ASELL SCHOOLS Advancing Science & Engineering through Laboratory Learning

TEACHER NOTES

Titration of citric acid in juice: Teacher Notes

Overview/Introduction: Teaching and learning context

St Ignatius College Geelong currently has a major inquiry and communication task in each of years 7-10, and there is desire to develop an inquiry and communication task involving the chemical sciences. While acid-base titrations are not part of the Victorian Curriculum F-10, there is a desire to introduce year 10 students to this technique, to better prepare them for VCE chemistry.

It is intended that the major inquiry and communication task would extend over several lessons, with students working in teams to produce a poster, communicating their inquiry and the results of that inquiry.

Lesson 1	Investigation of the contents of citric juice	***Individually***
Lessons 2 – 3	Investigating how to test the acidity in citric juice	***Group***
Lessons 4 – 5	Carry out investigation	***Group***
Lessons 6 – 7	Completing the Scientific Poster	***Individually***

The titration of citric acid in juice is intended either as the investigation / laboratory experimentation part of that inquiry module, or it can be used as a stand-alone titration investigation.

Curriculum Outcomes: Victorian Curriculum F-10

Levels 9 and 10

Science Understanding: Chemical sciences

- [Partial] Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (VCSSU126)
    - investigating reactions of acids with metals, bases, and carbonates

Science Inquiry Skills: Questioning and predicting

- [Partial] Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types (VCSIS135)
- [Partial] Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability (VCSIS136)

Science Inquiry Skills: Recording and processing

- Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data (VCSIS137)

Science Inquiry Skills: Analysing and evaluating

- Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence (VCSIS138)
- Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data (VCSIS139)

Science Inquiry Skills: Communicating

- Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (VCSIS140)

Key concepts

Volumetric analysis involves the precise and accurate measurement of volumes. These volumes, when combined with knowledge of the accurate concentration of one solution, or the accurate amount of one reagent, can be used to accurately determine the concentration or amount of the other reagent(s). The reagent(s) with (initially) unknown concentration(s) or amount(s) are called **analytes**.

The relationship between volume (V), concentration (c) and amount (n) is

$$n = c\,V$$

Amount of substance is a quantity proportional to the number of entities or particles or molecules in a sample [Footnote [1]]. The amount is measured using the unit, **mole** (abbreviation: mol). The term, **amount of substance**, and its definition have been agreed by international conventions (CIPM: Comité International des Poids et Mesures; IUPAC: International Union of Pure and Applied Chemistry; IUPAP: International Union of Pure and Applied Physics; ISO: International Organization for Standardization) since the 1970s.

Some books use **molarity** (M) instead of concentration (c). Molarity is the concentration measured in specific units of mol L^{-1}. The more general concentration can be measured in various units.

Precision and **accuracy** are often misunderstood by students. The common English meaning of both words is “exact”, and the two words are synonyms, in common usage. The scientific meanings are different, as follows:

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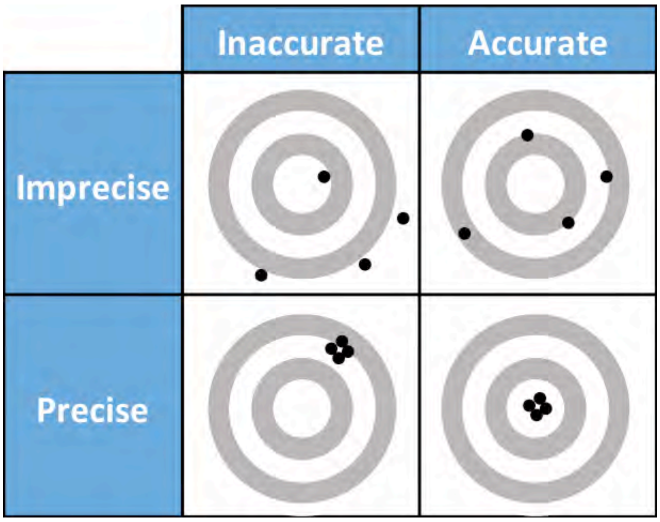
[1] Guggenheim (1961), *Journal of Chemical Education*, **38** (2), 86 <pubs.acs.org/doi/abs/10.1021/ed038p86>; Mills & Milton (2009), *Chemistry International*, **31**, 3-7 <www.iupac.org/publications/ci/2009/3102/1_mills.html>.

- **Precision** refers to the measured values being close to each other. This is associated with **reproducibility** of measurement. Precision or reproducibility gives confidence that the experimental method is reliable. Precision or reproducibility, by itself, does not ensure that the measured values are correct (accurate).

- **Accuracy** refers to the measured (average) value being close to the true value.



Precision and accuracy. Diagram by James Kanjo (2016). Used and shared with permission.

While, in principle, it is possible to be imprecise but accurate (top-right panel of diagram), such measurements are meaningless because they are not reliable (they are not reproducible).

Background information

Industry Links

Volumetric analysis laboratory at Rymill Winery, Coonawarra, South Australia. Photograph by Kieran Lim.

Volumetric analysis is a quick, relatively cheap and inexpensive method of measuring concentration. It is commonly used to measure the acid content of juices and wines, water quality, and in many other industrial applications. The Rymill Winery, in the Coonawarra, shows off its volumetric analysis laboratory as part of its Cellar Door tourist centre. Many other industries do likewise.

One of the aims of the exercise is to give students an introduction to acid-base titrations, so the aspect relating to the selection and use of appropriate equipment will either be prescription or confirmation level of inquiry. Other aspects will be structured, guided or open inquiry.

Pedagogy

Inquiry versus recipe laboratory learning activities

Curriculum outcome (slightly paraphrased)	Prescription	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry
1. Formulate questions or hypotheses (VCSIS134)	No question	Teacher provides question	Learner sharpens question	Learner selects question	Learner poses question
2. Independently plan, select and use appropriate investigation (VCSIS135)	No planning	Teacher provides plan	Teacher discusses possible plans	Learner guided while planning	Learner determines plan
3. Select and use appropriate equipment and collect and record data (VCSIS136)	Teacher selects	Learner told how to select and use	Learner sharpens selection and use	Learner guided while conducting and recording	Learner conducts and records
4. Construct and use representations, to record and summarise data (VCSIS137)	Teacher analyses	Learner told how to analyse data	Teacher discusses possible analyses	Learner guided in analysing	Learner analyses data, identifying trends
5. Analyse patterns and trends in data, and drawing conclusions (VCSIS138)	No problem solving	Teacher draws conclusions	Teacher discusses possible conclusions	Learner guided in drawing conclusions	Learner reasons to formulate conclusion
6. Use knowledge of scientific concepts to evaluate conclusions (VCSIS139)	No evaluation	Teacher evaluates	Teacher discusses possible evaluation	Learner guided in evaluation	Learner evaluates conclusions
7. Communicate scientific ideas and information, evidence-based arguments, using scientific language (VCSIS140)	No communication	Teacher summarises and communicates	Learner communicates	Learner guided in justifying conclusions and communicating	Learner justifies conclusions and communicates
	Prescription	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry

Aspects of Inquiry (Victorian Curriculum, Levels 9-10)

Inquiry has several aspects, ranging from open inquiry to prescription (or recipe). See the table above [Footnote [2]].

The selection and use of appropriate equipment will either be prescription or confirmation level of inquiry, since titrations will be new to students. In the context of St Ignatius College Geelong, students will have done major inquiry and communication task in each of the preceding years 7 9, so other aspects will be structured, guided or open inquiry.

Activity

Rinsing the burette and pipette

Rinsing the burette.
Source: Teaching and Learning Centre, University of Ontario Institute of Technology <www.youtube.com/watch?v=48do-3bzq3U>.
Used and shared under a Creative Commons Attribution licence.

The best way to rinse the burette is to put a small volume of solution (NaOH) into the burette, with the tap closed. By carefully moving the burette towards a horizontal position, and slightly (!) tipping the burette in a gentle seesaw motion, it is possible to move the small volume of liquid from one end of the burette to the other, wetting and rinsing the entire length of the burette. Gently rotating the burette will ensure that the entire inside of the burette is rinsed.

A similar procedure can be used to rinse the pipette.

Many students will find this a very challenging method, requiring steady hands. A simpler method has been suggested in the student notes.

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[2] Based on National Research Council (2000). Inqu*iry and the national science education standards: A guide for teaching and learning*. Washington DC: National Academic Press. Adapted for Victorian Curriculum by Lim, K. F. (2016), unpublished.

Using the burette tap

Using the burette tap.
Source: Teaching and Learning Centre, University of Ontario Institute of Technology <www.youtube.com/watch?v=48do-3bzq3U>.
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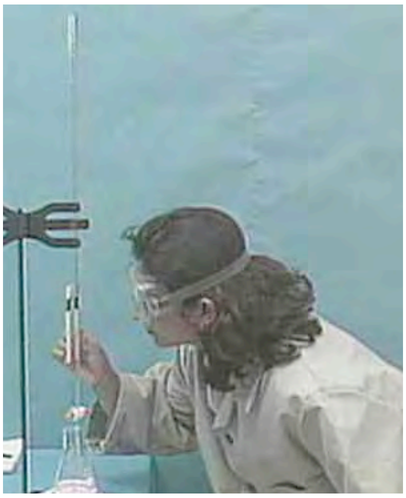
The burette tap is designed to be used by the less-dexterous hand. Right-handers should use their left hands to work the tap.

Reading the burette

To read the burette, the student's eye(s) must be level with the liquid surface.

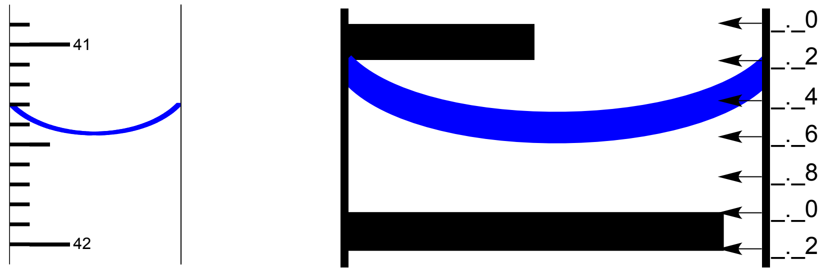
Incorrect (×): eyes are not level with the liquid surface



Correct (✓): eyes are level with the liquid surface

Position of the eyes when reading the burette.
Source: Journal of Chemical Education Software

A common mistake is to forget the scale runs downward. In the example (left-hand panel), the liquid level is between 41 and 42 mL. The divisions are 0.1 mL. At year 10 level and VCE levels, it is normally acceptable to estimate the volume to the nearest 0.05 mL, or half a division. 0.05 mL is very close to one drop.



reading_burrette_01.cdx

Reading the burette scale.
Left: At year 10 level and VCE levels, it is normally acceptable to estimate the volume to the nearest half-division, giving a reading to the nearest 0.05 mL.
Right: For the extended experimental investigation and in industry, the volume is estimated by mentally dividing the gap between the divisions into quarters, giving a reading to the nearest 0.02 mL.

Titration calculations

Textbooks set out sample titration calculations in a linear step-by-step manner, using a mixture of text and mathematical notations. While students have little difficulty performing a one-step titration calculation, they often have difficulty scaling up the process to multiple-titration calculations such as the 3-step procedure:

1. first preparing a primary standard,
2. standardising a secondary standard by titration against a primary standard, and
3. finally determining the concentration of an “unknown” solution.

While such more-involved calculations will not be encountered in year 10, students should be taught a more general method, because there is a significant leap in conceptual difficulty when "scaling-up" to more involved titration calculations with two or more steps. The **tabular approach to titration calculations** provides scaffolding to guide novice learners. Since the relationship between volume (V), concentration (c) and amount (n), n = c V ,

is fundamental to titration calculations, the **tabular approach** uses these quantities as the column headings.

	n =	c	v
step	amount	concentration	volume
Burrette (NaOH)	-	0.100 mol L^{-1}	-
Titration (NaOH)		0.100 mol L^{-1}	22.03 mL = 0.02203 L

Partial sample calculation of citric acid concentration in (diluted) lemon juice.

The concentration of the NaOH in the burette is the known (standard) solution, so that information is in the first row of the table. An average titre of 22.03 mL NaOH is dispensed from the burette into titration flask, so both the concentration and volume are entered onto the second row. The amount is unknown, so the student completes the second row by determining the amount of NaOH used in the titration.

	n =	c	v
step	amount	concentration	volume
Burrette (NaOH)	-	0.100 mol L^{-1}	-
Titration (NaOH)		0.100 mol L^{-1}	22.03 mL = 0.02203 L
Flask (citric acid)	3 NaOH + citric acid → trisodium citrate + 3 H_2O		
	7.34×10^{-4} mol	changing	
Pipette (cit. acid)	7.34×10^{-4} mol	0.0367 mol L^{-1}	20.00 mL = 0.02000 L
citric acid		**0.0367 mol L^{-1}**	

Sample calculation of citric acid concentration in (diluted) lemon juice.

The balanced chemical equation gives the relationship:

Amount of citric acid (measured in moles) = $^{1}/_{3}$ × amount of NaOH (measured in moles) , which gives the Amount of citric acid in the row corresponding to the titration flask.

Each row in the Table corresponds to one step in the experimental procedure. The student must consider what information (volume and either amount or concentration) has been collected or already known for each step (ie incomplete row of the Table), and then to use that information to determine what information will be obtained at the end of the experimental step corresponding with that row. Continuing in this manner, the student constructs the entire Table, row-by-row, during the course of setting out and performing the calculations.

Discussion

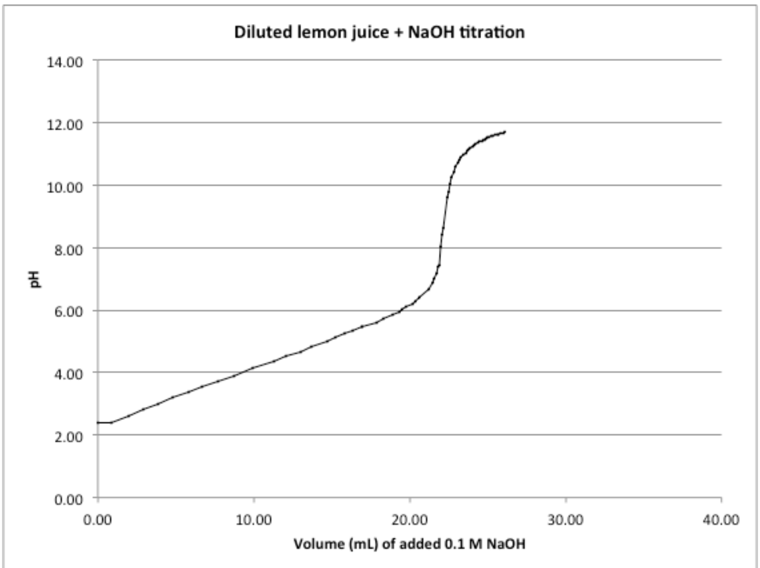
Common problems

Many books use **number of moles** instead of the correct term, **amount of substance** [Footnote 1]. The term, number of moles, is incorrect in the same way that number of degrees (instead of temperature) or number of metres (instead of height/length) or number of kilograms (instead of mass) are incorrect.

The **equivalence point** is the volume at which the reactants have the exact amounts for complete reaction.

The **endpoint** is the volume at which a colour change is seen. Choice of an appropriate indicator will result in negligible difference between the endpoint and the equivalence point. Choice of an inappropriate indicator will result in significant difference between the endpoint and the equivalence point.

pH curve



Titration of diluted commercial lemon juice with 0.1000 M NaoH

The pH curve from is data (obtained by us) using

- 20 mL diluted lemon juice (2 mL Woolworths Select Lemon Juice + 18 mL deionised water)
- 0.1000 M NaOH.
- 6 drops phenolphthalein

Citric acid has 3 acid protons per molecule. These three acid sites have a slight buffering capacity, resulting a pH curve that is not as vertical around the equivalence point as monoprotic acid titrations. Hence a few drops might the expected precision from student titrations of citric acid in lemon juice.

Hypothesis versus scientific question

The issue of **hypothesis versus scientific question** is probably more reverent for VCE Years 11 12, than for year 10.

The question of how much citric acid is present in juice is a valid **scientific question**. However, in any investigation involving titration or any measurement, there is some confusion about the **hypothesis**. The hypothesis that juice contains 3% (or some other number) citric acid is not reasonable as there is no justification for picking a particular number.

In titration or any measurement, there is an underlying assumption that the method is fit for purpose. Instead of assuming this idea, it should be used as the hypothesis. Industrial reports and scientific papers usually have a section on the validation/calibration of the measurement method, which essentially addresses the hypothesis that the method is fit for purpose.

It is suggested that teachers use the discussion in lessons 2 3 to suggest (structured inquiry) or guide (guided inquiry) students towards the following hypotheses:

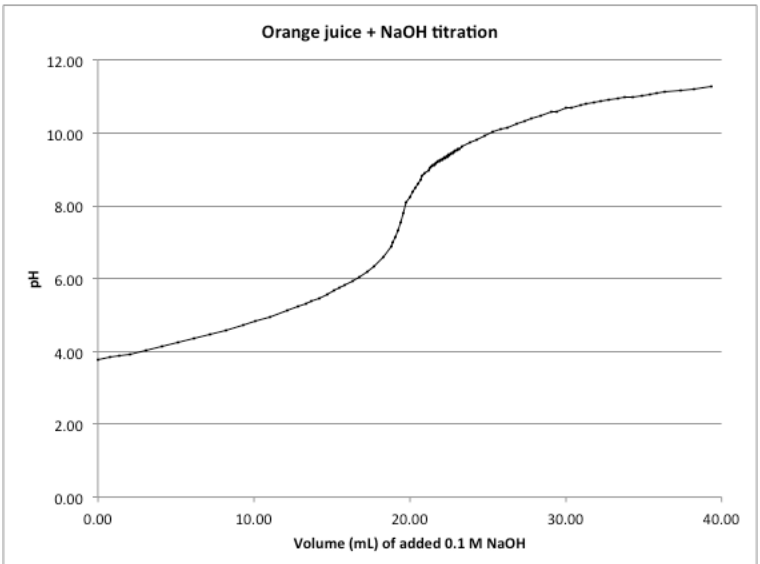
1. That ____ brand of juice has the most citric acid content (or another hypothesis).
2. That the chosen analytical method can be used to accurately and precisely measure the concentration of acid in a solution.
3. That the chosen analytical method can be used to measure the concentration of citric acid in juice.

Extensions and variations

Titration of citric acid in orange juice

There are several procedures for the titration of citric acid in orange juice that have been published on the internet. The following is data (obtained by us) using

- 20 mL undiluted orange juice (Daily Juice)
- 0.1000 M NaOH.
- 6 drops phenolphthalein



Titration of commercial orange juice with 0.1000 M NaoH

The observed equivalence point was below pH 8, and the endpoint was too hard to observe, unless a potentiometric titration is used.

At the time of writing, we are still being investigating if the colour of the orange juice can be removed/decreased by filtering.

Another possible approach, which is also being investigated, is whether the colour of the orange juice can be removed/decreased by the use of pectinase. [Footnotes [3,4]]

Titration of vitamin C (ascorbic acid) in juice

There are several procedures for the titration of vitamin C (ascorbic acid) juice that have been published on the internet. The procedure is to use iodine (I_2) solution. This is a reduction-oxidation reaction that reduces the coloured iodine to colourless iodide. The endpoint is the persistence of first permanent iodine colour.

References

Billet, D., & Thorpe, A. (2001). Tackling chemical calculations. *Chemistry Review*, **10** (4), 8-9.

Guggenheim, E. A. (1961). The mole and related quantities. *Journal of Chemical Education*, **38** (2), 86 <pubs.acs.org/doi/abs/10.1021/ed038p86>.

Lim, K. F. (2012). A tabular approach to titration calculations. *Teaching Science*, **58** (3), 33-39.

Mills, I., & Milton, M. (2009). Amount of Substance and the Mole. *Chemistry International*, **31**, 3-7 <www.iupac.org/publications/ci/2009/3102/1_mills.html>.

Teaching and Learning Centre. (2010). Burettes, University of Ontario Institute of Technology <www.youtube.com/watch?v=48do-3bzq3U>.

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3 Shiv Kumar, "Role of enzymes in fruit juice processing and its quality enhancement", *Advances in Applied Science Research*, 2015, 6(6):114-124.

4 Grant Crilly, "A Quick, Simple Way to Make Crystal-Clear Juice", ChefSteps, Seattle, <www.youtube.com/watch?v=K6_36_936fs> updated 28 Apr 2016, accessed 17 January 2017.