# Buffers

**Structure-Function-Properties Series**

*Instructor’s Guide*

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*Developed by the Teaching and Learning Laboratory at MIT for the Singapore University of Technology and Design*
Introduction

When to Use this Video

- In Chem 101, at home, in class, or in recitation, before or during Lectures 26 and 27.
- Prior knowledge: Students should have a basic understanding of chemical equilibria; know how to calculate the pH of acid-base solutions.

Learning Objectives

After watching this video students will be able to:

- Describe how the structure, or composition, of a buffer functions to resist changes in pH.
- Explain how the choices made in buffer design impact the properties of a buffer.

Motivation

Students often focus on the calculations related to buffers without thinking about how the various components of a buffer work together. As a result, they often show a poor understanding of the various factors that can influence the final properties of a buffer solution.

Student Experience

It is highly recommended that the video is paused when prompted so that students are able to attempt the activities on their own and then check their solutions against the video.

During the video, students will:

- Explain why a solution comprised solely of an acid in water could not effectively resist changes to its pH when more acid is added.
- Explain why a solution of a strong acid and a strong base will not resist changes in pH.
- Write the equilibrium expression for a weak acid.
- Evaluate the ability of a solution of a weak acid and strong base to create an effective buffer.
- Brainstorm factors that should be considered when designing a buffer solution.
- Consider how the ratio of weak acid to conjugate base will affect the buffering capacity of a solution.
Video Highlights

This table outlines a collection of activities and important ideas from the video.

<table>
<thead>
<tr>
<th>Time</th>
<th>Feature</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>2:22</td>
<td>Chapter 1: Making a Model</td>
<td>Students are introduced to a conceptual model of buffer solutions based on Legos®.</td>
</tr>
<tr>
<td>5:18</td>
<td>Legos® model of buffer solution</td>
<td>Introduction to Legos® model.</td>
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<tr>
<td>5:56</td>
<td>Combination of strong acid (HCl) and strong base (NaOH)</td>
<td>Legos® are used to model the complete dissociation of a strong acid and base and their subsequent neutralization reaction.</td>
</tr>
<tr>
<td>7:26</td>
<td>Weak acid (HA) and strong base (NaOH): Introduction</td>
<td>Legos® are used to model the reaction between a weak acid and strong base.</td>
</tr>
<tr>
<td>7:47</td>
<td>Student Activity</td>
<td>Students will determine the equilibrium expression for three different weak acids.</td>
</tr>
<tr>
<td>8:13</td>
<td>Weak acid (HA) and strong base (NaOH): Dissociation of HA</td>
<td>Legos® are used to model the partial dissociation of a weak acid (HA) in water.</td>
</tr>
<tr>
<td>8:56</td>
<td>Weak acid (HA) and strong base (NaOH): Addition of strong base</td>
<td>Legos® are used to model the effect of a strong base on a weak acid solution.</td>
</tr>
<tr>
<td>12:41</td>
<td>Chapter 2: Buffer Design</td>
<td>Students are introduced to buffer capacity and the factors that influence buffer properties.</td>
</tr>
<tr>
<td>13:30</td>
<td>Student Activity</td>
<td>Students are asked to list the factors they should consider when designing a buffer.</td>
</tr>
<tr>
<td>16:26</td>
<td>Summary of the main factors crucial to buffer design</td>
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Video Summary

In this video, Legos® are used to create possible molecular level models of a buffer. This is done to better understand how a buffer works and the components a buffer must contain in order to be effective. Students evaluate these models against a set of criteria determined at the beginning of the video and then consider other parameters that must be taken into account when designing a buffer.
Chem 101 Materials

Pre-Video Materials

When appropriate, this guide is accompanied by additional materials to aid in the delivery of some of the following activities and discussions.

1. Using Legos®, model solutions of a strong and weak acid and a strong and weak base. Have students review the definition of acids and bases and the differences between strong and weak acids and bases.

2. Amphoteric molecules
   (a) Identify the acid and base in the following reactions:
   • $\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{CO}_3^{2-}(aq)$
   • $\text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_2\text{CO}_3(aq) + \text{OH}^-(aq)$
   (b) Discuss the nature of amphoteric molecules such as $\text{HCO}_3^-$ and $\text{H}_2\text{O}$, which can function as either acids or bases depending on the reaction conditions. Emphasize the importance of writing out the chemical reaction and identifying the acids, bases, and their conjugates.

3. The $K_a$ of acid A is $1.8 \times 10^{-5}$. The $pK_a$ of acid B is 2.2. Which is the stronger acid?

4. $X$ moles of acetic acid ($pK_a 4.76$) are dissolved in 100 mL of water to form solution A. $Y$ moles of hydrochloric acid are dissolved in 100 mL of water to form solution B. The pH of solutions A and B are the same. What can you say about the quantities $X$ and $Y$?
Post-Video Materials

1. Using Legos®, model a buffer solution of a weak base and its conjugate acid, and determine what happens upon the addition of a strong acid or a strong base. Then, model a real-life buffer system, such as the carbonic acid buffer system in the blood.

Problems 2-4 are adapted from the Buffers Module developed by the MIT Council on Educational Technology (MICET) Chemistry Bridge Project.

2. Which of the following is true?
   (a) In a buffer system, the conjugate base is a H+ source that counteracts addition of strong acid.
   (b) In a buffer system, the acid is a H+ source that counteracts addition of strong acid.
   (c) In a buffer system, the acid is a H+ source that counteracts addition of strong base.
   (d) In a buffer system, the conjugate base is a OH- source that counteracts addition of strong base.

3. Buffer A has an equilibrium [acid]:[conjugate base] ratio of 4:1. Buffer B has an equilibrium [acid]:[conjugate base] ratio of 1:1. Which buffer will hold its pH better when 1 mL of 0.100M HCl is added?

4. Which of the following is not an appropriate way to make a buffer solution?
   (a) Prepare a solution of a weak acid with its conjugate base in approximately equal concentrations.
   (b) Partially titrate a weak acid with strong base.
   (c) Partially titrate a weak base with a strong acid.
   (d) Prepare a solution of strong acid with its conjugate base in approximately equal concentrations.
   (e) For the following equilibrium, addition of HCl will result in increased formation of what?

\[
\text{CH}_3\text{COOH}(aq) \leftrightarrow \text{CH}_3\text{COO}^-(aq) + \text{H}^+(aq)
\]
**Additional Resources**

**Going Further**

Buffers play extremely important roles in chemical, biological, and biochemical systems, as well as in scientific research. For example, serious medical conditions, such as organ failure, can arise from the disruption and failure of the body to maintain a narrow pH range in the blood. Furthermore, students that continue in research will likely experience making a buffered solution. Students should begin to recognize how buffers are used in a wide range of applications and how appropriate buffer design contributes to the overall success of a particular process.

**References**

The following articles provide an excellent introduction to the teaching and learning challenges related to buffers:


The following MIT OCW video lecture discusses buffers:

  - Lecture 22: Chemical and Biological Buffers
RES.TLL.004 STEM Concept Videos
Fall 2013

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