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INVESTIGATION

How Much Acid is in Fruit Juice and Soft Drinks?

■Central Challenge

Imagine that you have just been told the pain you feel in your chest after eating is caused by small amounts of stomach acid coming in contact with the lower part of your esophagus and irritating the lining of your esophagus over time. It is recommended that you avoid spicy foods, carbonated beverages, and orange juice. You wonder why. This laboratory investigation gives you an opportunity to explore that question as you design your own experimental procedure to determine how much acid is in fruit juice and soft drinks.

■Context for This Investigation

Perhaps you have wondered how doctors determine the ratios for IV drips during surgery or hospital stays. They use a common laboratory procedure called a titration to calculate specific ratios of different substances using volume measurements. A similar process occurs when someone uses a machine to monitor blood glucose levels, to analyze urine samples, or to conduct a pregnancy test. Pharmacists use titrations when compounding drugs, which allows them to more precisely match a person's drug prescription to their body weight, size, or medical condition. While it may sound like titrations are common practice only in the chemistry lab or medical community, titrations have great practical use. Food scientists use them when testing for levels of salt, sugar, and vitamins in different foods, and for deciding if wine and cheese are ready for consumption. Others use titrations to test for water quality or hardness and in neutralizing the free fatty acids in waste vegetable oil before refining it as biodiesel. In all cases, titrations are used to quantitatively analyze the unknown concentration of a solution or the amount of a substance by comparing it to a solution of known concentration.

Orange Juice:
- Citric acid
- Ascorbic acid
- Malic acid

Orange Soda:
Orange Soda (Fanta)
- Citric acid
- Citrate
- Acesulfame K
- Ascorbic acid
- Phosphoric acid

■Preparation

Materials

You my select from when the following materials when developing your lab procedure. The items may or may not be used. Please indicate in your lab report which pieces of equipment you will be using.

25 beakers of varying sizes (100 mL, 150 mL, 250 mL, and 400 mL)	Various acid-base indicators — methyl orange, methyl red, bromothymol blue, phenolphthalein, thymol blue (or others you may have on hand)
12–15 50 mL burets	pH meters or pH paper (if meters are unavailable)
15 Erlenmeyer flasks of varying sizes (125 and 250 mL)	500 mL total of 0.10 M acetic acid (CH_3COOH)
25 graduated cylinders of varying sizes (10 mL, 25 mL, and 100 mL)	Various light-colored and/or clear fruit juices and sodas
12–15 volumetric pipettes of varying sizes (10 mL and 25 mL)	12–15 100 mL bottles of standardized 0.10 *M* and 0.25 *M* sodium hydroxide (NaOH) solutions (4.0 L total of each solution)
25 droppers	12–15 wash bottles with distilled water

$$\frac{.200\,L\,NaOH}{} \left| \frac{0.500\,mol}{1.00\,L} \right| \frac{40\,g}{1\,mol} = 2\,g\,NaOH$$

Safety and Disposal

Chemical splash goggles are required when conducting this lab. Use caution when using the NaOH solutions, as they can irritate skin and cause burns. If the solution is spilled on skin, wash with water for up to 15 minutes, briefly rinse with dilute vinegar (50% vinegar by volume), and then wash with water again. After neutralization, solutions may be washed down the drain with lots of water. Fruit juice and sodas will leave a sticky residue on lab desks and glassware, so all surfaces should be washed prior to leaving the lab.

■Explanation to Strengthen Student Understanding

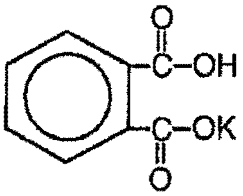
One of the first titrations you perform is the reaction between a hydrochloric acid solution of unknown concentration and sodium hydroxide. Since we are analyzing HCl to determine its concentration, we call it the analyte. The hydrochloric acid solution would be "titrated" by adding a standard solution of sodium hydroxide dropwise. The sodium hydroxide solution is called the titrant, and is a standard solution because its concentration is accurately known. In this example, the titrant (NaOH) reacts with the analyte (HCl) in the neutralization reaction shown below:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

The point at which enough titrant has been added to react exactly with the analyte is called the equivalence point. Here, the number of moles of $OH^-(aq)$ added is equal to the number of moles of $H^+(aq)$ consumed. Since this point is not visible to the eye, we use a pH indicator to help us detect it. The point at which the indicator changes color is called the endpoint, and, assuming it has been selected appropriately, indicates that the equivalence point has been reached. The best indicator for the titration is one in which the endpoint and equivalence point are as close together as possible.

The progress of an acid-base titration can also be followed by measuring the pH of the solution being analyzed as a function of the volume of titrant added. A plot of the resulting data is called a pH curve or titration curve. Titration curves allow a precise determination of the equivalence point of the titration without the use of an indicator. The concentration of the NaOH solution must be accurately known. To "standardize" the NaOH, that is, to find its exact molarity, the NaOH is titrated against a solid acid, potassium hydrogen phthalate (KHP). The KHP is chosen because it is easily dried and weighted and has a relatively high molar mass. The formula of KHP is:

KHP contains one ionizable H^+. The titration is followed using phenolphthalein as an indicator.



or $KHC_8H_4O_4$

The graph of pH versus volume of NaOH added (see Figure 1) is obtained by carefully following the titration with a pH meter. There is a significant change in pH in the vicinity of the equivalence point. Note that when a weak acid is titrated with a strong base, the equivalence point is NOT at pH 7, but is on the basic side. The value of the equilibrium constant for the dissociation of the acid is obtained from the graph. If the dissociation of the acid is represented as:

$$HA + H_2O \leftrightharpoons H_3O^+ + A^-$$

the equilibrium constant expression is:

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

When the acid is half neutralized, $[HA] = [A^-]$, these terms cancel in the above equation, and $K_a = [H_3O^+]$. Therefore, when the acid is ***half-neutralized***, the $pH = pK_a$.

The point where pH is equal to pK_a can be found from the graph. Refer to Figure 1.

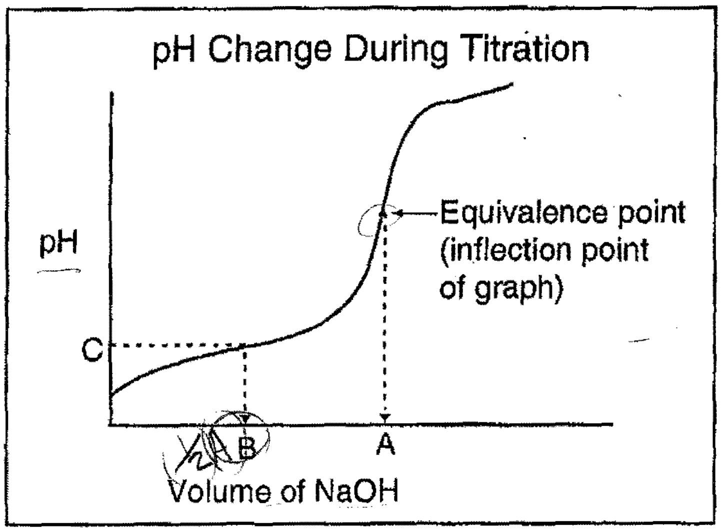


Figure 1. pH during titration of a monoprotic weak acid with sodium hydroxide

A = Volume NaOH at equivalence point

B = 1/2 A = the volume of NaOH required to neutralize one-half the acid when half-neutralized

C = pH when the acid is half neutralized = pK_a

In this experiment, you will design your own acid-base titration to determine the acid concentration of fruit juice or a carbonated beverage by using a standardized solution of sodium hydroxide, and make a prediction about how knowing the acid content of a certain beverage would be of benefit to them. Nutritionists cite the dangers of regular consumption of carbonated beverages on bone density and recommend a low-acid diet. Dentists caution patients about the relationship between acid and oral health. Is there cause for concern? Might the knowledge gained in this lab help us better understand their recommendations, and make reasonable decisions about our beverage of choice?

Prelab Preparation

Part 1 – Prelab Questions

Phosphoric acid is a triprotic acid (three ionizable hydrogens). The values of its stepwise ionization constants are $K_{a1} = 7.5 \times 10^{-3}$, $K_{a2} = 6.2 \times 10^{-8}$, and $K_{a3} = 4.2 \times 10^{-13}$.

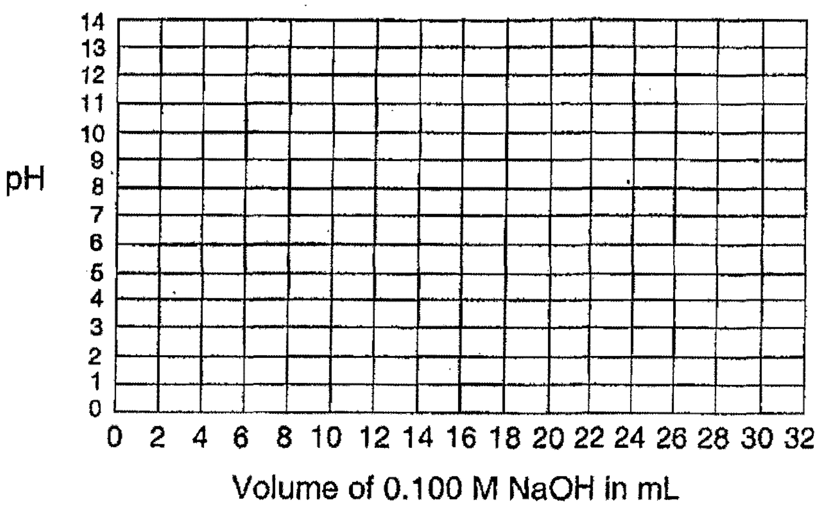
1. Write the chemical equation for the first ionization reaction of phosphoric acid with water.
2. Write the equilibrium constant expression, Ka_1, for this reaction.
3. What would be the pH of a solution when $[H_3PO_4] = [H_2PO_4^-]$?
4. Phenolphthalein would not be an appropriate indicator to use to determine Ka_1 for phosphoric acid. Why not? Choose a suitable indicator from the following color chart.

	pH										
Indicator	1	2	3	4	5	6	7	8	9	10	11
Phenolphthalein	Colorless							Pink		Red	
Methyl Red	Red				Orange		Yellow				
Orange IV	Orange		Peach		Yellow						

5. Calculate the molarity of a solution of sodium hydroxide, NaOH, if 23.64 mL of this solution is needed to neutralize 0.5632 g of potassium hydrogen phthalate.
6. It is found that 24.68 mL of 0.1165 M NaOH is needed to titrate 0.2931 g of an unknown acid to the phenolphthalein end point. Calculate the equivalent mass of the acid.
7. The following data was collected for the titration of 0.145 g of a weak acid with 0.100 M NaOH as the titrant:
   a. Graph the data on the chart provided below.

Volume NaOH added, mL	pH
0.00	2.88
5.00	4.15
10.00	4.58
12.50	4.76
15.00	4.93
20.00	5.36
24.00	6.14
24.90	7:15
25.00	8.73
26.00	11.29
30.00	11.96

Change of pH During Titration of Weak Acid with NaOH



   b. What is the pH at the equivalence point?

   c. Give the K_a and pK_a value of the acid. Explain.

   d. The following acid-base indicators are available to follow the titration. Which of the following would be most appropriate for signaling the endpoint of the titration? Explain.

Indicator	Color Change: Acid Form	Color Change: Base Form	pH Transition Interval
Bromphenol blue	yellow	blue	3.0–5.0
Bromthymol blue	yellow	blue	6.0–7.6
Thymol blue	yellow	blue	8.0–9.6

8. Write the complete chemical equation for the reaction of a solution of sodium hydroxide, NaOH, with hydrochloric acid, HCl.
9. How many mL of 0.1 M HCl are required to react completely with 5 mL of 0.1 M NaOH?
10. If equal molar amounts of NaOH and HCl are mixed, when the reaction is complete what will be the chemical species in the resulting solution?
11. Will the pH of the mixture in question 3 be acidic, basic, or neutral? Explain.
12. Write the complete chemical equation for a reaction of a 0.1 M solution of acetic acid, CH3COOH, with a 0.1 M solution of NaOH.
13. How many mL of the 0.1 M NaOH solution will be required to react completely with 5 mL of 0.1 M acetic acid solution? Explain.
14. When the reaction is complete, what will be the pH (acidic, basic, or neutral) of the solution in question 6? Explain.
15. How is it possible to determine when an acid-base reaction is complete when one of the reactant's concentration is unknown?
16. Using the table on p. 38 in your handout, explain how indicators are chosen and used during titration.
17. Summarize the video http://youtu.be/g8jdCWC10vQ

Part 2 - Standardizing the Sodium Hydroxide with KHP

1. Obtain a sample of potassium hydrogen phthalate (KHP) that has been previously dried in an oven and stored in a dessicator.
2. On an analytical balance, accurately weigh 0.4 to 0.6 g of KHP in a tared weighing dish. Record the mass of the KHP in your data table.
3. Transfer the KHP into an Erlenmeyer flask – pour the solid through a funnel into the flask. Use water from a wash bottle to rinse all of the remaining solid in the weighing dish or in the funnel into the flask as well.
4. Add about 40 mL of distilled water to the flask and swirl until all the KHP is dissolved.
5. Obtain about 75 mL of the sodium hydroxide, NaOH, solution.
6. Clean a 50 –mL buret, then rinse it with three small portions (about 7 mL each) of the NaOH solution.
7. Fill the buret to above the zero mark with the NaOH solution.
8. Open the buret stopcock to allow any air bubbles to escape from the tip. Close the stopcock when the liquid level is between the 0 - and 10 – mL marks.
9. Measure the precise volume of the solution in the buret and record this value in your data table as the initial volume. *NOTE:* Volumes are read from the top down in a buret. Always read from the bottom of the meniscus, remembering to include the appropriate number of significant figures (see Figure 2).
10. Position the buret over the Erlenmeyer flask so that the tip of the buret is within the flask but at least 2 cm above the liquid surface.
11. Add three drops of phenolphthalein solution to the KHP solution in the flask.
12. Begin the titration by adding 1.0 mL of the NaOH solution to the Erlenmeyer flask, then closing the buret stopcock and swirling the flask.
13. Repeat step 12 until 15 mL of the NaOH solution have been added to the flask. Be sure to continuously swirl the flask.
14. Reduce the incremental volumes of NaOH solution to ½ mL until the pink color starts to persist. Reduce the rate of addition of NaOH solution to drop by drop until the pink color persists for 15 seconds. Remember to constantly swirl the flask and to rinse the walls of the flask with distilled water before the endpoint is reached.
15. Measure the volume of NaOH remaining in the buret, estimating to the nearest 0.01 mL. Record this value as the "final volume in your data table.
16. Repeat the standardization two more times. Rinse the Erlenmeyer flask thoroughly between trials with deionized water.

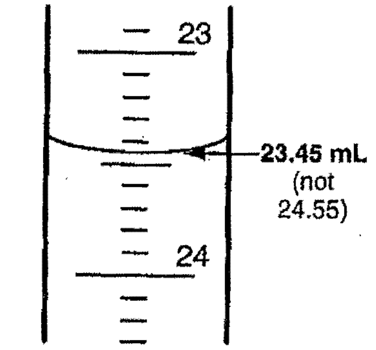


Figure 2. How to read a buret volume.

Standardization Data Table

	Trial 1	Trial 2	Trial 3
Mass KHP, g	.5155 g	.5105	.5230
Final Volume, mL	30 ml	29.61	29.56
Initial Volume, mL	.85 ml	.72 ml	.04
Volume of NaOH added, mL	29.15 ml	28.89	29.52

Molarity NaOH (Average) .08635 M

Part 3 – Planning Your Own Investigation: Use the planning sheet and rubric as you work with your team to design your experiment.

Planning Sheet

Background:
KA of Citric Acid is 7.4×10^{-4} = 3.13

Experimental Design

Purpose: To determine the PH of the Orange Juice & Orange Soda when titrating with NaOH

Prediction: I predict that the more NaOH dropped in the Juice/Soda, the higher the PH will be.

Independent Variable: NaOH solution

Dependent Variable: PH

Trials: 5 for each

Constants: NaOH solution, volume of Juice and Soda, type of Juice & Soda

Control Setup: The Juice/Soda that doesn't have

Testable Research Question: Does Orange Soda or Orange Juice reach equilibrium faster when titrating with NaOH

Hypothesis: If a beverage is titrated with a solution of NaOH with known concentration, then the Ka of the beverage can be determined because

Materials list:
- Burette
- NaOH solution
- Distilled water
- Orange Soda
- Orange Juice
- Gloves
- Goggles
- Apron
- Burette Clamp
- Waste Beaker
- Beaker for Juice/Soda
- Stirring Plate
- Indicator
- Erlenmeyer Flasks
- Buffer
- PH Sensor
- Labquest

Procedure List:
1. Put on Lab Safety
2. Clean burret w/ solution of NaOH
3. Set up ring stand w/ buret clamp
4. Set up beaker with 10 ml of beverage
5. Set up Lab Quest w/ PH sensor
6. Fill Burret with NaOH to the 40 ml mark
7. Calibrate PH Sensor
8. Place beaker under burett on top of a stirring plate with magnet inside
9. Drop 0.5 ml of the NaOH solution in the beverage
10. record PH of the beverage
11. Repeat steps 9 & 10 until a PH of 12.
12. Repeat step 11 for the 5 trials.

Data Table:

Planning Your Own Investigation

	Advanced (5)	Proficient (3)
I. Introduction:		
Experimental ID	Name, date, period identified in proper form and recorded in Table of Contents	Name, date period identified
Title	Title relates directly to experiment. Clearly identifies variables	Title relates directly to experiment
Purpose/Problem	Problem/purpose stated accurately & completely. Some background information given	Problem/purpose is stated accurately & completely
Hypothesis	Hypothesis stated clearly. Specifically predicts the relationship between dependent and independent variables	Hypothesis is stated clearly. It predicts the influence of one variable on another
II. Experimental Procedure:		
Materials	Complete, detailed list of appropriate materials (size, concentration, quantity).	Complete list of appropriate materials
Identification of Variables & Constants	Correctly identifies independent, dependent variables. Recognizes most constants	Clearly and accurately identifies variable being tested and some constants
Control Setup	Control setup clearly identified and justified	Control setup clearly identified.
Procedure	Tests hypothesis accurately & efficiently. Conducts or analyzes 3 or more trials. Reflects thoughtful use and elaboration of scientific principles involved. Procedure is accurate, complete, understandable, & repeatable by another person. Includes appropriate diagram(s) to clarify procedure. No errors.	Tests hypothesis in a logical manner. Conducts or analyzes 2 trials. Reflects clear understanding of scientific principles involved. Procedure is essentially complete, understandable, and repeatable. May contain a few errors.
Safety	Includes all appropriate safety concerns.	Includes most safety concerns.
III. Collect & Display Data:		
Collect & Record	Accurate & precise data reported in correct SI units.	Accurate data reported in correct SI units.
Organization	Data displayed in organized way, using the most appropriate format. All data & necessary units displayed; labeled completely.	Data displayed in the most appropriate format. Minor errors, few errors in labeling.
IV. Data Analysis:		
Calculations	Appropriate, complete (includes units), accurate. Formula(s) clearly stated, appropriate work shown.	Appropriate calculations completed (includes units), minor math errors.
Summary	All data summarized in a clear, concise, logical manner. Patterns identified & described. No additional explanation given.	Most data and patterns summarized in a logical manner.

V. Conclusion		
Explanation	Logical conclusion, well supported by data collected. Justification for multiple trials given. Clearly addresses problem & stated hypothesis.	Logical conclusion, supported by data collected. Adequately addresses problem & hypothesis.
Sources of Error	Sources of error identified & explained. Errors appropriate. Recommendations to eliminate errors appropriate.	Sources of error identified. Errors are appropriate.
Extensions	Student transfers learning to other settings by generating specific questions for future study or suggesting how the knowledge gained can be applied to "real world".	Student transfers learning to other settings by generating a specific question for future study or suggesting a way the knowledge gained can be applied to "real world".
VI. Presentation of Report:		
Format	Contains all components clearly labeled. Well-organized. No errors.	Contains all components clearly labeled and organized. Minor errors.
Mechanics	Excellent use of vocabulary, language mechanics & complete sentences. No errors.	Good use of vocab, language mechanics & complete sentences. Few errors do not detract from meaning.
Appearance	Write-up is neat, presentable & enhanced (e.g. word processed, diagrams, graphics, color, etc.)	Write-up is neat, presentable.
Language	Technical voice: No personal pronouns, clear, concise to the point.	Technical voice. No personal pronouns.

Juice and Soda Lab Rubric
How Much Acid is in Fruit Juice and Soft Drinks?

	Points Earned	Points Possible
Prelab Questions		
Show your work and include thorough explanations in clear, concise, well-written sentences.		50
Data Collection and Computation		
Standardize the Sodium Hydroxide with KHP and show the calculations for the known value of NaOH in your solution.		5
Write the balanced chemical equation for the reaction between sodium hydroxide and the primary acid in the fruit juices or sodas your lab team selected. If you identified more than one acid, write balanced equations for each of them.		3 for each acid
Graph the pH vs volume of base added for all beverages tested. Make a note of where the indicator you chose changes color. In general, as volume of titrant increases, what happens to the pH? Why does this occur?		10
Calculate the acid concentration of the beverage you tested, being sure to show all work and include units.		4
Share your results with three other lab groups, and then explain how your answers compare. What similarities and differences do you notice? Is this what you expected? Why or why not?		3
Calculate the pH of the fruit juices or sodas you tested.		2 for each
Argumentation and Documentation		
Pool class data and compare the identity of the primary acid, acid concentration, and associated pH of the various beverages tested. Provide a general statement and explanation for any trends you notice. In what ways do they surprise you and why?		6
If you were to perform this experiment again, what changes would you make to your procedure and why? How do your answers compare to those of other student groups?		3
Post-Lab Questions		
1. Suppose a student chose to measure solution volumes using the beakers or graduated cylinders provided. What effect would this have had on the calculated acid concentration? How might this affect the number of significant figures in your final answer? Explain your answers.		3
2. Another student rinsed the buret with water, but neglected to rinse the buret with titrant before conducting the experiment. What effect would this have on the calculated acid concentration in the juices or sodas? Why?		3
3. If you did not titrate a cola like Coke, Pepsi, or Dr. Pepper, find another lab group that did so, and ask them to discuss their procedure and results. What step was necessary to determine the endpoint when titrating a cola with a standard sodium hydroxide solution, and why did this step matter?		3
4. Imagine a lab team that consistently added base past the first appearance of a pale pink color. What would happen to the average calculated acid concentration of the juices or sodas? Explain your answer.		3
5. Create a diagram that shows the molecular interaction between the acid and base as the titration proceeds. Display this at the six labeled points along the titration curve provided and give an explanation for what is happening at the molecular level. As always, include at least 8 labeled particles in each drawing.		6
6. Review your graph of pH versus volume of base added. Where did the indicator change color for each trial? What was the pH associated with the color change? What assumptions can you make regarding the pH at this point and the shape of your titration curve? Use a diagram to show what you think might be happening at the molecular level.		4
7. After conducting this experiment, what recommendation(s) might you make for a person with acid-reflux disease or tooth decay despite the fact that they drink juice or diet sodas? Justify your answer.		3
Planning Your Own Investigation Score		**100**
Total Points		**239**