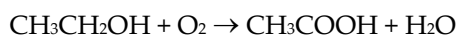


Lab 25. Acid-Base Titration and Neutralization Reactions: What Is the Concentration of Acetic Acid in Each Sample of Vinegar?

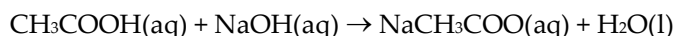
Introduction

Vinegar is basically a solution of acetic acid (CH_3COOH). It is commonly used as an ingredient in salad dressing and marinades. People also use it as a cleaning agent because it dissolves mineral deposits that often build up on appliances. The acetic acid found in vinegar is produced through the oxidation of ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) by bacteria from the genus *Acetobacter* that is added to alcoholic liquids such as wine, apple cider, and beer. The overall chemical reaction that is facilitated by these bacteria is



The acetic acid concentration of vinegar differs depending on its intended use. The acetic acid concentration in table vinegars, such as red wine, apple cider or balsamic, ranges from 4% to 8%. When used for pickling, the acetic acid concentration of vinegar can be as high as 12%. Companies that produce vinegar therefore need to be able to determine the exact concentration of acetic acid in a sample of vinegar in order to ensure consistency between batches and to maintain quality control over their product. One way to determine the exact concentration of acid in a solution is to use a technique called an acid-base titration.

An acid-base titration is based on the premise that acids and bases neutralize each other when mixed in an exact stoichiometric ratio. For example, when sodium hydroxide is added to acetic acid, the sodium hydroxide will react with and consume the acetic acid based on the following neutralization reaction:



This balanced chemical equation indicates that 1 mole of NaOH is needed to completely neutralize 1 mole of CH_3COOH . A chemist, as a result, can use this proportional relationship to determine how many moles of acetic acid are present in a solution. To accomplish this task, the chemist must first determine how many moles of sodium hydroxide need to be added to the solution in order to neutralize the acetic acid in it. The chemist can then use the stoichiometric ratio that exists between the reactants to determine the number of moles of acetic acid in the solution. Finally, the chemist can calculate the concentration of acetic acid in the solution based on the moles of acetic acid found in the sample and the volume of the sample.

In this investigation you will use an acid-base titration to determine the concentration of acetic acid in several different types of vinegar. This is important for you to be able to do because a common question that chemists have to answer is how much acid or base is present in a given solution. It is also a key aspect of doing acid-base chemistry.

Your Task

Determine the concentration of acetic acid in three different samples of vinegar.

The guiding question for this investigation is, **What is the concentration of acetic acid in each sample of vinegar?**

Materials

You may use any of the following materials during this investigation:

Consumables	Equipment
<ul style="list-style-type: none">• Potassium hydrogen phthalate, KHP• 0.1 M NaOH solution• Vinegar sample A• Vinegar sample B• Vinegar sample C• Distilled water (in a wash bottle)	<ul style="list-style-type: none">• Volumetric pipette (5 ml)• Pipette bulb• Burette (50 ml)• Burette clamp• Test tube clamp• Ring stand

<p><i>Indicators</i></p> <ul style="list-style-type: none"> • Bromthymol blue • Cresol red • Phenolphthalein • Thymol blue 	<ul style="list-style-type: none"> • 2 beakers (each 250 ml) • 2 Erlenmeyer flasks (each 250 ml) • Graduated cylinder (25 ml) • Magnetic stirrer or glass stirring rod • Funnel • Electronic or triple beam balance
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Safety Precautions

Follow all normal lab safety rules. Acetic acid and sodium hydroxide are corrosive to eyes, skin, and other body tissues. Sodium hydroxide is also toxic by ingestion. Phenolphthalein is an alcohol-based solution and is flammable, and it is moderately toxic by ingestion. Keep away from flames. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? Yes No

Getting Started

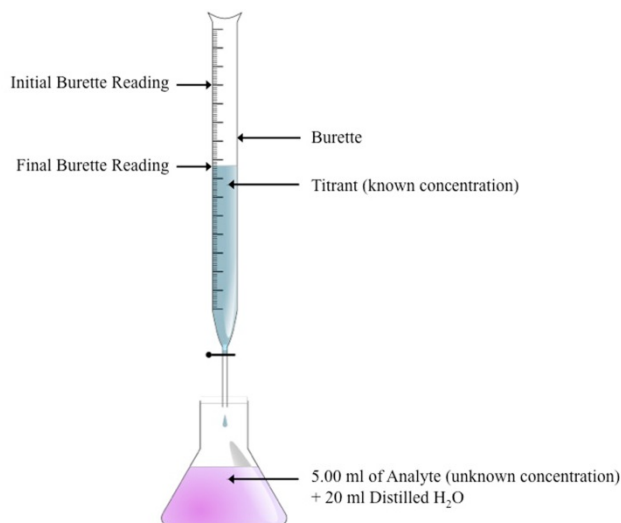
The objective of an acid-base titration is to measure the volume of one reactant of known concentration that is required to neutralize another reactant of unknown concentration. The reactant with the known concentration is called the *titrant*, and the reactant with the unknown concentration is called the *analyte*. The titrant is gradually added to the analyte in small amounts until an end point is reached. The end point is represented by a color change in an indicator that is added to the analyte. If the indicator is chosen well, the end point will correspond with the equivalence point of reaction. The equivalence point is the point at which the amount of titrant is stoichiometrically equivalent to the amount of the analyte.

To perform an acid-base titration, you first need to understand how to measure the volume of the titrant needed to neutralize a specific volume of the analyte. The equipment setup for the process is illustrated in Figure L25.1. The basic steps are as follows:

1. Use a 5 ml volumetric pipette to add exactly 5 ml of the analyte (solution of unknown concentration) to a 250 ml beaker or 250 ml Erlenmeyer flask.
2. Add about 20 ml of deionized water to the analyte.
3. Add a few drops of indicator solution to the analyte.
4. Fill the burette with the titrant and record the initial burette reading.
5. Add the titrant drop by drop until the end point is reached. Be sure to stir or swirl the analyte as the titrant is added to make sure the chemicals are completely mixed.
6. Record the final burette reading.

FIGURE L25.1

Equipment setup for titration



Once the end point is reached, the volume of the titrant that was added to the analyte is used to calculate the molarity of the sample, as follows:

1. Determine the moles of titrant used in the reaction from the known molarity of the titrant and the volume of titrant needed to reach the end point.
2. Determine the moles of the analyte reactant using the stoichiometric ratio of the reactants provided in the neutralization equation and the number of moles of titrant used.
3. Determine the molarity of the unknown solution from the moles of the analyte reactant and the volume of the unknown sample (molarity = moles/L).

The concentration of the analyte can also be expressed as a mass percent. To determine the mass percent of the reactant in the analyte, perform the following calculations:

1. Use the moles of the analyte reactant and the molar mass of the analyte reactant to determine the mass of the reactant in the sample.
2. Determine the total mass of the sample.
3. Determine the mass percent of the analyte reactant from the mass of the analyte reactant in the sample and the total mass of the sample.

When performing a titration, it is important to know the exact concentration of the titrant. Solid NaOH, for example, tends to absorb moisture from the air. It is therefore often difficult to determine the exact mass of NaOH that is added to solution, which leads to inaccurate molarity calculations. In addition, solutions of NaOH tend to absorb carbon dioxide from the air, which neutralizes some of the base. NaOH should therefore be standardized before it is used as the titrant in a titration. Your instructor will either tell you the standardized concentration of the NaOH solution that you will use during this investigation or have you standardize your NaOH solution using a primary standard called potassium hydrogen phthalate (KHP).

TABLE L25.1

Potential indicators

Indicator	pH range	Low pH color	High pH color
Bromthymol blue	6.0–7.6	Yellow	Blue
Cresol red	7.2–8.8	Orange	Red
Phenolphthalein	8.0–9.6	Clear	Pink
Thymol blue	8.0–9.6	Yellow	Blue

It is also important to choose an indicator solution that will signal the end point of the titration that is as close as possible to the equivalence point of the reaction. Acetic acid is a weak acid. The equivalence point of the reaction between acetic acid and sodium hydroxide is at a pH of 8.72. KHP is also a weak acid. The equivalence point of the reaction between KHP and sodium hydroxide is at a pH of 8.50. Table L25.1 provides a list of the potential indicators that you can use for this investigation.

Now that you understand how to perform a titration, you will need to determine what type of data you need to collect, how you will collect the data, and how you will analyze the data to answer the guiding question.

- To determine *what type of data you need to collect*, think about the following questions: What type of measurements will you need to record during your investigation?
- When will you need to take your measurements?

To determine *how you will collect the data*, think about the following questions:

- What samples of vinegar will you need to titrate?
- Which indicator will you use and why?
- How will you eliminate confounding variables?
- How will you reduce measurement error? (Hint: You can run multiple trials and then determine if the results are significantly close. You will also need to average your results.)
- How will you keep track of the data you collect?

To determine *how you will analyze the data*, think about the following questions:

- What types of calculations will you need to make to determine the concentration of acetic acid in each sample of vinegar?
- How will you determine which sample of vinegar has the greatest concentration?
- What type of graph could you create to help make sense of your data?

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

- the importance of recognizing and using proportional relationships,
- the importance of tracking how matter moves into and within a system,
- the difference between observations and inferences in science, and
- how science is influenced by the society and culture in which it is practiced.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L25.2.

FIGURE L25.2

Argument presentation on a whiteboard

The Guiding Question:	
Our Claim:	
Our Evidence:	Our Justification of the Evidence:

Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!