1. For the reaction \( \text{N}_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g) \) at 400 K, \( K_p = 41 \). Find the value of \( K_p \) for each of the following reactions:
   a. \( 2 \text{NH}_3(g) \rightleftharpoons \text{N}_2(g) + 3 \text{H}_2(g) \)
   b. \( \frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g) \rightleftharpoons \text{NH}_3(g) \)
   c. \( 2 \text{N}_2(g) + 6 \text{H}_2(g) \rightleftharpoons 4 \text{NH}_3(g) \)

2. Use the following data, which were collected at 460°C, and are equilibrium molar concentrations, to determine \( K_c \) for the reaction \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI(g)} \):

<table>
<thead>
<tr>
<th>[H(_2)], mol·L(^{-1})</th>
<th>[I(_2)], mol·L(^{-1})</th>
<th>[HI], mol·L(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.47 × 10(^{-3})</td>
<td>0.594 × 10(^{-3})</td>
<td>0.0137</td>
</tr>
<tr>
<td>3.84 × 10(^{-3})</td>
<td>1.52 × 10(^{-3})</td>
<td>0.0169</td>
</tr>
<tr>
<td>1.43 × 10(^{-3})</td>
<td>1.43 × 10(^{-3})</td>
<td>0.0100</td>
</tr>
</tbody>
</table>

3. Write the reaction quotients \( Q_c \) for
   a. \( \text{Cu(s)} + \text{Cl}_2(g) \rightleftharpoons \text{CuCl}_2(s) \)
   b. \( \text{NH}_4\text{NO}_3(s) \rightleftharpoons \text{N}_2\text{O}_2(g) + 2\text{H}_2\text{O}(g) \)
   c. \( \text{MgCO}_3(s) \rightleftharpoons \text{MgO}(s) + \text{CO}_2(g) \)

4. In a gas-phase equilibrium mixture of \( \text{H}_2 \), \( \text{I}_2 \), and \( \text{HI} \) at 500 K, \( [\text{HI}] = 2.23 \times 10^{-3} \text{ mol·L}^{-1} \) and \( [\text{I}_2] = 1.46 \times 10^{-3} \text{ mol·L}^{-1} \). Given that the \( K_c \) for the formation of \( \text{HI} \) is 160 at 500 K, calculate the concentration of \( \text{H}_2 \).

5. For the same reaction in #4 above at the same temperature, analysis of a reaction mixture showed that it had a composition of \( 4.8 \times 10^{-3} \text{ mol·L}^{-1} \) \( \text{H}_2 \), \( 2.4 \times 10^{-3} \text{ mol·L}^{-1} \) \( \text{I}_2 \), and \( 2.4 \times 10^{-3} \text{ mol·L}^{-1} \) \( \text{HI} \).
   a. Calculate the reaction quotient.
   b. Is the reaction at equilibrium?
   c. If not, is there a tendency to form more reactants or more products?

6. When 0.0172 mol of \( \text{HI} \) is heated to 500 K in a sealed 2.00-L container, the resulting equilibrium mixture contains 1.90 g \( \text{HI} \). Calculate \( K_c \) for the decomposition reaction \( 2 \text{HI(g)} \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \).

7. The initial concentration of \( \text{HBr} \) in a reaction vessel is \( 1.2 \times 10^{-3} \text{ mol·L}^{-1} \). If the vessel is heated to 500 K, what is the percentage decomposition of the \( \text{HBr} \) and the equilibrium composition of the mixture? For \( 2 \text{HBr(g)} \rightleftharpoons \text{H}_2(g) + \text{Br}_2(g) \), \( K_c = 7.7 \times 10^{-11} \).

8. The equilibrium constant \( (K_c) \) has a value of \( 1.1 \times 10^{-2} \) for the reaction \( \text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \) at 400 K.
   a. Given that 1.0 g of \( \text{PCl}_5 \) was initially placed in a 250-mL reaction vessel, determine the molar concentrations in the mixture at equilibrium.
   b. What percentage of \( \text{PCl}_5 \) is decomposed at 400 K?

9. When solid \( \text{NH}_4\text{HS} \) and 0.400 mol of gaseous \( \text{NH}_3 \) were placed into a 2.0-L vessel at 24°C, the equilibrium \( \text{NH}_4\text{HS}(s) \rightleftharpoons \text{NH}_3(g) + \text{H}_2\text{S(g)} \) for which \( K_c = 1.6 \times 10^{-4} \) was reached. What are the equilibrium concentrations of \( \text{NH}_3 \) and \( \text{H}_2\text{S} \)?

10. The equilibrium constant \( K_c \) for the reaction \( \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{NO(g)} \) at 1200°C is \( 1.00 \times 10^{-5} \). Calculate
the equilibrium molar concentrations of NO, N₂, and O₂ in a 1.00-L reaction vessel that initially held 0.114 mol N₂ and 0.114 mol O₂.

11. The four gases NH₃, O₂, NO, and H₂O are mixed in a reaction vessel and allowed to reach equilibrium in the reaction 4 NH₃(g) + 5 O₂(g) → 4 NO(g) + 6 H₂O(g). Certain changes (see table) are made to this mixture. Considering each change separately, state the effect (increase, i; decrease, d; or no change, nc) that the change has on the original equilibrium value of the quantity in the second column (or K_C, if that is specified). The temperature and volume are constant unless otherwise noted.

<table>
<thead>
<tr>
<th>Change</th>
<th>Quantity</th>
<th>Effect</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>add NO</td>
<td>Amount of H₂O</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>add NO</td>
<td>Amount of O₂</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>remove H₂O</td>
<td>Amount of NO</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>remove O₂</td>
<td>Amount of NH₃</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>add NH₃</td>
<td>K_C</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>remove NO</td>
<td>Amount of NH₃</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>add NH₃</td>
<td>Amount of O₂</td>
<td>i</td>
<td>d</td>
</tr>
</tbody>
</table>

12. State whether reactants or products will be favored by an increase in the total pressure on each of the following equilibria. If no change occurs, explain why that is so.
   a. 2 O³(g) ⇌ 3 O₂(g)
   b. H₂O(g) + C(s) ⇌ H₂(g) + CO(g)
   c. 4 NH₃(g) + 5 O₂(g) ⇌ 4 NO(g) + 6 H₂O(g)
   d. 2 HD(g) ⇌ H₂(g) + D₂(g)
   e. Cl₂(g) ⇌ 2 Cl(g)

13. The density of quartz (SiO₂) is greater than that of the glassy form of silica (also SiO₂). Would glass or quartz be favored as the pressure is increased?

14. Predict whether each of the following equilibria will shift toward products or reactants with a temperature increase:
   a. N₂O₄(g) ⇌ 2 NO₂(g) ΔH° = +57 kJ
   b. X₂(g) ⇌ 2 X(g), where X is a halogen
   c. Ni(s) + 4 CO(g) ⇌ Ni(CO)₄(g) ΔH° = −161 kJ
   d. CO₂(g) + 2 NH₃(g) ⇌ CO(NH₂)₂(s) + H₂O(g) ΔH° = −90 kJ

15. Write the reaction quotients Q_C and Q_P for the following reactions:
   a. S(s) + O₂(g) ⇌ SO₂(g)
   b. SO₃(g) + H₂(g) ⇌ SO₂(g) + H₂O(g)
   c. W(s) + 6 HCl(g) ⇌ WCl₆(g) + 3 H₂(g)

16. A mixture of 0.0560 mol O₂ and 0.0200 mol N₂O is placed in a 1.00-L reaction vessel at 25°C. When the reaction 2 N₂O(g) + 3 O₂(g) ⇌ 4 NO₂(g) is at equilibrium, 0.0200 mol NO₂ is present.
   a. What are the equilibrium concentrations of O₂ and N₂O?
   b. What is the value of K_C?

17. The photosynthesis reaction is 6 CO₂(g) + 6 H₂O(l) → C₆H₁₂O₆(s) + 6 O₂(g), and ΔH° = +2802 kJ. Suppose that the reaction is at equilibrium. State the effect that each of the following changes will have
on the equilibrium composition (tend to shift toward the formation of reactants, tend to shift toward the formation of products, or have no effect).

a. The partial pressure of O\textsubscript{2} is increased.
b. The system is compressed.
c. The amount of CO\textsubscript{2} is increased.
d. The temperature is increased.
e. Some of the C\textsubscript{6}H\textsubscript{12}O\textsubscript{6} is removed.
f. Water is added.
g. The partial pressure of CO\textsubscript{2} is decreased.
1. a) 0.024; b) 6.4; c) $1.7 \times 10^3$
2. a) 48.8; b) 48.9; c) 48.9
3. a) $Q_c = \frac{1}{[Cl_2]}$ b) $Q_c = [N_2O][H_2O]^2$ c) $Q_c = [CO_2]$
4. $2.09 \times 10^{-5}$ mol·L$^{-1}$
5. a) 0.50; b) Not @ equilibrium; c) more products
6. $6.2 \times 10^{-3}$
7. $[H_2] = [Br_2] = 1.1 \times 10^{-8}$ mol·L$^{-1}$; $[HBr] = 1.2 \times 10^{-3}$ mol·L$^{-1}$; 0.0018%
8. $[PCl_5] = 9 \times 10^{-3}$; $[PCl_3] = 1.0 \times 10^{-2}$; $[Cl_2] = 1.0 \times 10^{-2}$; 52%
9. $[NH_3] = 0.2$ mol·L$^{-1}$; $[H_2S] = 8.0 \times 10^{-4}$ mol·L$^{-1}$
10. $[NO] = 3.60 \times 10^{-4}$ mol·L$^{-1}$; $[N_2] = 0.114$ mol·L$^{-1}$; $[O_2] = 0.114$ mol·L$^{-1}$

<table>
<thead>
<tr>
<th>Change</th>
<th>Quantity</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>add NO</td>
<td>Amount of H$_2$O</td>
<td>d</td>
</tr>
<tr>
<td>add NO</td>
<td>Amount of O$_2$</td>
<td>i</td>
</tr>
<tr>
<td>remove H$_2$O</td>
<td>Amount of NO</td>
<td>i</td>
</tr>
<tr>
<td>remove O$_2$</td>
<td>Amount of NH$_3$</td>
<td>i</td>
</tr>
<tr>
<td>add NH$_3$</td>
<td>$K_C$</td>
<td>nc</td>
</tr>
<tr>
<td>remove NO</td>
<td>Amount of NH$_3$</td>
<td>d</td>
</tr>
<tr>
<td>add NH$_3$</td>
<td>Amount of O$_2$</td>
<td>d</td>
</tr>
</tbody>
</table>

12. a) reactants; b) reactants; c) reactants; d) no change (same # of mol of gas on each side); e) reactants
13. Quartz – increase in pressure favors the more dense phase
14. a) products; b) products; c) reactants; d) reactants
15. a) $Q_c = \frac{[SO_2]}{[O_2]}$; $Q_p = \frac{P_{SO_2}}{P_{O_2}}$
   b) $Q_c = \frac{[SO_2][H_2O]}{[SO_3][H_2]}$; $Q_p = \frac{P_{SO_2} \cdot P_{H_2O}}{P_{SO_3} \cdot P_{H_2}}$
   c) $Q_c = \frac{[WCl_6][H_2]^3}{[HCl]^6}$; $Q_p = \frac{P_{WCl_6} \cdot (P_{H_2})^3}{(P_{HCl})^6}$
16. a) $[N_2O] = 0.0100$ mol·L$^{-1}$; $[O_2] = 0.0410$ mol·L$^{-1}$ b) $K_C = 23.2$
17. a) reactants; b) no effect; c) products; d) products; e) no effect; f) no effect; g) reactants