Vitamin C Titration to Survive a High Seas Journey

ND Lights

Summary:
In this experiment, students determine the amount of vitamin C in everyday fruits in order to decide which fruit to take with them on a sea voyage to the New World. Students first titrate a vitamin C standard with iodine solution, and then use this information to determine the vitamin C content in everyday citrus fruits. The goal is to decide which fruit is smartest to take on their cross-Atlantic voyage to the New World in order to prevent scurvy. This is a more advanced, project-based experiment, but with additional guidance, it can easily be modified to suit beginning chemistry students too.

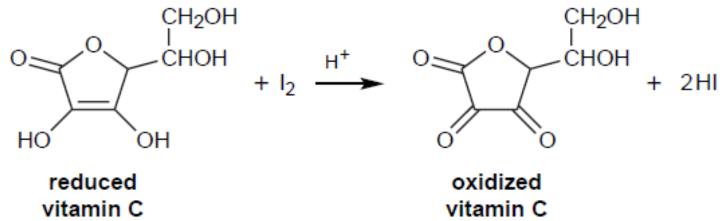
Based on:
Sowa, S. and Kondo, A.E. Sailing on the "C": A Vitamin Titration with a Twist. *J. Chem. Ed.* **2003**, *80* (5), 550-551.

Introduction

Vitamins are essential micronutrients in our diet. We need them in small amounts to stay healthy. Although they were originally thought to be "vital amines," we now know that there are two categories of vitamins: fat-soluble (A, D, E, K) and water-soluble (the B complex and C). Most vitamins act as cofactors with metabolic enzymes to maintain our life processes. Vitamin C, or ascorbic acid, is a water-soluble molecule that acts as an antioxidant, i.e. if oxidizing agents attack a cell, then the vitamin C acts as a target in place of another more important target such as a protein. Vitamin C also acts as a cofactor for an important enzyme that synthesizes collagen, the most abundant protein in vertebrate animals (such as humans). Collagen is a fibrous protein in connective tissue that literally holds us together. Vitamin C deficiency results in a disease called scurvy, which is characterized by skin lesions, bleeding gums, and tooth loss.

Historically, vitamin C played an important role in the discovery of the "New World." Sailors on long voyages with no available fresh fruit or vegetables commonly developed scurvy, which was described by Jacques Cartier during his exploration of North America in 1535. In 1768, James Cook introduced the addition of lime juice to the diets of British sailors, who then became known as "limeys." By 1795, Lind advocated fresh citrus as a cure for scurvy. Dutch and Hungarian sailors also used sauerkraut as a source of vitamin C, and American sailors carried cranberries. The chemical structure of vitamin C was not discovered until 1932. More recently (1970's) the two time Nobel laureate Linus Pauling controversially advocated large doses of vitamin C as a prevention for the common cold.

Vitamin C can be measured using a technique called titration. Because vitamin C is easily oxidized, we can use this chemical reactivity to detect it in solution. If we react vitamin C with iodine, the vitamin C is oxidized and the iodine is reduced. Iodine (I_2 molecules) form a purple complex with starch in solution, but reduced iodine, iodide, (I^-) is colorless in the presence of starch.



If we add iodine to react with the vitamin C in an acidic solution that also contains starch, then once we've oxidized all of the vitamin C, the I2 will remain, and a purple color will be produced. This color change is the basis for the titration reaction, and the purple color is used to determine the endpoint.

In today's experiment you are presented with a challenge: imagine that it is 1799, and that you are the captain of a British ship about to set sail on a 50-day voyage to the New World. You are ahead of your time because you know that each member of your 20-man crew needs 75 mg of vitamin C per day to prevent scurvy (and you want to keep your teeth so you can eat that American corn-on-the-cob that everybody's talking about). Your challenge is to determine whether to pack oranges, lemons, limes or grapefruits for your journey. Remember that you have a limited amount of cargo space on your ship! (Think of this as the first "Survivor" challenge). A word of caution: before you begin your titrations, it might be wise to plan your method of problem solving. What data do you NEED to meet the challenge? How are you going to approach the problem in order to solve it?

Experiment

Materials

Equipment: You may use any equipment in your lab drawer or on the side bench. If you need a particular piece of equipment that is not in either place, request it from your instructor, but be prepared to justify why you need it.

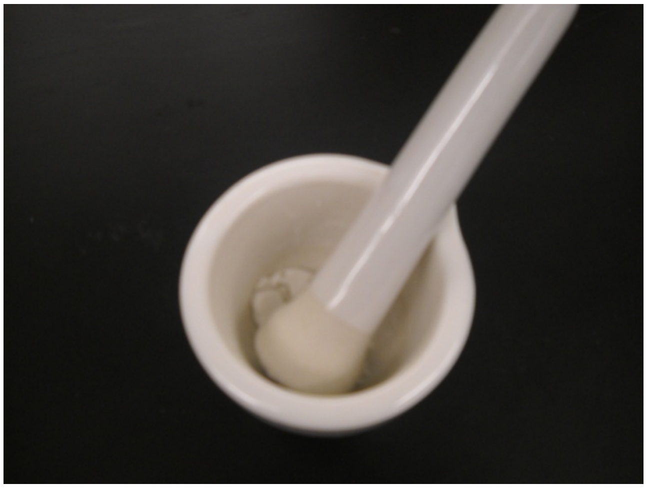
Reagents:
vitamin C tablet
iodine solution
0.2 M acetic acid
2% starch solution
a lemon, a lime, an orange, a grapefruit

Procedure

A. Standardization of iodine solution

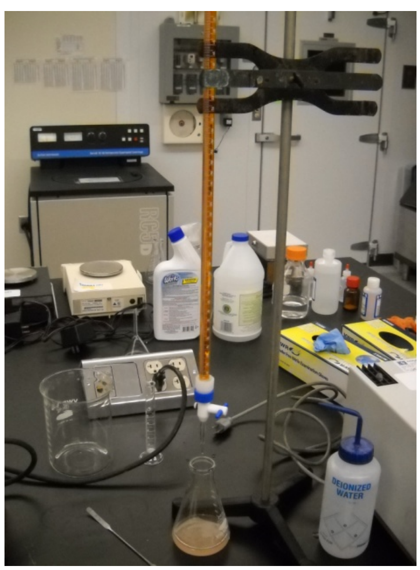
Before you can begin testing the fruits for vitamin C content, it is necessary to standardize your iodine solution using a known quantity of vitamin C.
What does "standardization" mean? Why do you need to do this?

Take a vitamin C tablet and note the content in mg per tablet. You will want to dissolve the tablet in water. (What is the fastest way to dissolve something?) A suggestion: dissolve the tablet in a measured volume of distilled water so that 50 mL of solution contains 25 mg of vitamin C. For example, if you have a 500-mg tablet, crush it up and dissolve it entirely in 1 L of distilled water. Then use 50 mL of that solution for standardization.



Is the quantity 50 mL important? What would happen if you used 250 mL?

Place the buret in the clamp on the ring stand. Using a funnel, carefully fill the buret with iodine solution. (Note: iodine will stain!).



Why are you putting iodine solution in the buret, and titrating the vitamin C sample, instead of putting the vitamin C sample in the buret, and titrating a sample of iodine? What do you think would happen if you did this?

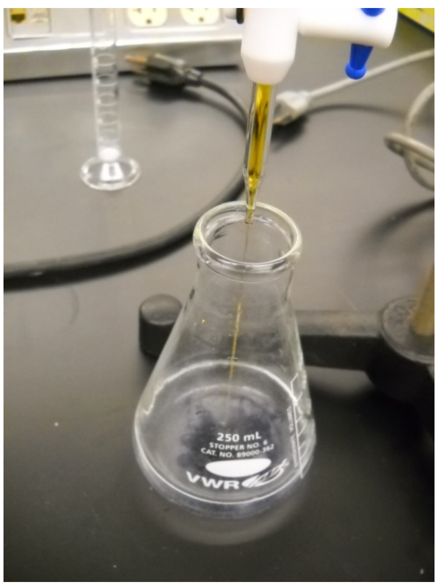
Be sure that the tip of the buret is filled with solution and contains no air spaces. Drain the iodine to the zero mark on the buret.

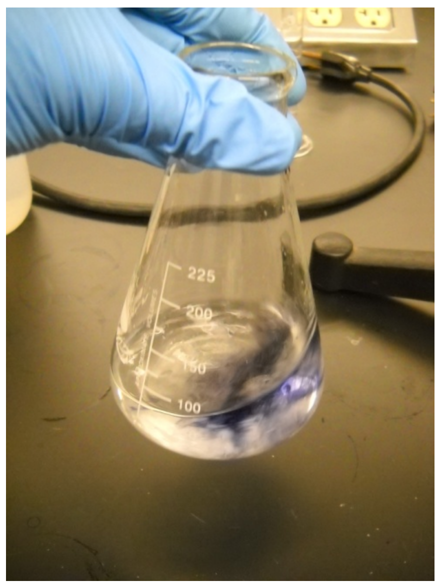
Oops! Your lab partner drained more iodine solution that necessary. How might this affect your results? What should you do?

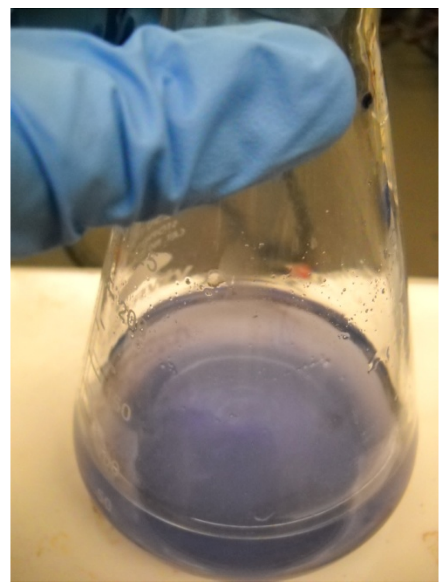
Transfer 50 mL of the vitamin C solution to the 250-mL Erlenmeyer flask. Add 20 drops (~1 mL) of 0.2 M acetic acid, and 10 drops of 2% starch solution – this step is critical!

Why is this step critical? What is the chemical importance of this step?

Swirl to mix well.
Place the flask under the buret and begin adding iodine solution. Try to swirl the flask continuously under a slow stream of iodine solution from the buret. When you begin to see the formation of a purple swirl, slow down!
Note the volume reading on the buret. Add iodine dropwise until the solution remains purple (or blue-black). Don't overshoot the endpoint!







What would happen if you overshoot the endpoint? How would this affect your results?

Record the final volume reading on the buret. Calculate the standardization factor for your iodine solution as given below.

Data

Mass of vitamin C in tablet: _________ mg

Mass of vitamin C titrated: __________ mg

Initial buret reading: __________ mL

Final buret reading: __________ mL

Volume iodine solution used: ___________ mL

$$Standardization\ factor = \left(\frac{mass\ of\ vit\ C\ titrated}{volume\ of\ iodine\ solution\ used}\right) = \_\_\_\_\_\_\_\_ \frac{mg\ vit\ C}{mL\ iodine\ sol'n}$$

What is the importance of this standardization factor? What can you use it for?

Now you have a factor that can be used to determine the amount of vitamin C in any unknown solution that you titrate. You can measure the volume of iodine solution needed to titrate a measured amount of juice, and by multiplying the iodine volume by the standardization factor, you will obtain the amount of vitamin C present in the juice sample:

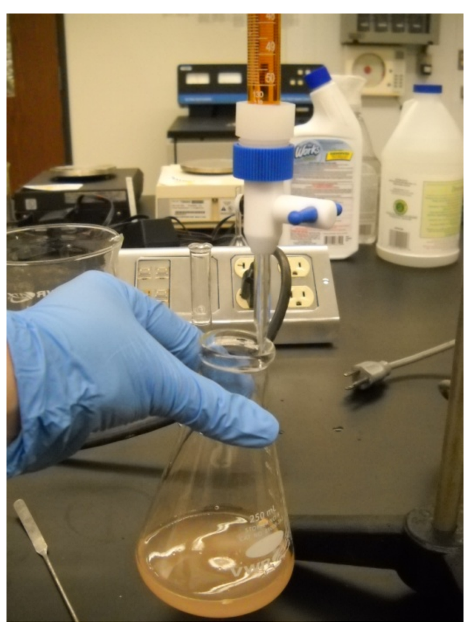
$$\_\_\_\_\_\_\_ \frac{mg\ vit\ C}{mL\ iodine\ solution} \times \_\_\_\_\_\_\_\ mL\ iodine\ solution = \_\_\_\_\_\_\_\_\ mg\ vit\ C$$

B. Determining vitamin C content of a fruit juice sample

To determine the vitamin C content of a fruit juice sample, obtain a measured volume (I recommend a minimum of 20 mL) of juice.

What volume of juice should you use? Does the amount matter? (These questions are an important key to titrations – why?)
Does it matter how much juice is contained in each fruit? Why? (or why not?)

Dilute your fruit juice sample to 50 mL using distilled water, and place the juice sample in a clean 250-mL Erlenmeyer flask.



What effect does the dilution have on your results?

Add 20 drops of 0.2 M acetic acid, and 10 drops of 2% starch solution. Mix well. Titrate with iodine solution (you might have to refill the buret) and record results in the Table.

Table: Vitamin C content of Different Fruits

Type of Fruit	Volume of juice titrated (mL)	Initial buret reading (mL)	Final buret reading (mL)	Volume iodine used (mL)	Vitamin C in juice sample (mg)*

Show calculations below:

Question: (there's only one, but it's complicated)
Which fruit should you take on your journey to prevent scurvy?
Explain why you chose the fruit you did, including all of the considerations you made when making your choice.
Be creative as well as quantitative, and "outwit, outplay, outlast" your fellow lab survivors.

NOTES TO INSTRUCTORS

Equipment:
50-mL buret
Ring stand with buret clamp
250-mL Erlenmeyer flask
Mortar and pestle
Graduated cylinders
Funnel
Juicer
Knife
100 mL beaker
1 L beaker
Tape measure

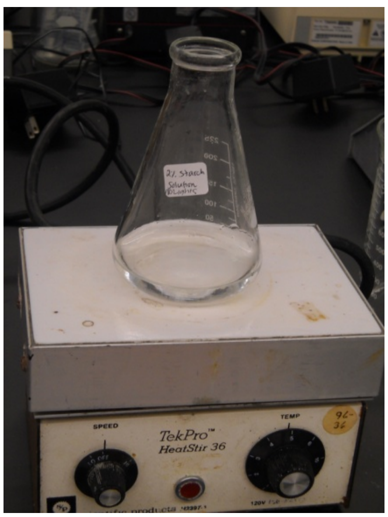
The mortar and pestle are for crushing the vitamin C table; the larger beaker and tape measure are for students who want to measure the size of the whole fruit either by volume displacement or direct measurement, respectively.

Materials:

Iodine (CAS # 7553-56-2), potassium iodide (CAS # 7681-11-0), acetic acid (CAS # 64-19-7) and soluble starch (CAS # 9005-25-8) were purchased from Fisher. Iodine should be handled in a fume hood; protective gloves and clothing are recommended. The volatility of the crystals does not affect preparation of the solution. Iodine should not be flushed to sewer. Collected unused iodine solution in a waste bottle, and dispose of according to local environmental regulations.

Vitamin C tablets (ascorbic acid; CAS# 50-81-7) were purchased from a local supermarket. Iodine solution is 2% I2 /4% KI; 20 g I2 + 40 g KI per liter (1000 mL).

Starch solutions must be heated when prepared for the starch to dissolve in water. Common practice is to make a concentrated (5%) starch "paste" and add to boiling water to dilute to 2%. Starch solutions have a short shelf-life, and should be refrigerated between uses, or made fresh daily. It is important to check them to make sure no bacterial growth has occurred!



Students can work in groups and combine data for the different fruits.

Kitchen knives to halve the fruit and basic juicers are also required.

Typical student results

If solutions are made as directed, 100 mg of vitamin C will use less than 20 mL of I2 solution. 20 mL of fruit juice (obtainable from each type of fruit) will use a volume of I2 that is "reasonable" : 5 –10 mL, not just a few drops or "burets-ful". The "solution" to the challenge will vary, depending on the age and source of the fruits.

Instructor's Role

Titration is the key technique required in this experiment. For students who have not yet done a titration, instructors will need to cover the theory and practice of using a buret. For students who have previously performed titrations, we recommend that the instructor review the use of the buret.

Instructors should monitor student progress continuously. We recommend instructors walk around checking answers to guided-inquiry questions, and re-direct students with appropriate questions, as needed. (eg., "Why are you using this quantity vs. that quantity?")

Some students might not realize that they need to measure the entire amount of juice contained in each fruit in order to solve the challenge. It would help to encourage them to PLAN their experiment before collecting the data to insure a higher degree of success. We often ask our students to explain what they are planning to do and why, prior to actually doing anything. Tape measures (direct measurement) or large beakers (water displacement) can also be made available as hints for determining the volume of each fruit, for consideration of storage factors.

Where time permits, students may be permitted to resume experimenting after completing their calculations, to obtain any missing data.

Appendix: VWR Product Information

Equipment	Quantity	VWR Product Number	Price
Measuring Burets	Case of 6	89090-914	$507.08
100 mL Graduated Cylinders	Case of 12	65000-006	$132.49
1L Glass Beakers	Pack of 6	89000-212	$83.77
250 mL Erlenmeyer Flasks	Pack of 12	89000-362	$72.53
Mortars	Pack of 9	89038-144	$133.20
Pestles	Pack of 9	89038-160	$155.86
0.01M Iodine	1L	MKH17505	$34.69
0.2M Acetate Buffer	225mL	100503-702	$13.00
Starch from Rice Powder	500g	700011-352	$50.67