28. Le Châtelier's Principle

Driving Questions

Some chemical reactions perform a balancing act much like walking a tightrope. If something disturbs a reaction that is in equilibrium, it needs to adjust in order to regain its balance. Chemists purposefully disrupt certain chemical reactions that are in equilibrium in order to produce more products. How can disturbing a system lead to more desired products?

Background

Many chemical reactions produce products while consuming all of the reactants. The reactions go to completion and it is difficult to remake the original reactants. Other reactions, such as dissociation and redox reactions, are reversible in that the products can reform the reactants.

In a system that is in dynamic equilibrium, the forward reaction (forming products) and the reverse reaction (reforming the reactants) occur at the same time and at the same rate. This leads to constant concentration of the chemical compounds in the reaction flask. To an observer, it appears that nothing is happening even though the forward and reverse reactions are taking place.

A reaction in dynamic equilibrium remains balanced until it is disturbed. Disruption occurs because of an outside influence: changing the amount of product or reactants present, changing the temperature, or (if a reactant or product is a gas) changing the pressure of the system. The disturbed system reacts and adjusts the amount of product and reactant being formed in order to reestablish a new equilibrium. This is Le Châtelier's principle.

According to Le Châtelier's principle, if product is removed, more reactants come together to replace the missing product. If reactant is added, more product is formed in order to reduce the amount of added reactants.

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Beaker (2), 100-mL
- Beaker (2), 50-mL
- Graduated cylinder, 25-mL
- Graduated cylinder, 50-mL or 100-mL
- Transfer pipet (3)
- Waste container
- Wash bottle filled with distilled (deionized) water
- Buffer solution pH 4, 25 mL
- Buffer solution pH 10, 25 mL
- Distilled (deionized) water, 100 mL
- Phenolphthalein indicator, 4 drops
- 0.1 M Hydrochloric acid (HCl), 5 mL
- 0.1 M Sodium hydroxide (NaOH), 5 mL
- 0.5 M Acetic acid ($HC_2H_3O_2$), 50 mL
- 0.5 M Sodium acetate ($NaC_2H_3O_2$), 10 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide, hydrochloric acid, and acetic acid are corrosive irritants. Avoid contact with the eyes and wash hands after handling.
- Be sure that all acids and bases are neutralized before being disposed.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

Use the pH and color of the HCl and NaOH solutions to predict how to make the color of the current solution change.	Add 5 drops phenolphthalein to two separate beakers of distilled water. Record the pH and color of each solution.	Add 5 drops of HCl to one beaker and 5 drops of NaOH to the other beaker. Record the pH and color of each solution.	Test your prediction and use the results to predict how the pH of an acetic acid solution will change when sodium acetate is added.	Test your prediction by measuring the pH of an acetic acid solution before and after sodium acetate is added.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Part 1 - Phenolphthalein

Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect a pH sensor to the data collection system. �(2.1)

3. ☐ Place 25 mL of pH 4 buffer solution in a 50-mL beaker and 25 mL of pH 10 buffer solutions in a second 50-mL beaker. Use these solutions to calibrate the pH sensor. �(3.6)

4. ☐ Label a 100-mL beaker as "A" and add approximately 50 mL of distilled water. Repeat for beaker "B".

5. ☐ Add 1 to 2 drops of phenolphthalein indicator to the distilled water in each beaker. Record the color of the solution in each beaker after adding the phenolphthalein in Table 1 below (in the Collect Data section).

Note: Phenolphthalein is a weak acid and is used as an indicator for acid-base reactions. The weak acid is colorless (Hphph) and its ion is pink ($phph^-$). In aqueous solutions, the two forms are in equilibrium according to the equation below.

$$\underset{\text{(colorless)}}{\mathbf{Hphph}} + \mathbf{H_2O} \rightleftharpoons \mathbf{H_3O^+} + \underset{\text{(pink)}}{\mathbf{phph^-}}$$

6. ☐ Does the equilibrium of phenolphthalein in water favor the products or reactants? How do you know?

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7. ☐ Predict what will happen when hydronium ions (H_3O^+) are *removed* from the solution. Explain your prediction.

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8. ☐ How might hydronium ions be removed from the solution?

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9. ☐ Predict what will happen when hydronium ions are *added* to the solution. Explain your prediction.

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10. ☐ How might hydronium ions be added?

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Collect Data

11. ☐ Monitor live pH data in a digits display. �(6.1)

12. ☐ Place the pH sensor in beaker A, allow the pH reading to stabilize, and then record the pH of the solution in Table 1 below.

Table 1: Color and pH with phenolpthalein

Equilibrium Conditions	**Color**	**pH**
Beaker A: distilled water with phenolphthalein		
Beaker B: distilled water with phenolphthalein		
Beaker A: after adding 5 drops of HCl		
Beaker B: after adding 5 drops of NaOH		

13. ☐ Rinse the pH sensor with distilled water.

14. ☐ Repeat for beaker B: place the pH sensor in the solution, allow the reading to stabilize, record in the pH value in Table 1; and rinse the pH sensor.

15. ☐ Add 5 drops of 0.1 M HCl to beaker A and record the color in Table 1 above.

16. ☐ Measure the pH in beaker A and record the pH value in Table 1 above.

17. ☐ Rinse the pH sensor with distilled water.

18. ☐ Add 5 drops of 0.1 M NaOH to beaker B.

19. ☐ Measure the pH in beaker B and record both the color and the pH in Table 1 above.

20. ☐ Remove the pH senor from solution and rinse the sensor with distilled water.

21. ☐ What color is the solution in beaker A right now? If the solution is pink, what can you do to make it turn clear? If the solution is clear what can you do to make it turn pink? Why will this work?

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22. ☐ What color is the solution in beaker B right now? If the solution is pink, what can you do to make it turn clear? If the solution is clear what can you do to make it turn pink? Why will this work?

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23. ☐ Test the predictions you made. Record exactly what you added to each solution, whether or not the color changed, and the final pH of the solution after you made the change in Table 2 below.

Table 2: Color and pH after shifting equilibrium with NaOH and HCl

Equilibrium Conditions	**Action Taken**	**Color Change?**	**pH**
Beaker A with phenolphthalein + HCl			
Beaker B with phenolphthalein + NaOH			

24. ☐ Dispose of the solutions according to the teacher's instructions.

25. ☐ Wash the equipment that you used so that it can be reused in the next section.

Part 2 – Acetic Acid

Set Up

26. ☐ Add 50.0 mL of 0.5 M acetic acid solution to a 100-mL beaker.

27. ☐ As indicated by the following equilibrium system, will the pH of the 0.5 M acetic acid solution be greater than, less than, or equal to 7? Explain your reasoning.

    $HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_2H_3O_2^-(aq)$

    Note: This represents the dissociation of acetic acid in water.

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28. ☐ Measure 10.0 mL of 0.5 M sodium acetate in a graduated cylinder.

29. ☐ What will happen to the concentration of acetate ions when sodium acetate is added to the acetic acid solution? Hint: Sodium acetate dissociates completely in water according to the chemical equation below.

    $NaC_2H_3O_2(s) \rightarrow Na^+(aq) + C_2H_3O_2^-(aq)$

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30. ☐ What will happen to the pH of the acetic acid solution when sodium acetate is added? Explain your prediction.

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Collect Data

31. ☐ Place the pH sensor in the beaker containing acetic acid.

32. ☐ Allow the pH reading to stabilize, and then record the value in Table 3 below.

Table 3: pH for acetic acid and for sodium acetate

Equilibrium Conditions	pH
0.5 M acetic acid	
0.5 M acetic acid + 0.5 M sodium acetate	

33. ☐ Pour the 10 mL of 0.5 M sodium acetate into the beaker containing acetic acid and stir gently with the pH sensor.

34. ☐ Allow the pH reading to stabilize, and then record the value in Table 3 above.

35. ☐ Clean the lab station according to the teacher's instructions, especially those for the disposal of the solutions.

Analysis Questions

1. **How were the equilibria of the solutions in the experiment disturbed?**

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2. **Why was pH data recorded?**

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3. **What are two different ways H_3O^+ concentrations were detected in this experiment?**

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Synthesis Questions

Use available resources to help you answer the following questions.

1. **Write the chemical equation for the equilibrium established in a saturated sodium chloride (NaCl) solution. Do not include water in the equation, but be sure to include the appropriate state symbols.**

2. **What two ways could you cause NaCl to precipitate out of a saturated solution without adding more NaCl? Explain your answer?**

3. **What are three variables of a system that can be changed to disrupt its equilibrium?**

4. **In the following system at equilibrium, explain how cooling the system shifts the equilibrium.**

$$C(s) + H_2O(g) + \text{heat} \rightleftharpoons CO(g) + H_2(g)$$

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **Le Châtelier's principle states that**

   A. A chemical reaction always goes to completion.

   B. A system is at equilibrium when the concentration of products equals the concentration of the reactants.

   C. A system favors the products when a stress is placed on it.

   D. A system responds to a stress in such a manner that it relieves the stress.

Use the following equilibrium equation to answer Multiple Choice Questions 2 and 3 below.

Fe^{+3}(aq)	**+**	**SCN^{-}(aq)**	**⇌**	**$FeSCN^{2+}$(aq)**
(colorless)	**+**	**(colorless)**		**(brown/deep red)**

2. **What happens to the color of the solution when you add $Fe(NO_3)_3$ to it?**

   A. It turns darker because the reaction shifts to make more products.

   B. It turns darker because the reaction shifts to make more reactants.

   C. It turns lighter because the reaction shifts to make more reactants.

   D. It turns lighter because the reaction shifts to make more products.

3. **What will happen when SCN^{-} ions are removed from the solution?**

   A. More products will form.

   B. More reactants will form.

   C. More reactants and products will form.

   D. Nothing will happen.

4. **How might the equilibrium be shifted towards the products in the following reaction?**

   $$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$$

   A. Add more O_2.

   B. Add more CO_2.

   C. Remove CO.

   D. Remove O_2.

5. **Which change may disrupt a system in equilibrium?**

   A. A change in the pressure of the system (if gases are present).

   B. A change in the temperature of the system.

   C. A change in the concentration of the products or reactants.

   D. All of the above.

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. A ________________________ is one in which reactants are converted to products. A ________________________ is also possible in which the newly created products revert back to the original reactants. Many chemical reactions can proceed in both directions at the same time. Shortly after the forward reaction begins, the reverse reaction also takes place such that both are occurring at the same time. Eventually, a ________________________ is established where the rate of the forward reaction equals the rate of the reverse reaction. The equation recognizes the dual process with opposite arrows ($\rightleftharpoons$). Even though both the forward and reverse reactions continue to happen, the relative amounts of reactants and products are ________________________. This establishes a ________________________ equilibrium where it only appears that nothing is changing. Common types of equilibrium reactions include the ________________________ of weak acids or weak bases in solution, many types of redox reactions, and the dissociation of slightly soluble salts in solution.

2. A system at equilibrium can be disturbed by changing the ________________________ of reactants or products, the ________________________ of the system, or the ________________________ of the system (if gaseous substances are involved). The system will then adjust in order to reestablish a new equilibrium between its reactants and products. ________________________ states that a system at equilibrium responds to a change in such a manner that it relieves the stress. For example, a weak acid partially dissociates in aqueous solutions until it reaches equilibrium. If additional ions are ________________________ the weak acid will reform. If ions are ________________________, however, the weak acid will dissociate to produce more ions.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
chemical equilibrium	added
combustion	amount
decomposition	Charles's law
decrease	Le Châtelier's principle
dissociation	physical state
dynamic	pressure
forward reaction	removed
increased	temperature
neutralization	
reverse reaction	
static	
the same	