RLP-CHEMB · RLP Chemistry B — Energy, Equilibrium, Earth Systems and Nuclear Chemistry

Unit 2: Reaction Rates, Equilibrium and Designing Chemical Systems

Practice Workbook. The same problems, in the same order, as the Practice sections of the online lessons.

Name _____ Period _____

Lesson 2.1 — Why Warm Food Spoils Faster: Collision Theory and Reaction Rate

FLUENCY

1. A reactant falls from 0.600 M to 0.450 M in 50.0 s. Calculate the average rate.

2. A reactant falls from 1.20 M to 0.900 M in 2.50 min. Give the average rate in M/s.

3. Name the three conditions that a collision must meet to produce a reaction.

4. State which of these makes a reaction faster and give a one-sentence reason for each: (a) a higher temperature, (b) a higher concentration, (c) a finely crushed solid.

5. Convert 90 °F to °C and K (three significant figures).

APPLICATION

6. Using the Arrhenius ratio with E_a = 75.0 kJ/mol, by what factor does the rate increase from 20.0 °C to 30.0 °C?

7. For E_a = 50.0 kJ/mol, by what factor does the rate increase from 25.0 °C to 45.0 °C?

8. Calculate the fraction of collisions with energy of at least E_a = 60.0 kJ/mol at 298.15 K and at 323.15 K, and the ratio of the two.

9. In a gas reaction the rate is proportional to [A][B]. At [A] = 0.10 M and [B] = 0.20 M the rate is 5.0×10^{-4} M/s. Predict the rate when both concentrations double, and explain with collision theory.

CHALLENGE

10. For E_a = 50.0 kJ/mol, at what temperature (in °C) does the rate become exactly double its value at 25.0 °C (298.15 K)?

11. Raising the temperature by 10 °C from about 298 K increases the average kinetic energy by about 3.4%, yet the rate roughly doubles. Explain how both can be true.

12. A food-safety sheet says to discard perishable food left out more than two hours, or more than one hour above 90 °F. Explain whether your calculated rate ratio between 70 °F and 90 °F supports halving the time.

REVIEW

13. How many moles of $CaCO_3$ (100.09 g/mol) are in 250 g?

14. For $N_2 + 3\ H_2 \rightarrow 2\ NH_3$, how many moles of NH_3 form from 12.0 mol of H_2 with excess N_2?

15. What volume does 1.00 mol of CO_2 occupy at 100. kPa and 298.15 K? (R = 8.314 L·kPa/(mol·K))

Lesson 2.2 — Measuring Reaction Rate: Temperature and Concentration

FLUENCY

1. Three trials give 90 s, 95 s and 93 s. Find the mean time to 0.1 s.

2. Calculate the rate (1000 ÷ mean time) for the 20 °C data above.

3. Convert 5 °C, 20 °C, 35 °C and 50 °C to kelvin.

4. Name two variables you must hold constant in the tablet experiment when you change only the water temperature.

APPLICATION

5. Using the recorded rates 26.53 (35 °C) and 10.79 (20 °C), by what factor does the rate rise?

6. Calculate E_a from the 5 °C (3.95) and 35 °C (26.53) rates.

7. For vinegar fractions of 100% and 25% the recorded rates are 14.43 and 3.62. Find the ratio and say whether the rate looks proportional to concentration.

8. If the rate is proportional to the vinegar fraction, predict the time at 60% vinegar starting from the 100% mean time of 69.3 s.

CHALLENGE

9. The least-squares line through ln(rate) against $1/T$ for the four recorded points has slope -5,473 K and intercept 14.139. Use it to find the activation energy and then to predict the rate at 27 °C (300.15 K).

10. The three 5 °C times spread over 6.3% of the mean. Explain whether this scatter could account for the difference between the 20 °C and 35 °C means (92.7 s and 37.7 s).

11. Describe an improvement that would make the vinegar experiment more reliable and say which uncertainty it reduces.

REVIEW

12. Baking soda is $NaHCO_3$. Calculate its molar mass using 22.990, 1.008, 12.011 and 15.999 g/mol.

13. $NaHCO_3$ reacts with acid in a 1 : 1 ratio to give CO_2. How many moles of CO_2 can 2.00 g of baking soda release?

14. What volume would that CO_2 occupy at 298.15 K and 101.3 kPa? (R = 8.314 L·kPa/(mol·K))

Lesson 2.3 — Dynamic Equilibrium, K and Q: From Missouri Caves to ICE Tables

FLUENCY

1. Write the equilibrium expression for $2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$.

2. Write K for $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$ and explain why the solids are not in it.

3. At equilibrium $[SO_2] = 0.0400$ M, $[O_2] = 0.0200$ M and $[SO_3] = 0.0800$ M. Calculate K_c.

4. True or false: at equilibrium the concentrations of reactants and products must be equal. Explain.

APPLICATION

5. For $N_2O_4 \rightleftharpoons 2\ NO_2$ with $K_p = 0.148$, a mixture has $P(N_2O_4) = 0.500$ bar and $P(NO_2) = 0.100$ bar. Calculate Q and state which way it shifts.

6. Same system, but $P(N_2O_4) = 0.200$ bar and $P(NO_2) = 0.300$ bar. Calculate Q and the direction of shift.

7. Solve an ICE table for $H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$ with $K_c = 50.0$ (given for this problem) starting with 0.200 M H_2 and 0.200 M I_2 and no HI. Give the equilibrium [HI].

8. Starting with 0.500 bar of N_2O_4 ($K_p = 0.148$), solve for the equilibrium pressures.

9. Using NIST data ($\Delta H° = 57.12$ kJ, $\Delta S° = 175.70$ J/K) calculate $\Delta G°$ and K_p for $N_2O_4 \rightleftharpoons 2\ NO_2$ at 298.15 K.

CHALLENGE

10. A groundwater sample has hardness 85 mg/L as $CaCO_3$. Convert to mol/L using 100.09 g/mol and say what USGS category it falls in (soft 0–60, moderately hard 61–120, hard 121–180, very hard more than 180 mg/L).

11. NOAA reports 426.07 ppm CO_2 for September 2026. Express it as a partial pressure in bar for a total pressure of 1.00 bar and explain how a drip of water in a cave with lower $P(CO_2)$ affects Q for $CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2\ HCO_3^-$.

12. Why can K be very large for a reaction that is slow?

REVIEW

13. Calculate the molar mass of CO_2 (12.011 and 15.999 g/mol).

14. What mass of $CaCO_3$ (100.09 g/mol) is 0.0500 mol?

15. A solution of 2.00 mol of HCl in 0.500 L has what molarity?

Lesson 2.4 — Le Chatelier and Industrial Design: Ammonia and the Lime Kiln

FLUENCY

1. For $N_2 + 3\ H_2 \rightleftharpoons 2\ NH_3$ ($\Delta H = -91.88$ kJ), which way does the equilibrium shift if the temperature rises, and what happens to K?

2. For $2\ SO_2 + O_2 \rightleftharpoons 2\ SO_3$, which way does an increase in pressure shift the equilibrium?

3. Does a catalyst change the value of K? Does it change the time to reach equilibrium?

4. In the lime kiln $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$, what happens to the equilibrium when CO_2 is removed continuously?

APPLICATION

5. Using $K = 2.03 \times 10^{-12} \exp(101{,}600 \div (8.314\ T))$, calculate K for ammonia synthesis at 400 °C (673.15 K).

6. Find the ratio $K(350\ °C) \div K(550\ °C)$ for ammonia synthesis (6.67×10^{-4} and 5.69×10^{-6} bar^{-2}).

7. Ammonia synthesis releases 91.88 kJ for each 2 mol of NH_3 formed. How much energy is released when 10.0 mol of NH_3 forms?

8. An N_2O_4/NO_2 mixture at equilibrium at 298.15 K has $P(N_2O_4)$ = 0.825 bar and $P(NO_2)$ = 0.350 bar. The volume is halved (all pressures double). Calculate Q and the direction of shift. (K_p = 0.148)

CHALLENGE

9. At 450 °C (4.43×10^{-5} bar^{-2}), an equilibrium mixture has $P(N_2)$ = 40.0 bar and $P(H_2)$ = 120. bar. Calculate $P(NH_3)$. Then halve the volume and show that Q is one-quarter of K.

10. For $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$, the fit to the tabulated points gives ΔH = 175 kJ/mol and $\ln K = 18.036 - (174{,}723/8.314)/T$. Find the temperature at which the equilibrium CO_2 pressure is 0.20 bar.

11. A designer proposes raising the ammonia reactor pressure from 100 bar to 300 bar and lowering the temperature from 450 °C to 350 °C. Using the table (15.5% NH_3 at 450 °C and 100 bar; 53.8% at 350 °C and 300 bar), explain what improves, what gets worse and what the designer must check.

REVIEW

12. How many grams of NH_3 (17.03 g/mol) are in 8.00 mol?

13. How many moles of N_2 are needed to make 6.00 mol NH_3 ($N_2 + 3\ H_2 \rightarrow 2\ NH_3$)?

14. A gas at 2.00 atm and 300. K in a 5.00 L vessel is heated to 450. K at constant volume. What is the new pressure?

Unit 2 checkpoint

1. Which change would NOT speed up a reaction between a solid and a liquid?
   A. Crushing the solid
   B. Raising the temperature
   C. Increasing the concentration of the liquid reactant
   D. Lowering the temperature

2. A reactant falls from 0.800 M to 0.620 M in 90 s. The average rate is _____ × 10^{−3} M/s.

3. With E_a = 50.0 kJ/mol, the rate at 305.35 K compared with 277.55 K is about
   A. 1.1 times
   B. 2.0 times
   C. 7.19 times
   D. 37 times
4. True or false: A 10 °C rise roughly doubles many reaction rates even though the average kinetic energy rises only a few percent.
5. A recorded mean time of 37.7 s gives a rate of _____ × 10^{−3} s^{−1}.
6. For CaCO₃(s) ⇌ CaO(s) + CO₂(g), the equilibrium expression is
   A. K = [CaO][CO₂] ÷ [CaCO₃]
   B. K = P(CO₂)
   C. K = 1 ÷ P(CO₂)
   D. K = [CaO] ÷ [CaCO₃]
7. True or false: At equilibrium the forward and reverse reactions have stopped.
8. At equilibrium [SO₂] = 0.0400 M, [O₂] = 0.0200 M and [SO₃] = 0.0800 M, so K_c for 2 SO₂ + O₂ ⇌ 2 SO₃ is _____.
9. For N₂O₄ ⇌ 2 NO₂ (K_p = 0.148), Q = 0.45 for a mixture. The mixture will
   A. shift backward
   B. shift forward
   C. stay as it is
   D. have a new K
10. For the exothermic reaction N₂ + 3 H₂ ⇌ 2 NH₃, which condition gives the largest equilibrium yield of NH₃?
    A. High temperature, low pressure
    B. Low temperature, high pressure
    C. High temperature, high pressure
    D. Low temperature, low pressure
11. True or false: Adding a catalyst to an equilibrium mixture changes the equilibrium constant.
12. At 450 °C the fitted K for ammonia synthesis is 4.43 × 10^{−5} bar^{−2}. If P(N₂) = 40.0 bar and P(H₂) = 120. bar at equilibrium, P(NH₃) = _____ bar (three significant figures).
13. A design improves the equilibrium yield but makes the reactor much slower. The best description is
    A. a trade-off that should be judged against prioritized criteria
    B. a failure with no value
    C. a result that proves the model wrong
    D. a change with no cost