VIRTUAL LABORATORY ACTIVITY

OSUN Connected Learning Contest Winner

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Course: General Chemistry II

This lab activity is part of the unit on applications of aqueous equilibria and is an extension of the previous unit on acid-base reactions. It is typically assigned towards the end of the spring semester, and it integrates previously learned concepts such as buffered solutions, chemical equilibrium, and properties of acids and bases.

In the previous unit, students learned about the difference between strong and weak acids in terms of their composition and extent of dissociation in water. In this virtual lab, students investigated the behavior of a weak acid when it reacts with a strong base and later compare it to that of a strong acid. They monitored pH changes as a strong base is added in the solution until the acid is completely neutralized. Using Google Spreadsheet or Excel, students generated a graph (titration curve) and analyzed its features, including the buffered region and equivalence point.

When we moved to remote learning, I introduced virtual labs using the resources in the ChemCollective website (http://ir.chem.cmu.edu/) where students learned to gather materials using a virtual "Stockroom" and and work on a simulated "Workbench". Before this titration activity, students have done three virtual lab activities and are familiar with the website features. They are also familiar with the titration technique as we have done it in the fall semester. I modified the write-up in our existing laboratory activity on this topic and adapted the procedures to the virtual set-up. Students worked in groups when conducting the experiment and were able to run the experiment at least two times within our laboratory period. They then worked individually and on their own time to generate the graph. The following class times, we discussed the features of the graph. As a class, we reviewed what information they need to determine the unknown concentration as well as the multi-step calculations involved in determining the acid equilibrium constant (Ka).

General Chemistry II

This second-semester chemistry course is designed to build upon the first-semester chemistry (General Chemistry I) curriculum and to prepare students for further study in chemistry. Principal topics include, chemical kinetics, chemical thermodynamics, chemical equilibrium, acid-base chemistry, reaction mechanism and electrochemistry.

Practical and pedagogical value

The topic of acid-base titration is one of those that require in depth discussion and hands-on experience in order to solidify student understanding. But more so in the second semester college chemistry class because of the integration of chemical equilibrium, pH calculations and buffers concepts. Students often get confused about what strategy to use in solving related problems and lose their way in the multi-step calculations. A strategy that I discuss in class is the use of tables to organize information given in the problem. The lab activity allows them to explore the different strategies and systematically work their way in solving titration problems.

One of the ways this virtual lab activity works is that it allows students to think independently as they carry out all aspects of the experiment and perform data analysis, which is a challenge during in-person laboratory due to limited time and resources. In addition, the ease of "grabbing" materials and set-up in a virtual setting, allowed students to perform the experiment multiple times without using a lot of materials or not finishing experiments on time. It was also easier for me to give them timely feedback on their work assigned as a Google Doc in Google Classroom or for them to ask clarifying questions to their group mates using the Screen Share and Breakout Room features of Zoom when doing the activity. Furthermore, I think that this activity will also be helpful to support struggling students even during in-class activities when assigned as a pre-lab activity.

As with any lab activity, it is important to have clear instructions and experimental procedures. In using virtual labs, I find it useful to start with simple activities to let students explore the features of the website before doing complex activities. Before doing the titration lab, we have done chemical equilibrium and preparation of buffer solutions where students gained experience on how to use the Stockroom and Workbench features.

I used the website ChemCollective, which has virtual labs which provides problems and customizable assignments. It also features a walk through video and supporting information. I also used Google Classroom to assign the activity written in a Google Doc to individual students. I wrote my comments on the doc. Students also used Google Spreadsheet and Excel, which they have used in previous experiments. Some students may need to help in using these tools, for example: inserting graphs, changing scales of the axes, etc.

The Assignment

The assignment is a virtual laboratory activity involving an acid-base reaction. The goal of the activity is to apply one of the fundamental analytical laboratory techniques called titration to determine the unknown concentration of a weak acid by reacting with a strong base as well as to determine the equilibrium constant of the acid. The activity allows students to generate and interpret a titration curve to obtain the necessary data to accomplish the aforementioned goals.

NAME:

Lab: Titration of a Weak acid with a Strong Base

Background Information

The relative acidity or basicity of a substance or a system is of critical importance in many situations, such as the quality of drinking water, food preservation, soil conditions for agriculture, and physiological functions. One measure of the strength of an acid is its ability to donate protons to a base.

The **acid dissociation constant, K_a,** is a quantitative measure of the strength of an acid. The ionization of a generic acid, HA, can be represented by the following equation:

$$\mathbf{HA(aq) + H_2O(l) \rightarrow H_3O^+(aq) + A^-(aq)}$$

in which the weak acid donates a proton, H^+, to a water molecule, to form the hydronium ion, H_3O^+, and the conjugate base of the weak acid, A^-. The corresponding acid ionization constant expression, K_a, can be written as: $K_a = \frac{[H_3O^+][A^-]}{[HA]}$

The K_a value indicates the relative strength of an acid and the extent of ionization. The K_a value is directly proportional to acid strength.

In this experiment, you will determine the concentration of a sample of an unknown monoprotic weak acid , as well as its K_a, by monitoring the pH as you titrate it with a base, sodium hydroxide (NaOH). The solution pH will be monitored using a simulation. A graph of measured pH (y-axis) versus the volume of NaOH added (x-axis) will be plotted. This graph is called a **titration curve** and has the general features shown in Figure 1.

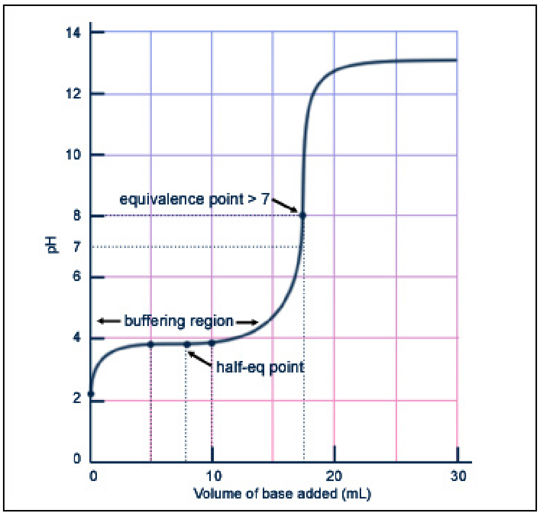

Figure 1. Sample Titration Curve[1]

[1] http://www.core.org.cn/OcwWeb/Chemistry/5-111Fall-2005/CourseHome/index.htm

Titration curves for weak acids, such as acetic acid (CH_3COOH), typically show an initial small rise in pH, but then lead into a region where the pH changes only slowly. The solution composition here is a buffer and this part of the titration curve is called the *buffer region*.

Eventually, the pH climbs very sharply and produces an *inflection* in the curve. At the center of this inflection is the *equivalence point*, at which a stoichiometric amount of base has been added. At the equivalence point, the moles of NaOH added equal to the moles of the acd.

Past the equivalence point, the pH changes slowly as determined by the amount of excess NaOH.

Two important applications of titration curves are illustrated in this experiment.

1) The first is the quantitative determination of the molar concentration of an unknown weak acid. This requires the location of the equivalence point and the titration curve is used to obtain this location. The equivalence point is taken as the steepest point in the titration curve's inflection.

2) The second application of this titration curve is the determination of the dissociation constant (K_a) of acetic acid. The key data needed are titration curve points located in the buffer region. Three points are selected, occurring at approximately ¼, ½, and ¾ of the distance from the initial point to the equivalence point. Each of these three points yields a K_a value from which an average K_a value is calculated. To calculate K_a, we will use the **Henderson-Hasselbalch Equation**:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

Procedure:

Part A. Collecting Data for Titration Curve

1. Using a computer that is running Microsoft windows or Macintosh OS 10.1 or higher, go to http://ir.chem.cmu.edu and click on "**Virtual Labs**" under **Resources by Type**. Find the**"Acid-Base Chemistry"** tab. Under this tab, select **"Unknown Acid and Base Problem"** then hit "Go".

   From the Stockroom, you will need the following solutions: Unknown Acid, 0.1M NaOH and the phenolphthalein indicator. You will also need a buret and 250-mL Erlenmeyer flask.

2. Fill the buret with 50 mL of 0.10M NaOH.
3. Pour 50 mL of the Unknown Acid into a 250-mL Erlenmeyer flask. Record the initial pH of the unknown acid.
4. Add 0.25 mL of the phenolphthalein indicator into the flask with the unknown acid.
5. Before starting the titration, you need to set up data tracking. This allows you to save your data that include pH and volume change in a csv file that you can open in a Google Spreadsheet. Click on the sample flask with the unknown acid and you will see the Information tab appear on the left side of the Workbench. Click on the three horizontal lines on the right of the Information tab, then check on "Vessel Tracking". The "Track Vessel" button will appear under the pH reading.
6. Click on the "Track Vessel" button. Select the "When something is poured to the vessel" check box, then click "Start Tracking".
7. Now begin adding the NaOH solution from the buret into the flask in 1 mL increments. If you were not able to set up the automatic data tracking, manually record the pH on a Spreadsheet after each 1 mL of base addition.
8. Initially, the pH changes will be relatively small. As you proceed and when you notice a larger pH change for each addition, add smaller amounts of base. Near the equivalence point, you may observe very large changes in pH. Continue adding base until your solution reaches a pH of 11-12.
9. Repeat the experiment for a more precise determination of the equivalence point. Since you have an idea where the equivalence point was from the first experiment, you should pour a smaller increment (0.2 mL) when you are 1-2 mL away from the equivalence point in order to get a better data set.

Data: Copy your data and the titration curve from Google Spreadsheet or Excel and paste it here.

Part B: Data Analysis- Determination of Concentration of the Unknown Acid

For your second trial only:

1. On Excel or Google Spreadsheet, make a graph of pH (y-axis) vs. volume NaOH added (x-axis). Use x,y scatter graph with points only (no lines connecting the dots).
2. Add horizontal and vertical Gridlines to your graph (adjust to Minor Gridline: 4). Determine the equivalence point from the graph. Mark this point on the graph.
3. Note the volume of NaOH added at this point. Knowing this volume and the concentration of the NaOH solution, you can now solve for the concentration of the unknown acid. **Show your dimensional analysis and write the units. Report the molarity to two significant digits.**

   Using the generic formula HA for the monoprotic unknown acid, the balanced equation for this acid-base reaction is: $HA(aq) + NaOH(aq) \rightarrow H_2O(l) + NaA(aq)$

Part C: Data Analysis - Determination of Ka of the Unknown Acid using the Titration Curve

1. From your spreadsheet data, select three *experimental points* (mL NaOH, pH) at ¼, ½, and ¾ of the distance between the initial point and the equivalence point of the titration. These points are taken from the *buffer region* in which appreciable amounts of both acetic acid and acetate ion are present. Mark the points chosen on the titration curve printout.
2. Using the three data points chosen, calculate the value of K_a for acetic acid. Report the K_a values to two significant digits.

Calculations

Molarity of NaOH: ______________________

	equivalence point	**¼ equivalence point**	**½ equivalence point**	**¾ equivalence point**
Volume of NaOH added (L)				
Moles of NaOH added				
pH				

Use the following steps to determine the Ka of the unknown acid, HA:

1) Concentration of HA (from Part B): ___________
2) Calculate the number of moles of HA present in a 50-mL solution of HA.

- **Calculate Ka at ¼ equivalence point:**

Reaction: **HA + OH^- → A^- + H_2O**

	HA	OH^-	A^-	H_2O
Before addition (moles)				---
Addition (moles)				---
After addition (moles)				---

Calculate Ka using: $pH = pK_a + log \frac{[A-]}{[HA]}$

Calculate Ka at ½ equivalence point:

Reaction: **HA** + **OH^-** → **A^-** + **H_2O**

	HA	OH^-	A^-	H_2O
Before addition (moles)				---
Addition (moles)				---
After addition (moles)				---

Calculate Ka using: $pH = pK_a + \frac{[A-]}{[HA]}$

- **Calculate Ka at ¾ equivalence point:**

Reaction:	**HA** +	**OH^-**	→ **A^-** +	**H_2O**
Before addition (moles)				---
Addition (moles)				---
After addition (moles)				---

Calculate Ka using: $pH = pK_a + \log log \frac{[A-]}{[HA]}$

- Calculate an average value of K_a.

Post-Lab Analysis

1. For weak acid-strong base titration, the pH at equivalence point is greater than 7.
    a. What is the pH at the equivalence point?

    b. How many moles of A^- ions are present at the equivalence point?

    c. What is the A^- ion concentration at this point? Note: You need to consider here the total volume of the solution.

    d. Write the base dissociation reaction for the A^- ion.

    e. Using the RICE (Reaction, Initial, Change, Equilibrium) table method, calculate the pH of the solution at equivalence point. How does this value compare to the pH in the titration curve you generated?