text{rate}_{H_2(g)} = -\left( \dfrac{D[H_2(g)]}{Dt} \right)$

$\qquad\qquad\quad = -\left( \dfrac{[H_2(g)]_{t=4.32\,s} - [H_2(g)]_{t=2.16\,s}}{4.32\,s - 2.16\,s} \right)$

$\qquad\qquad\quad = -\left( \dfrac{0.250\ mol/L - 0.500\ mol/L}{2.16\,s} \right)$

$\qquad\qquad\quad = -(-0.116\ mol/(L \cdot s))$

$\qquad \text{rate}_{H_2(g)} = 0.116\ mol/(L \cdot s)$

**Statement:** The average rate of disappearance of hydrogen gas between 2.16 s and 4.32 s is 0.116 mol/(L×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 $t = 5$ s and $t = 10$ s.

$\text{rate} = \dfrac{Dy}{Dx}$

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

$[O_2(g)]_{t=5\,s} = 0.13$ mol/L; $[O_2(g)]_{t=10\,s} = 0.15$ mol/L

**Step 2.** Calculate the slope of the secant line.

$$\text{rate}_{O_2\,(g)} = \frac{Dy}{Dx}$$

$$= \frac{0.15\ \text{mol/L} - 0.13\ \text{mol/L}}{10\ \text{s} - 5\ \text{s}}$$

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

**Statement:** The average rate of appearance of oxygen gas between 5 s and 10 s is $4 \times 10^{-3}$ mol/(L×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, $D[O_2(g)]_{t=4\ s}$, and $\Delta x$ is the change in time, $\Delta t$. Determine $D[O_2(g)]_{t=4\ s}$ 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 $D[O_2(g)]_{t=4\ s}$ and $\Delta t$.

$$D[O_2(g)]_{t=4\ s} = 0.135\ \text{mol/L} - 0.085\ \text{mol/L} \qquad Dt = 7.3\ \text{s} - 0.7\ \text{s}$$

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

Use the slope formula to determine the instantaneous rate.
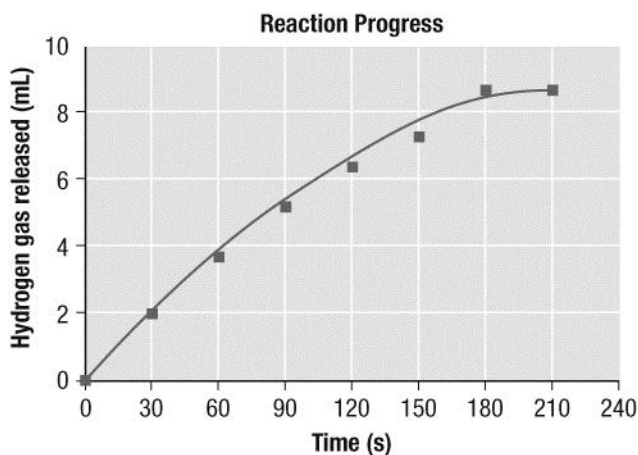
$$\text{rate}_{\text{instantaneous at } t=4\ s} = \text{ slope of the tangent line at 4 s}$$

$$= \frac{Dy}{Dx}\ \text{at 4 s}$$

$$= \frac{D[O_2(g)]_{t=4\ s}}{Dt}$$

$$= \frac{0.05\ \text{mol/L}}{6.6\ \text{s}}$$

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

**Statement:** The instantaneous rate of appearance of oxygen gas at 4 s is $8 \times 10^{-3}$ mol/(L×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.
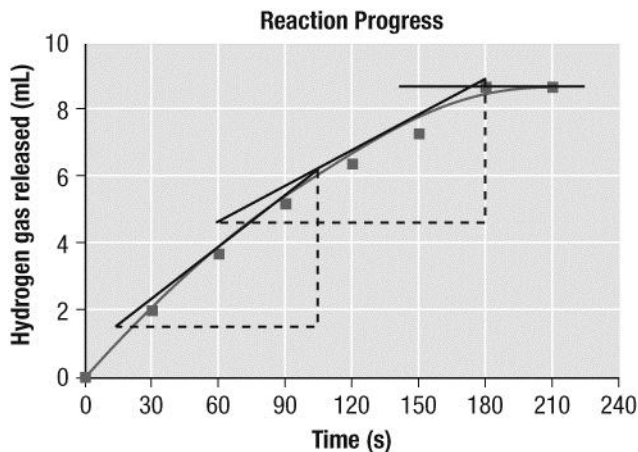
**Solution:** To calculate the instantaneous rate at $t = 60$ s, use the points (14 s, 1.5 mL) and (105 s, 6.3 mL) on the tangent to the curve at 60 s.

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

$$= \frac{Dy}{Dx} \text{ at 60 s}$$

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

$$\text{rate}_{\text{instantaneous at } t = 60 \text{ s}} = 0.053 \text{ mL/s}$$

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.

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

$$= \frac{Dy}{Dx} \text{ at 150 s}$$

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

$$\text{rate}_{\text{instantaneous at } t = 150 \text{ s}} = 0.031 \text{ mL/s}$$

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.

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

$$= \frac{Dy}{Dx} \text{ at 210 s}$$

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

$$\text{rate}_{\text{instantaneous at } t = 150 \text{ s}} = 0.010 \text{ mL/s}$$

**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:** $N_2(g) + 3 H_2(g) \rightarrow 2 NH_3(g)$
**Required:** stoichiometric rate relationships
**Analysis:** Rate relationships are proportional to the stoichiometric relationships in the chemical equation.
**Solution:**
**(a)** $H_2(g):NH_3(g) = 3:2$
**(b)** $N_2(g):H_2(g) = 1:3$
**(c)** $N_2(g):NH_3(g) = 1:2$

**2. Given:** $4 NH_3(g) + 5 O_2(g) \rightarrow 4 NO(g) + 6 H_2O(g)$; instantaneous rate of consumption of

$NH_3(g)$, $\dfrac{D[NH_3(g)]}{Dt} = 1.8 \times 10^{-2}$ mol/(L·s)

**Required: (a)** rate of consumption of $O_2(g)$

**(b)** rate of appearance of $H_2O(g)$

**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:** $\dfrac{1}{4}\left( -\dfrac{D[NH_3(g)]}{Dt} \right) = \dfrac{1}{5}\left( -\dfrac{D[O_2(g)]}{Dt} \right) = \dfrac{1}{6}\left( \dfrac{D[H_2O(g)]}{Dt} \right)$

**(a)** $\dfrac{1}{5}\left( -\dfrac{D[O_2(g)]}{Dt} \right) = \dfrac{1}{4}\left( -\dfrac{D[NH_3(g)]}{Dt} \right)$

$\qquad -\dfrac{D[O_2(g)]}{Dt} = \dfrac{5}{4}(1.8 \times 10^{-2}$ mol/(L·s))

$\qquad \dfrac{D[O_2(g)]}{Dt} = 2.3 \times 10^{-2}$ mol/(L·s)

**(b)** $\dfrac{1}{6}\left( \dfrac{D[H_2O(g)]}{Dt} \right) = \dfrac{1}{4}\left( -\dfrac{D[NH_3(g)]}{Dt} \right)$

$\qquad \dfrac{D[H_2O(g)]}{Dt} = \dfrac{6}{4}(1.8 \times 10^{-2}$ mol/(L·s))

$\qquad \dfrac{D[H_2O(g)]}{Dt} = 2.7 \times 10^{-2}$ mol/(L·s)

**Statement:** (a) The rate of consumption of $O_2(g)$ is $2.3 \times 10^{-2}$ mol/(L×s).

(b) The rate of appearance of $H_2O(g)$ is $2.7 \times 10^{-2}$ mol/(L×s).

**3. Given:** $aA + bB \rightarrow cC$

$\dfrac{1}{a}\left( -\dfrac{DA}{Dt} \right) = \dfrac{1}{b}\left( -\dfrac{DB}{Dt} \right) = \dfrac{1}{c}\left( \dfrac{DC}{Dt} \right)$

$\dfrac{DA}{Dt} = 0.0080$ mol/(L·s); $\quad \dfrac{DB}{Dt} = 0.0120$ mol/(L·s); $\quad \dfrac{DC}{Dt} = 0.0160$ mol/(L·s)

**Required:** $a, b, c$

**Analysis:** $a:b:c = 0.0080:0.0120:0.0160$

**Solution:** $a:b:c = 0.0080:0.0120:0.0160$

$\qquad\qquad = \dfrac{0.0080}{0.004} : \dfrac{0.0120}{0.004} : \dfrac{0.0160}{0.004}$

$\qquad a:b:c = 2:3:4$

**Statement:** The values of the coefficients of A, B, and C are $a = 2$, $b = 3$, and $c = 4$.

**Section 6.1 Questions, page 361**

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

$$rate_A = -\frac{D[A]}{Dt}$$

**Solution:** 
$$rate_{O_2(g)} = -\left(\frac{D[O_2(g)]}{Dt}\right)$$

$$= -\left(\frac{[O_2(g)]_{t=40\,s} - [O_2(g)]_{t=0\,s}}{40\,s - 0\,s}\right)$$

$$= -\left(\frac{0.000\ mol/L - 0.200\ mol/L}{40\,s}\right)$$

$$= -(-5 \times 10^{-3}\ mol/(L \cdot s))$$

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

**Statement:** The average rate of disappearance of oxygen gas over the first 40 s of the reaction is $5 \times 10^{-3}$ mol/(L×s).

**2. Given:** $MnO_4^-(aq) + 5\ Fe^{2+}(aq) + 8\ H^+(aq) \rightarrow Mn^{2+}(aq) + 5\ Fe^{3+}(aq) + 4\ H_2O(l)$;

instantaneous rate of consumption of $MnO_4^-(aq)$, $\dfrac{D[MnO_4^-(aq)]}{Dt} = 4.0 \times 10^{-2}$ mol/(L·s)

**Required:** rate of consumption of $Fe^{2+}(aq)$ and $H^+(aq)$; rate of appearance of $Mn^{2+}(aq)$, $Fe^{3+}(aq)$, and $H_2O(l)$

**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:** 
$$-\frac{D[MnO_4^-(aq)]}{Dt} = \frac{1}{5}\left(-\frac{D[Fe^{2+}(aq)]}{Dt}\right) = \frac{1}{8}\left(-\frac{D[H^+(aq)]}{Dt}\right)$$

$$= \frac{D[Mn^{2+}(aq)]}{Dt} = \frac{1}{5}\left(\frac{D[Fe^{3+}(aq)]}{Dt}\right) = \frac{1}{4}\left(\frac{D[H_2O(l)]}{Dt}\right)$$

Rate of consumption of $Fe^{2+}$(aq): 
$$\frac{1}{5}\left(-\frac{D[Fe^{2+}(aq)]}{Dt}\right) = -\frac{D[MnO_4^-(aq)]}{Dt}$$

$$-\frac{D[Fe^{2+}(aq)]}{Dt} = 5\left(-\frac{D[MnO_4^-(aq)]}{Dt}\right)$$

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

$$-\frac{D[Fe^{2+}(aq)]}{Dt} = 0.20\ mol/(L \cdot s)$$

Rate of consumption of $H^+$(aq): $\frac{1}{8}\left(-\frac{D[H^+(aq)]}{Dt}\right) = -\frac{D[MnO_4^-(aq)]}{Dt}$

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

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

$$-\frac{D[H^+(aq)]}{Dt} = 0.32\ mol/(L \cdot s)$$

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

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

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

$$\frac{D[Fe^{3+}(aq)]}{Dt} = 5\left(-\frac{D[MnO4^-]}{Dt}\right)$$

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

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

Rate of appearance of $H_2O$(l): $\frac{1}{4}\left(\frac{D[H_2O(l)]}{Dt}\right) = -\frac{D[MnO_4^-(aq)]}{Dt}$

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

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

$$\frac{D[H_2O(l)]}{Dt} = 0.16\ mol/(L \cdot s)$$

**Statement:** The rate of consumption of $Fe^{2+}$(aq) is $0.20\ mol/(L \times s)$, and of $H^+$(aq), $0.32\ mol/(L \times s)$. The rate of appearance of $Mn^{2+}$(aq) is $0.040\ mol/(L \times s)$; of $Fe^{3+}$(aq), $0.20\ mol/(L \times s)$; and of $H_2O$(l), $0.16\ mol/(L \times s)$.

**3. (a) Given:** $4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$; instantaneous rate of consumption of $NH_3(g)$ at 10 s is $2.0\ \times 10^{-2}\ mol/(L \times s)$

**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:** $4 NH_3(g) + 5 O_2(g) \rightarrow 4 NO(g) + 6 H_2O(g)$

$$\frac{1}{4}\left(-\frac{D[NH_3(g)]}{Dt}\right) = \frac{1}{5}\left(-\frac{D[O_2(g)]}{Dt}\right) = \frac{1}{6}\left(\frac{D[H_2O(g)]}{Dt}\right)$$

**(i)** $\dfrac{1}{5}\left(-\dfrac{D[O_2(g)]}{Dt}\right) = \dfrac{1}{4}\left(-\dfrac{D[NH_3(g)]}{Dt}\right)$

$$-\frac{D[O_2(g)]}{Dt} = \frac{5}{4}(2.0 \times 10^{-2} \text{ mol/(L} \cdot \text{s)})$$

$$-\frac{D[O_2(g)]}{Dt} = 2.5 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}$$

**(ii)** $\dfrac{1}{6}\left(\dfrac{D[H_2O(g)]}{Dt}\right) = \dfrac{1}{4}\left(-\dfrac{D[NH_3(g)]}{Dt}\right)$

$$\frac{D[H_2O(g)]}{Dt} = \frac{6}{4}(2.0 \times 10^{-2} \text{ mol/(L} \cdot \text{s)})$$

$$\frac{D[H_2O(g)]}{Dt} = 3.0 \times 10^{-2} \text{ mol/(L} \cdot \text{s)}$$

**Statement:** (i) The rate of consumption of oxygen gas at 10 s is $2.5 \times 10^{-2}$ mol/(L×s).

(ii) The rate of appearance of water vapour at 10 s is $3.0 \times 10^{-2}$ mol/(L×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:** $2 NO(g) + O_2(g) \rightarrow 2 NO_2(g)$

$$\frac{D[O_2(g)]}{Dt} = -2.0 \times 10^{-3} \text{ mol/(L} \cdot \text{s)}$$

**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 $NO_2(g)$ formation is

rate $= \dfrac{D[NO_2(g)]}{Dt}$. 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.** $\dfrac{1}{2}\left(\dfrac{D[NO_2(g)]}{Dt}\right) = -\dfrac{D[O_2(g)]}{Dt}$

$$\frac{D[NO_2(g)]}{Dt} = 2\left(-\frac{D[O_2(g)]}{Dt}\right)$$

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

$$\frac{D[NO_2(g)]}{Dt} = 4.0 \times 10^{-3} \text{ mol/(L} \cdot \text{s)}$$

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

rate $= \dfrac{D[NO_2(g)]}{Dt}$, and the rate of $NO_2(g)$ formation is $4.0 \times 10^{-2}$ mol/(L×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.

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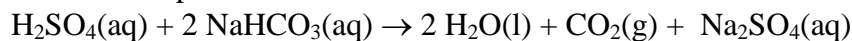
**(b) Given:** $H_2SO_4(aq) + 2\,NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2\,CO_2(g) + 2\,H_2O(l)$;

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:

$$\text{rate} = \frac{\text{amount reacted / produced}}{\text{time interval}}$$

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

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

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

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:

$$M_{NaHCO_3} = M_{Na} + M_{H} + M_{C} + 3M_{O}$$

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

$$M_{NaHCO_3} = 84.01 \text{ g/mol}$$

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

$$m_{NaHCO_3} = 3.192 \text{ g} \quad \text{(two extra digits carried)}$$

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

$$= \frac{3.192 \text{ g}}{20 \text{ s}}$$

$$\text{rate of consumption of } NaHCO_3(aq) = 2 \times 10^{-1} \text{ g/s}$$

**(ii)** rate of consumption of $H_2SO_4(aq)$ = $\dfrac{1}{2}$(rate of consumption of $NaHCO_3(aq)$)

$$= \dfrac{1}{2}\left(\dfrac{\text{amount } NaHCO_3(aq) \text{ reacted}}{\mathrm{D}t}\right)$$

$$= \dfrac{1}{2}\left(\dfrac{0.038\text{ mol}}{20\text{ s}}\right)$$

rate of consumption of $H_2SO_4(aq) = 1\times 10^{-3}\text{mol}/\text{s}$

**(iii)** $\dfrac{1}{2}$(rate of formation of $CO_2(aq)$) = $\dfrac{1}{2}$(rate of consumption of $NaHCO_3(aq)$)

$$= \dfrac{0.038\text{ mol}}{20\text{ s}}$$

rate of formation of $CO_2(aq) = 2 \times 10^{-3}\text{mol}/\text{s}$

**Statement:** In this reaction, (i) $2 \times 10^{-1}$ g of sodium hydrogen carbonate is consumed per second; (ii) $1 \times 10^{-3}$ mol sulfuric acid is consumed per second; and, (iii) $2 \times 10^{-3}$ mol of carbon dioxide gas is formed per second.