Buffers

Structure-Function-Properties Series

Instructor's Guide

Contents

Intro

Chem 101

Resources

Table of Contents

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.

Key Information

Duration: 17:30
Narrator: George Zaidan
Materials Needed:
• paper
• pencil
• Legos® (optional)

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.

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

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:

- $HCO_3^-{}_{(aq)} + H_2O_{(l)} \leftrightarrow H_3O^+{}_{(aq)} + CO_3^{-2}{}_{(aq)}$
- $HCO_3^-{}_{(aq)} + H_2O_{(l)} \leftrightarrow H_2CO_{3(aq)} + OH^-{}_{(aq)}$

(b) Discuss the nature of amphoteric molecules such as HCO_3^- and H_2O, 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 Ka of acid A is 1.8 x 10-5. The pKa of acid B is 2.2. Which is the stronger acid?

4. X moles of acetic acid (pKa 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?
CH3COOH(aq) ↔ $CH3COO^-$(aq) + 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:

- Cheung, D. (2009). The Adverse Effects of Le Chatelier's Principle on Teacher Understanding of Chemical Equilibrium. *J Chem. Ed. 86* (4), 514-518.
- Orgill, M.K. and Sutherland, A. (2008). Undergraduate chemistry students' perceptions of and misconceptions about buffers and buffer problems. *Chem. Educ. Res. Pract. 9*, 131-143.
- Tyson, L. and Treagust, D.F. (1999). The Complexity of Teaching and Learning Chemical Equilibrium. *J. Chem. Ed. 76* (4), 554-558.

The following MIT OCW video lecture discusses buffers:

- Drennan, Catherine, and Elizabeth Taylor. 5.111 Principles of Chemical Science, Fall 2008. (MIT OpenCourseWare: Massachusetts Institute of Technology), http://ocw.mit.edu/courses/chemistry/5-111-principles-of-chemical-science-fall-2008 (Accessed 6 Jan, 2014). License: Creative Commons BY-NC-SA
  - -Lecture 22: Chemical and Biological Buffers