

5. d
6. a
7. b
8. d
9. d
10. e
11. c
12. b
13. c
14. Since the system is not closed, the reaction rates are not equal, and equilibrium cannot be established.
15. No, the K_{eq} value does not indicate anything about reaction rates, it only indicates that once equilibrium is reached, the reactant concentrations will be high and the product concentrations will be low.
16. The system has dynamic equilibrium because some solid iodine crystals are subliming to gaseous iodine and at the same time some gaseous iodine crystals are depositing as solid iodine crystals. Both processes are occurring at the same rate so the macroscopic properties remain constant.
17. An increase in pressure will result in a shift to the left where there are fewer gas molecules.
18. Pumping in a non-reacting gas has no effect on the equilibrium. This is because there is no change in the concentrations of the reacting gases.
19. In a chemical system at equilibrium, the concentrations of reactants and products are not in the same ratio as the coefficients in the chemical equation. The coefficients in a chemical equation describe the ratio in which substances react, not the concentrations at equilibrium.
20. Chemical equilibrium is a dynamic state because, at the molecular level, both the forward and the reverse reactions continue to take place.
21. a. heterogeneous
b. homogeneous
c. heterogeneous
22. The rate of a reaction depends on the concentration of reactants and the rate constant. If the reaction is started with only reactants present, the rate of the forward reaction is relatively large while the rate of the reverse reaction is essentially zero. As reactants form products, the concentration of reactants decreases and the rate of the forward reaction also decreases. As the concentration of products increases, the rate of the reverse reaction also increases. At equilibrium, both forward and reverse reactions are taking place at the same rate. At the molecular level, particles are constantly colliding and taking part in reactions, even though there is no overall change in the reaction mixture. This is the nature of a dynamic equilibrium.
23. At the beginning of the reaction, the concentrations of hydrogen and nitrogen were relatively high and the concentration of ammonia was zero. As the reaction proceeded, nitrogen and hydrogen combined to form ammonia. At the same time, ammonia decomposed to form nitrogen and hydrogen again. At some point in time, represented by the dashed line, the forward reaction rate and the reverse reaction rate were equal. The synthesis of ammonia occurred at the same rate as its decomposition and the system reached equilibrium.
24. The reaction shifts to the right at higher temperature. Therefore, according to Le Châtelier's principle, the reaction is endothermic.
25. The reaction in the forward direction is exothermic, but the reverse reaction is endothermic. At equilibrium, the forward and reverse reaction rates are equal. The rate at which heat is generated is the same as the rate at which the heat is absorbed in the reverse process. As a result, there is no net change in temperature.
26. Changes in pressure do not affect solids or pure liquids, as they are not compressible. As a result, a change in pressure does not affect the $\text{PbI}_2(\text{s})$ or the water associated with the aqueous system. This means that the position of equilibrium will not be affected by any pressure change in this system.
27. As soon as the container is opened, the system is no longer closed and the gas will escape, thus preventing the reaction where this gas is a reactant from occurring. As a result, only the reaction that generates the gas can occur and thus the reaction is no longer at equilibrium.
28. a. $K_{\text{eq}} = \frac{[\text{CO}_2]^3[\text{H}_2\text{O}]^4}{[\text{C}_3\text{H}_8][\text{O}_2]^5}$
b. $K_{\text{eq}} = \frac{[\text{NO}]^2[\text{H}_2\text{O}]^2}{[\text{N}_2\text{H}_4][\text{O}_2]^2}$
c. $K_{\text{eq}} = \frac{[\text{Cu}(\text{NH}_3)_4^{2+}]}{[\text{Cu}^{2+}][\text{NH}_3]^4}$
29. a. A large K_{eq} value indicates that product formation is favoured.
b. If this process were to be reversed, reactants and products would be reversed, which would mean

the K_{eq} expression would be the reciprocal of the original K_{eq} expression. The reciprocal of a very large value is a very small value, so the reverse reaction would have a K_{eq} value much smaller than 1.

- 30.** The factors that can affect the equilibrium of a reaction are: the concentration of reactants or products; the pressure of a gaseous system where the number of gas molecules changes during the reaction; and temperature. Of these factors, only temperature affects the value of K_{eq} .

31. a. $K_p = \frac{P_{\text{CO}} P_{\text{H}_2}}{P_{\text{H}_2\text{O}}}$

b. Since no substances are in the gas phase, a K_p expression does not exist for this system.

c. $K_p = \frac{P_{\text{H}_2\text{O}}^3}{P_{\text{H}_2}^3}$

d. $K_p = \frac{P_{\text{NOCl}}^2 P_{\text{PCl}_3}}{P_{\text{PCl}_5} P_{\text{NO}}^2}$

32. $K_{\text{eq}} = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$

$$0.21 = \frac{[\text{NO}_2]^2}{4.18}$$

$$[\text{NO}_2]^2 = 0.21 \times 4.18$$

$$[\text{NO}_2]^2 = 0.8778$$

$$[\text{NO}_2] = 0.9369$$

$$[\text{NO}_2] = 0.94$$

The correct answer is b.

- 33. a.** reaction shifts to the right

b. reaction shifts to the left

c. reaction shifts to the right

34. $[\text{CO}_2]_i = \frac{1.41 \text{ mol}}{1.5 \text{ L}}$

$$= 0.94 \frac{\text{mol}}{\text{L}}$$

$$[\text{H}_2]_i = \frac{2.61 \text{ mol}}{1.5 \text{ L}}$$

$$= 1.74 \frac{\text{mol}}{\text{L}}$$

	$[\text{CO}_2]$	$[\text{H}_2]$	$[\text{CO}]$	$[\text{H}_2\text{O}]$
I	0.94	1.74	0	0
C	$-x$	$-x$	x	x
E	$0.94 - x$	$1.74 - x$	x	x

$$K_{\text{eq}} = \frac{[\text{CO}][\text{H}_2\text{O}]}{[\text{CO}_2][\text{H}_2]}$$

$$0.74 = \frac{x \cdot x}{(0.94 - x)(1.74 - x)}$$

$$0.74 = \frac{x^2}{(1.63356 - 2.68x + x^2)}$$

$$(0.74)(1.63356 - 2.68x + x^2) = x^2$$

$$1.21034 - 1.9832x + 0.74x^2 = x^2$$

$$0.26x^2 + 1.9832x - 1.21034 = 0$$

$$x = \frac{-1.9832 \pm \sqrt{1.9832^2 - 4(0.26)(1.21034)}}{2(0.26)}$$

$$x = \frac{-1.9832 \pm 2.27856}{0.52}$$

The value of x cannot be negative so use the positive value.

$$x = 0.568$$

$$[\text{CO}]_{\text{eq}} = 0.568 \text{ mol/L}$$

$$n = cV$$

$$n = \left(0.568 \frac{\text{mol}}{\cancel{\text{L}}}\right)(1.5 \cancel{\text{L}})$$

$$= 0.85 \text{ mol}$$

- 35. a.** $4\text{HCl}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{H}_2\text{O}(\text{g}) + 2\text{Cl}_2(\text{g})$

b. $K_{\text{eq}} = \frac{[\text{H}_2\text{O}]^2 [\text{Cl}_2]^2}{[\text{O}_2] [\text{HCl}]^4}$

$$= \frac{(7.8 \times 10^{-3})^2 (3.6 \times 10^{-3})^2}{(8.6 \times 10^{-2})(2.7 \times 10^{-2})^4}$$

$$= \frac{7.8849 \times 10^{-10}}{4.5704 \times 10^{-8}}$$

$$= 1.7252 \times 10^{-2}$$

$$= 1.7 \times 10^{-2}$$

36.

	$[\text{SO}_2]$	$[\text{O}_2]$	$[\text{SO}_3]$
I	3.8	3.8	0
C	$-2x$	$-x$	$+2x$
E	$3.8 - 2x \cong 3.8$	$3.8 - x \cong 3.8$	$2x$

$$1000K_{\text{eq}} = 3.6 < 3.8$$

The value of $1000K_{\text{eq}}$ is too close to the initial concentration of a reactant to be accurate. However, if the approximation is not used, a cubic equation will be generated. There is no simple method or formula for solving cubic equations. To do so, you need a programmable calculator or a Web page that has a calculator. Both solutions will be shown here.

$$K_{\text{eq}} = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$$

Approximation:

$$3.6 \times 10^{-3} = \frac{(2x)^2}{(3.8)^2 (3.8)}$$

$$= \frac{4x^2}{54.872}$$

$$4x^2 = 54.872(3.6 \times 10^{-3})$$

$$= 0.19754$$

$$x^2 = \frac{0.19754}{4}$$

$$= 0.049385$$

$$x = 0.22223$$

$$[\text{SO}_3] = 2x$$

$$[\text{SO}_3] = 2 \times 0.22223$$

$$[\text{SO}_3] = 0.44 \text{ mol/L}$$

Cubic equation:

$$3.6 \times 10^{-3} = \frac{(2x)^2}{(3.8 - 2x)^2 (3.8 - x)}$$

$$= \frac{4x^2}{(14.44 - 15.2x + 4x^2)(3.8 - x)}$$

$$= \frac{4x^2}{(54.872 - 72.2x + 30.4x^2 - 4x^3)}$$

$$4x^2 = (3.6 \times 10^{-3})(54.872 - 72.2x + 30.4x^2 - 4x^3)$$

$$= -0.0144x^3 + 0.10944x^2 - 0.25992x + 0.19754$$

$$0 = -0.0144x^3 + 3.8906x^2 - 0.25992x + 0.19754$$

Substitute coefficients into calculator.

$$x = 0.194329 \text{ or } -270.1135 \text{ or } -0.26134$$

The answer cannot be negative, so use $x = 0.194329$.

$$[\text{SO}_3] = 2x$$

$$[\text{SO}_3] = 2 \times 0.194329$$

$$[\text{SO}_3] = 0.38865$$

$$[\text{SO}_3] = 0.39 \text{ mol/L}$$

Notice that using the approximation resulted in nearly 13% error.

$$37. K_{\text{eq}} = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$$

Experiment 1

$$K_{\text{eq}} = \frac{3.50^2}{(1.50)^2 (1.25)}$$

$$= 4.35$$

Experiment 2

$$K_{\text{eq}} = \frac{0.260^2}{(0.590)^2 (0.0450)}$$

$$= 4.31$$

In experiment 1, $K_{\text{eq}} = 4.35$; in experiment 2, $K_{\text{eq}} = 4.31$. Within experimental error, these two can be considered the same value.

- 38.** There is no way to draw a valid conclusion in this instance, as it is also possible that the reaction has simply gone to completion and the colour change could no longer continue. More testing would need to be done, such as seeing if the products of the process could be used as reactants and allow for the formation of the materials that were products in the original process, before a valid conclusion could be reached.
- 39.** In a smaller volume, more $\text{NO}_2(\text{g}) - \text{O}_2(\text{g})$ collisions will occur, which will temporarily increase the rate of the forward reaction. With this rate increased, the forward reaction will be favoured until the rate of the reverse reaction where $\text{NO}_3(\text{g})$ molecules are colliding increases to a point where the two rates are once again equal.
- 40. a.** Increasing the amount of methane would shift the equilibrium to the right, increasing the concentration of hydrogen.
- b.** Increasing the amount of carbon dioxide would shift the equilibrium to the left, decreasing the concentration of hydrogen.
- c.** Decreasing the amount of water vapour would shift the equilibrium to the left, decreasing the concentration of hydrogen.
- d.** The reaction is endothermic and raising the temperature would shift the equilibrium to the right, increasing the concentration of hydrogen.
- e.** Adding a catalyst would have no effect on the concentration of hydrogen.
- f.** Adding helium gas to the mixture would have no effect on the concentration of hydrogen.
- g.** Transferring the mixture of gases to a container with greater volume would have the effect of reducing the pressure of the reacting mixture. The equilibrium would shift to the right, increasing the concentration of hydrogen.
- 41.** Changing the volume of the mixture has no effect in this case because there is the same number of gas molecules on each side of the equation. A decrease in temperature will shift the equilibrium to the right because the reaction is exothermic. Le Châtelier's principle predicts that increasing the temperature

will shift the position of equilibrium towards the endothermic reaction, thus reducing the effect of the change.

42. At equilibrium, $\text{rate}_{\text{forward}} = \text{rate}_{\text{reverse}}$

$$\text{rate}_{\text{forward}} = k_{\text{forward}} [\text{N}_2\text{O}_4]$$

$$\text{rate}_{\text{reverse}} = k_{\text{reverse}} [\text{NO}_2]^2$$

The equilibrium constant expression is defined as the ratio of reaction rates:

$$k_{\text{forward}} [\text{N}_2\text{O}_4] = k_{\text{reverse}} [\text{NO}_2]^2$$

$$\frac{k_{\text{forward}}}{k_{\text{reverse}}} = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$$

$$K_{\text{eq}} = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$$

43. $4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightleftharpoons 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$

$$K_{\text{eq}} = \frac{[\text{NO}]^4 [\text{H}_2\text{O}]^6}{[\text{NH}_3]^4 [\text{O}_2]^5}$$

$$= \frac{[\text{NO}]^4 2.0^6}{[\text{NH}_3]^4 3.0^5}$$

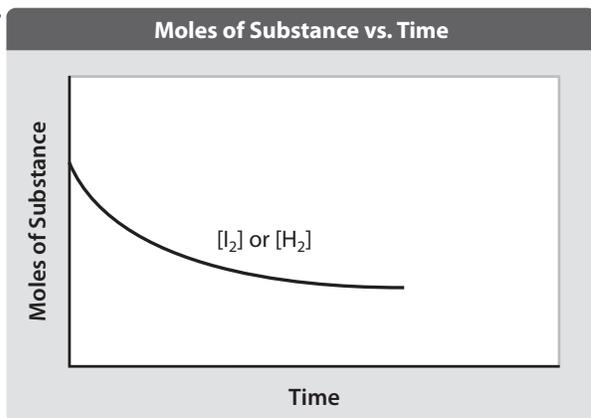
$$= 0.26337$$

$$= 0.26$$

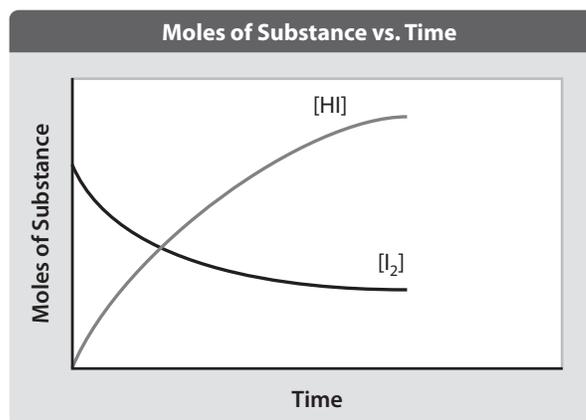
44. A chart similar to the following:

Macroscopic Property	Monitor
pH	pH electrode or universal indicator
colour intensity	a comparison to solutions of known concentrations of the material producing the colour
pressure	a pressure sensor or similar
temperature	thermometer or temperature gauge

45. a.



b. Yes, over time I_2 reacts with H_2 to produce HI and the concentration of I_2 decreases and the concentration of HI increases.



46. Coffee is freeze dried in a process in which the liquid coffee is frozen. Then, the pressure is dropped in the container. The pressure drop causes the ice to sublime, which means that ice goes directly to the water vapour state. The pressure drop caused a shift in the equilibrium between the ice and water vapour. To further drive the water out to the coffee, the water vapour is removed from the container. This reinforces the shift in the equilibrium process from ice to water vapour production.

47. Depending on the choice of reaction, a graph for a reaction that goes to completion should have reactant concentrations that proceed to zero (or at least one reactant concentration that goes to zero) while the concentration of product(s) increase from zero then plateau off. For the reaction that reaches equilibrium, reactant concentrations should decrease then level off, and product concentrations should increase then level off as well, at the same time as the reactant concentrations level off.

48. Styles and content will differ, but all students should outline the idea that nitrogen narcosis is a reversible process where scuba divers experience an alteration in consciousness, similar to alcohol intoxication or nitrous oxide inhalation. It is caused by the increased solubility of gases in body tissues at elevated pressures of a deep dive. It should be outlined that this is similar to carbon monoxide poisoning in that as long as the exposure is not for a long period of time, breathing clean atmospheric air will help to alleviate the symptoms. As well, in both cases, if exposure is for a longer period of time, a hyperbaric chamber treatment may be needed. In both cases, the onset of both is difficult for the person to recognize, and continued exposure can lead to severe illness or even death.

49. At the start of the reaction, only the forward reaction is occurring as reactants form products. At this point, the macroscopic property used to monitor the reaction is changing rapidly. Once the reverse reaction starts to occur at a higher and higher rate (approaching that of the forward reaction rate), the macroscopic property seems to be change more slowly. This does not mean that the forward reaction is slowing to a stop, it simply means that the two rates are getting close to being equal. When they are equal, the reaction will be at equilibrium and the macroscopic property will no longer be changing.

Include a concentration diagram and label the start of the reaction as the point when the macroscopic property is changing most rapidly. Later on the graph, as the concentrations start to level off, label this area as the area where the macroscopic property would be changing slowly.

- 50.** Choice of graphic organizer will differ, but student work must include some concept of stress added to the system and then an appropriate shift to offset the stress if the system is at equilibrium, and no response if the system has gone to completion (unless the stress is adding a reactant and it happens to be the limiting reactant for the system that has gone to completion. Then there will be a false positive for reaction at equilibrium, so many stresses will need to be tested).
- 51.** Design and look of the poster will vary, but all must indicate that when $K_{\text{eq}} < 1$, reactant formation is favoured, when $K_{\text{eq}} \approx 1$, there are approximately equal concentrations of reactants and products, and when $K_{\text{eq}} > 1$, product formation is favoured.
- 52.** Format of the email will differ, but all should include that increasing the temperature will always favour the endothermic reaction, in an attempt to use up the extra energy added as heat, while decreasing the temperature will always favour the exothermic reaction as the system adjusts to release more heat to offset the stress.
- 53.** Response will depend on the student choice of system and reaction, but all should have a pamphlet format, with the chemistry of the system and how it is affected by the position of equilibrium clearly outlined in their work.
- 54.** Answers will show a variety of styles of graphic organizers, but all should include the concepts of Le Châtelier's principle and how this principle is applied to systems at equilibrium. The organizer should also include the mathematical process of determining the equilibrium constant, changes to concentrations

mathematically, how to determine if a system is at equilibrium, and, if not, in which direction it will move. The organizer should also mention K_{eq} and K_{p} values, using concentrations or partial pressures.

- 55.** Responses should include the meaning of *dynamic* as it applies to chemistry in general and their choice of their specific system. Reference should be made to how the system responds to changing conditions and how these changes occur in a predictable manner.
- 56.** Responses should include the name and description of the process, chemical reaction and equilibrium constant associated with the process. The response should focus on how the equilibrium process is controlled, including the optimum conditions that the reaction uses for temperature, pressure, catalysis, and so on.
- 57.** Answers should include the concept of shifts in the economy and how these shifts parallel the shifts in an equilibrium system. All changes are met with adjustments to offset the stress placed on the economy with respect to the commodity, which is exactly what Le Châtelier's principle predicts will happen in a chemical system at equilibrium.
- 58.** The statement is false. At equilibrium, the rate of change in opposite directions is equal, but the amounts are determined by the position of equilibrium.
- 59.** Cousteau used a mix of helium and oxygen (Heliox) with relatively small $\text{O}_2(\text{g})$ concentration to make sure his blood oxygen concentration did not reach toxic levels.
- 60.** Methane gas is first reacted with water vapour and heat to generate carbon monoxide and hydrogen gas in the equilibrium process:
$$\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) + \text{heat} \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$$

The mixture of $\text{CO}(\text{g})$ and $\text{H}_2(\text{g})$ is then reacted in the presence of a catalyst at a pressure of 5–10 MPa to form methanol:
$$\text{CO}(\text{g}) + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$$

The heat released in this process is used to heat the reaction of the methane gas and steam in the first step of the process. Three moles of hydrogen gas are generated in step 1 and only two moles are used in step 2, so the excess can be used to remove sulfur from gasoline and diesel at nearby plants.
- 61.** *Possibility 1.* increase temperature
Possibility 2. increase volume
Possibility 3. decrease pressure
Possibility 4. increase $\text{NO}_2(\text{g})$ concentrations

Possibility 5. remove NO(g) as is it forms or release O₂(g) as it forms

62. Nitrous oxide has a strong tendency to decompose due to the extremely high value of K_{eq} .

$$\begin{aligned} 63. \text{ a. } Q_{\text{eq}} &= \frac{[\text{C}_2\text{H}_2][\text{H}_2]^3}{[\text{CH}_4]^2} \\ &= \frac{15.74 \times 4.75^3}{4.76^2} \\ &= 74.45 \\ &= 74.4 \end{aligned}$$

b. Since $Q_{\text{eq}} < K_{\text{eq}}$ the system will be moving to the right to reach equilibrium.

$$64. K_{\text{eq}} = 1.1 \times 10^{-5}$$

$$1000 \times 1.1 \times 10^{-5} = 0.011 < 0.20$$

Therefore, use the approximation shown in the E row in the table.

	[N ₂]	[H ₂]	[NO]
I	0.80	0.20	0
C	-x	-x	+2x
E	0.80 - x \cong 0.80	0.20 - x \cong 0.20	2x

$$\begin{aligned} K_{\text{eq}} &= \frac{[\text{NO}]^2}{[\text{N}_2][\text{O}_2]} \\ 1.1 \times 10^{-5} &= \frac{(2x)^2}{(0.80)(0.20)} \\ &= \frac{4x^2}{0.16} \\ 4x^2 &= 0.16(1.1 \times 10^{-5}) \\ &= 1.76 \times 10^{-6} \\ x^2 &= 4.4 \times 10^{-7} \\ x &= 6.633 \times 10^{-4} \\ [\text{NO}] &= 2x \\ &= 2(6.633 \times 10^{-4}) \\ &= 1.326 \times 10^{-3} \\ &= 1.3 \times 10^{-3} \frac{\text{mol}}{\text{L}} \end{aligned}$$

65. Since sleep apnea is characterized by abnormal pauses in breathing, the amount of oxygen that can be delivered to the blood decreases, thus causing lower levels of oxygen in the blood and elevated levels of CO₂ remaining in the blood. Thus the oxygen hemoglobin equilibrium in the blood is shifted away from the direction of higher concentrations of oxygenated hemoglobin, which can cause dramatic health related issues.

66.

	[HI]	[H ₂]	[I ₂]
I	$\frac{2.62 \text{ mol}}{1.15 \text{ L}} = 2.2783 \frac{\text{mol}}{\text{L}}$	0	0
C	-2x	+x	+x
E	2.2783 - 2x	x	x

$$K_{\text{eq}} = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$$

$$0.022 = \frac{(x)(x)}{(2.2783 - 2x)^2}$$

The right side is a perfect square so take the square root of both sides.

$$\begin{aligned} 0.14832 &= \frac{(x)}{2.2783 - 2x} \\ x &= (0.14832)(2.2783 - 2x) \\ x &= 0.33793 - 0.29665x \end{aligned}$$

$$1.29665x = 0.33793$$

$$x = 0.2606$$

$$[\text{H}_2] = x$$

$$[\text{H}_2] = 0.261 \frac{\text{mol}}{\text{L}}$$

$$[\text{I}_2] = x$$

$$[\text{I}_2] = 0.261 \frac{\text{mol}}{\text{L}}$$

$$[\text{HI}] = 2.2783 - 2x$$

$$[\text{HI}] = 2.2783 - 2(0.2606)$$

$$[\text{HI}] = 1.76 \frac{\text{mol}}{\text{L}}$$

67. a. The reaction conditions that favour increasing the yield of nitrogen monoxide are low pressure and low temperature.

b. The catalyst has no effect on the position of equilibrium. A catalyst favours the production of NO(g) because it will increase the rate of the reaction.

c. The reaction temperature is relatively high because, although the yield decreases at higher temperature, this is more than offset by an increase in the rate of the reaction.

d. A relatively low pressure is used because this favours the production of NO(g). The cost of increasing the pressure in the system would not be justified.

e. The reaction is exothermic, so cooling the gases forces the equilibrium towards more product. Also, it is probable that cooling the gases is a safety measure to prevent the reaction vessel from becoming dangerously overheated. The heat extracted would be used elsewhere in the plant.

$$68. K_{\text{eq}} = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}; K_{\text{eq}}(1) = \frac{(0.104)^2}{0.052}; K_{\text{eq}}(2) = \frac{(0.074)^2}{0.082}$$

$$= 0.208 \qquad = 0.006678$$

$$= 0.21 \qquad = 0.0067$$

$$K_{\text{eq}}(3) = \frac{(0.630)^2}{0.018}; K_{\text{eq}}(4) = \frac{(0.037)^2}{0.0065}$$

$$= 22.05 \qquad = 0.2106$$

$$= 22 \qquad = 0.21$$

Reactions 1 and 4 are at equilibrium while 2 and 3 are not.

69. The degree to which the hemoglobin in the blood is oxygenated affects overall performance during athletic activities. An understanding of this principle is essential for planning any training routine for athletes. The training goal is to increase the level of oxygenation of hemoglobin in order to more effectively transport needed oxygen molecules to muscle cells that require it during activity. Increasing the athlete's level of cardiovascular fitness is known to increase the level to which hemoglobin in the blood can be oxygenated.

Answers to Chapter 7 Self-Assessment Questions

(Student textbook pages 488-9)

- a
- d
- c
- e
- e
- e
- c
- The values of $[\text{CO}_2]$ and $[\text{H}_2]$ are unknown but equal so set them equal to x .

$$K_{\text{eq}} = \frac{[\text{CO}][\text{H}_2\text{O}]}{[\text{CO}_2][\text{H}_2]}$$

$$4.19 \times 10^{-3} = \frac{(0.11)(0.11)}{(x)(x)}$$

$$= \frac{(0.11)^2}{(x)^2}$$

$$\sqrt{4.19 \times 10^{-3}} = \sqrt{\frac{(0.11)^2}{(x)^2}}$$

$$7.0 \times 10^{-2} = \frac{0.11}{x}$$

$$x = \frac{0.11}{7.0 \times 10^{-2}}$$

$$x = 1.574$$

$$[\text{CO}_2] = [\text{H}_2] = 1.6 \text{ mol/L}$$

- High pressures and low temperatures.
- To allow equilibrium in his/her blood gases to normalize and to avoid the issue of the bends for the divers.
- Since solids and pure liquids have a constant mass and volume, their concentrations do not change, and so they are not included in the equilibrium expressions.
- Sample paragraph:* Prior to the development of the Haber-Bosch process, ammonia could only be produced using sodium nitrate imported from Chile. Germany was at war and needed a domestic supply of raw materials that could be used to produce ammonia. This process allowed Germany to produce ammonia for explosives and other materials that required ammonia.
- Since $PV = nRT$, if the temperature, pressure and volume are held constant, there is a direct relationship between the number of moles of substances (and thus concentration) and the pressure that they exert. As a result, partial pressure can be used in the expression for the equilibrium constant similar to how concentration is used.
- Ice and water form an equilibrium mixture (slush) at 0°C and 1 atmosphere pressure. At temperatures above 0°C , the ice will melt. At temperatures below 0°C , the water will freeze.
- The centre flask contains approximately equal concentrations of $\text{NO}_2(\text{g})$ and $\text{N}_2\text{O}_4(\text{g})$. The dark brown flask on the right contains mostly nitrogen dioxide and the light brown flask contains mostly nitrogen tetraoxide.
- This is due to the fact that neither the forward nor the reverse reaction is favoured when the volume changes, as there are 2 moles of gas on each side of the reaction, so a change in volume will have no effect on the system.
- Once $\text{Cl}_2(\text{g})$ is added, more $\text{Cl}_2(\text{g})\text{-PCl}_3(\text{g})$ collisions will occur, thus causing more chances of $\text{PCl}_5(\text{g})$ molecules to form. Eventually this will cause more $\text{PCl}_5(\text{g})$ molecules to decompose in the reverse process, and the two rates will once again be equal.
The diagram should show a flask with $\text{Cl}_2(\text{g})$ and $\text{PCl}_3(\text{g})$ molecules floating around and colliding. A second diagram should show more $\text{Cl}_2(\text{g})$ molecules and more reactant molecule collisions.
- $\text{H}_2(\text{g})$ is added—shift to the right; an inert gas is added—no effect; the volume is decreased—shift to the left; the system is heated—shift to the left; and $\text{NH}_3(\text{g})$ is removed—shift to the right.

19. Only the change in temperature will affect the K_{eq} value. All other changes will have no effect on the K_{eq} value for the reaction.

20.

	[NOCl]	[NO]	[Cl ₂]
I	$\frac{1.00 \text{ mol}}{2.00 \text{ L}} = 0.500 \frac{\text{mol}}{\text{L}}$	0	0
C	$-2x$	$+2x$	$+x$
E	$0.500 - 2x \cong 0.500$	$2x$	x

$1000K_{\text{eq}} = 1.6 \times 10^{-2} \gg 0.500$ Therefore, use approximation in row E.

$$K_{\text{eq}} = \frac{[\text{NO}]^2[\text{Cl}_2]}{[\text{NOCl}]^2}$$

$$1.6 \times 10^{-5} = \frac{4x^3}{(0.500)^2}$$

$$0.250(1.6 \times 10^{-5}) = 4x^3$$

$$x^3 = 1.00 \times 10^{-6}$$

$$\sqrt[3]{x^3} = \sqrt[3]{1.00 \times 10^{-6}}$$

$$x = 1.0 \times 10^{-2}$$

$$[\text{NO}] = 2x$$

$$[\text{NO}] = 2(1.0 \times 10^{-2})$$

$$[\text{NO}] = 2.0 \times 10^{-2} \text{ mol/L}$$

$$[\text{Cl}_2] = x$$

$$[\text{Cl}_2] = 1.0 \times 10^{-2} \text{ mol/L}$$

$$\begin{aligned} 21. K_{\text{eq}} &= \frac{[\text{N}_2]^2 [\text{O}_2]}{[\text{N}_2\text{O}]^2} \\ &= \frac{\left(\frac{3.54 \text{ mol}}{3.50 \text{ L}}\right)^2 \left(\frac{4.41 \text{ mol}}{3.50 \text{ L}}\right)}{\left(\frac{0.14 \text{ mol}}{3.50 \text{ L}}\right)^2} \\ &= 805.603 \\ &= 8.1 \times 10^2 \end{aligned}$$

$$\begin{aligned} 22. Q_p &= \frac{P_{\text{SO}_2}^2 P_{\text{O}_2}}{P_{\text{SO}_3}^2} \\ &= \frac{(4.54)^2 (2.12)}{(1.54)^2} \\ &= 18.425 \\ &= 18.4 \end{aligned}$$

23. $\text{CO}_2(\text{g})$ is removed from your system in your lungs as you breath out. When this $\text{CO}_2(\text{g})$ is removed from the blood at the lungs, the system must shift to offset the stress and so the reaction is favoured in the forward direction. This means that more $\text{H}_2\text{CO}_3(\text{aq})$ will decompose to form more $\text{CO}_2(\text{g})$ and thus the carbonic acid level in the blood decreases.

$$24. E_p = \frac{P_{\text{NOBr}}^2}{P_{\text{NO}}^2 P_{\text{Br}_2}}$$

$$0.013 = \frac{P_{\text{NOBr}}^2}{(1.71)^2 (0.71)}$$

$$P_{\text{NOBr}}^2 = (1.71)^2 (0.71)(0.013)$$

$$= 0.026989$$

$$P_{\text{NOBr}} = 0.1643$$

$$= 0.016 \text{ atm}$$

25. The style and detail on student posters will vary, but all must include the reaction $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) + \text{heat}$, as well as an indication that the reaction operates at high pressures and low temperatures, with a catalyst to speed up the time to get to equilibrium. Some possibilities for everyday uses are: fertilizers, formation of nitrogenous compounds, some cleaners, in woodworking, in the textile industry, and as an antimicrobial agent for food products.

Chapter 8 Acid-Base Equilibrium Systems

Answers to Learning Check Questions

(Student textbook page 497)

1. An Arrhenius acid is a substance that contains hydrogen in its chemical formula, and it ionizes in water to form the hydronium ion, $\text{H}_3\text{O}^+(\text{aq})$. An Arrhenius base is a substance that contains OH in its chemical formula, and it ionizes in water to form the hydroxide ion, $\text{OH}^-(\text{aq})$.
2. A Brønsted-Lowry acid is a proton donor or any substance that donates a hydrogen ion. Such acid must contain hydrogen in its formula, for example, HCl and HNO_3 . A Brønsted-Lowry base is a proton acceptor or any substance that accepts a hydrogen ion. Such base must have a lone pair of electrons to bind with the hydrogen ion. The hydroxide ion, $\text{OH}^-(\text{aq})$, does not have to be present.
3. Two molecules or ions that differ because of the transfer of a proton are called a conjugate acid-base pair. The acid of an acid-base pair has one more proton than its conjugate base.
4. The conjugate base of an acid is the particle that remains when a proton is removed from the acid. The conjugate acid of a base is the particle formed when the base receives the proton from the acid.
5. A proton or hydrogen ion, $\text{H}^+(\text{aq})$, is released from the acid. This positively charged hydrogen ion from the acid is attracted to the negatively charged electrons on the surrounding water molecules. This results in the formation of a hydronium ion, $\text{H}_3\text{O}^+(\text{aq})$.