Abstract:

This experiment will test and exercise the principles of acid-base titration and determination of equivalence, as well as exercises on the determination of the pKa of a weak acid. Through the use of the known reactivity of a base, an acid of unknown reactivity and measured mass will be reacted to determine equivalence, and equivalent weight, and by recording changes in pH, these data can be used to determine the pKa. Success will be determined by comparing the resulting pKa with the table of pKa values listed at the back of the text with a reasonable result being within 10% of any listed value.

Procedure:

1. Approximately 0.250 grams of the unknown acid was weighed and added to the beaker, along with 50 mL of water and 1 drop of phenolphthalein.

2. Standardized sodium hydroxide (NaOH) was titrated into the solution, the changes in pH were recorded, more data points were recorded, smaller volumes were added, as the rate of change increased.

3. The data was plotted, the first derivative was calculated and plotted, and the equivalence point and pKa values were determined graphically. The EW was calculated.
Discussion:

Many times, instead of using a molecular weight and concentration, chemists simplify calculations and the amount of material that must be remembered by expressing the concentration in terms of Normality, and Equivalent Weight. Normality is an expression of the number of equivalents per liter. Sodium hydroxide at a 1 M concentration is also 1 N, because 1 mole of NaOH provides one mole of OH-. Equivalent Weight is an expression of the number of equivalents in a given amount of substance. In this experiment, we used a sodium hydroxide solution of known normality to titrate an acid of unknown number of equivalents to find equivalent weight. Sodium hydroxide reacts with monoprotic acids (or in reactions where only one proton per molecule dissociates) according to the following reaction:

\[
A^-_{(aq)} + H^+_{(aq)} + Na^+_{(aq)} + OH^-_{(aq)} \rightarrow A^-_{(aq)} + Na^+_{(aq)} + H2O_{(l)}
\]

So, by knowing the normality of the sodium hydroxide titrated, or the number of equivalents per liter, we can determine how many protons reacted with the number of moles of hydroxide in solution (as they are equivalent). Knowing the number of equivalents and the mass of the unknown acid, it is a simple matter to calculate Equivalent Weight, or the number of grams per equivalent.

Another way to tell the equivalence point is the point at which the rate of pH change is the largest with a titrated amount of acid or base. By plotting the pH versus the volume added, and plotting the first derivative (change in pH with respect to the change in volume) versus volume, and extrapolating the equivalence point. At the equivalence point, all of the weak acid or weak base will be converted to its conjugate acid or base. At half the volume added from the equivalence point, the amount of weak acid or weak base equals the amount of conjugate acid or base in solution. This makes the log term in the Henderson-Hasselbalch equation zero and provides a direct relationship between pH and pKa:

\[
pH = pK_a + \log [A^-]/[HA]
\]

if \([A^-]=[HA]\) then \(\log [A^-]/[HA] = 0\)

so \(pH = pK_a\)

At this point, the buffering capacity of the solution is greatest, and the pH of the solution is the pKa. By extrapolating the pKa, it is then a simple matter to calculate the acid (or base) dissociation constant of the acid (or base) using the Henderson-Hasselbalch equation.

Conclusion:

Unknown acid # 110 was found to have an equivalent weight of 59.7638 g / eq. The pK_a of the acid was found to be approximately 3.2, with a K_a of 6.31 \times 10^{-3}.

(No replicate runs were made, therefore calculations for Standard Deviation and %RSD which are normally reported here cannot be made.)
Data Table(5):

Example Calculations(4): Addenda:

[Insert Raw Data, Notebook Copy, Graphs and Other Attachments Here]
**Pre-Lab Questions (1):**

(The web master makes no claims as to the correctness of the following answers)

1. Calculate the pH and pOH of a 1.0 x 10^{-5} M solution of HCl?

HCl is a strong acid, so \([\text{HCl}] = [\text{H}_3\text{O}^+] = 1.0 \times 10^{-5}\)
\[
\text{pH} = -\log [\text{H}_3\text{O}^+] = -\log (1.0 \times 10^{-5}) = 5
\]
\[
\text{K}_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}
\]
\[
\text{pOH} = -\log [\text{OH}^-] = -\log (1 \times 10^{-9}) = 9
\]
\[
\text{pH} = 14 - \text{pOH} = 5
\]

2. What is the pH of a buffer prepared by mixing 15 mL each of 0.10 M acetic acid and 0.10 M sodium acetate (\(K_a = 1.75 \times 10^{-5}\))?

\[
\text{pH} = pK_a + \log [\text{A}^-]/[\text{HA}]
\]
\[
\text{pH} = -\log (1.75 \times 10^{-5}) + \log (.10/1.0) = 4.76
\]

3. Calculate the pH of 0.100 M Na_3PO_4 solution (\(K_3 = 7.1 \times 10^{-13}\))?

\[
\text{K}_3 = 7.1 \times 10^{-13} = [\text{BH}^+][\text{OH}^-]/[\text{B}] = x^2 / 0.10 \Rightarrow x = \sqrt{7.1 \times 10^{-13} \times 0.1} = [\text{BH}^+][\text{OH}^-]
\]
\[
x = 2.66 \times 10^{-7} = [\text{OH}^-]
\]
\[
\text{K}_w = 1 \times 10^{-14} = [\text{H}_3\text{O}^+][\text{OH}^-]
\]
\[
[\text{H}_3\text{O}^+] = 3.75 \times 10^{-8}
\]
\[
\text{pH} = -\log [\text{H}_3\text{O}^+] = 7.43
\]

4. The following data were obtained for the titration of 500 uL of 0.10 M acetic acid with 0.10 M NaOH. Plot the titration curve and first derivative curve on a sheet of graph (EXCEL) paper. Determine the equivalence point of the titration and find the \(K_a\) of acetic acid.

See attached.

**Post-Lab Questions(1):**

1. If the pH of the solution is 2.03, what is the [H^+]?

\[
2.03 = -\log [\text{H}^+] \Rightarrow [\text{H}^+] = 0.0093
\]

2. The HPO_4^{2-} / H_2PO_4^- couple is an effective buffer system in the blood. If the pH is 7.40, what is ratio of [HPO_4^{2-}]/[H_2PO_4^-]?

\[
\text{pH} = pK_a - \log [\text{A}^-]/[\text{HA}]
\]
\[
7.20 - 7.20 = \log [\text{A}^-]/[\text{HA}]
\]
\[
\log [\text{A}^-]/[\text{HA}] = 0.20
\]
\[
[\text{A}^-]/[\text{HA}] = 1.58
\]