

Determination of the Concentration of a Hydrochloric Acid Solution Using a Standard Solution
of Sodium Hydroxide

OWEN MILLER

BAE SYSTEMS, UNIVERSITY OF WALES TRINITY ST DAVID

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1. Aim

- 1.1. The aim of this lab experiment was to as accurately as possible determine the concentration of a hydrochloric acid (HCl) solution using sodium hydroxide (NaOH) in the form of a standard solution. Using the standard solution of a base to react with a known volume of acid solution accurately measuring the volume of base used to neutralize the acid. Using the volume and concentration of base (mol/L), the concentration of acid can be calculated and then the molar value from the concentration.
- 1.2. The completion of this task allowed for the procedure of titration to be tested for reliability compared to other methods of finding the molarity of an unknown substance, showcasing how sources of experimental error can affect final calculated data and how titration could be used in a practical/workplace environment.

2. Theory of titration

- 1.2. Titration is a common technique used within laboratory environments to determine an unknown concentration of a specific substance in a solution using a known concentration of a base solution. Through this process, the solution of known mol/L (Titrant) is slowly added to the unknown concentration (Analyte) until the reaction between the two substances is complete. At this point, equivalence (the point at which the two values are equal; in this case the moles) is reached and is measured using an indicator which will hold a consistent colour once said chemical reaction is complete [1].
- 1.3. Titration comes in various types, which depends on the substance being tested and its nature. A common form of titration, and the one used within this lab report, is acid-base titration. In this form of titration, the reaction occurs between an acid (unknown) and the base (known molarity alkali). The reaction between these two substances is a neutralisation reaction where the reactions output substances are water and salt, hence, why this form of titration is also known as neutralisation [2].

3. Chemicals and equipment

3.1. The equipment used within this experiment include:

Equipment for experiment
1x Burette
1x Erlenmeyer flask
1x small funnel
1x tile (for under flask)
1x pipette
1x waste flask
1x stand + Clamp

3.1.1. All equipment used to accurately measure volumetric amounts must be calibrated to ensure all values recorded are accurate to the level stated on the piece of equipment itself, for example, the burette (0.05ml). If the volumetric equipment is not calibrated, values implemented into calculations could be incorrect to the true volumetric value, thus, causing errors in calculations.

3.2. The chemicals used:

Chemicals for experiment
1x unknown solution hydrochloric acid (HCl)
1x known solution sodium hydroxide (NaOH)
1x phenolphthalein indicator

3.2.1. Ensure material safety data sheets (MSDS) for all substances used within the experiment are readily available so correct handling procedures are followed, and in the event of an incident the correct clean-up and medical procedures are followed to mitigate damage to persons.

3.3. Health and safety equipment:

Health and safety equipment
1x Lab coat
1x disposable latex gloves
1x goggles

3.3.1. It is required within the laboratory environment that a lab coat is worn at all times, eye protection is to be worn when handling chemicals, and disposable gloves are to be worn when handling chemicals to avoid skin contact. All chemicals used within this experiment are irritants to the skin and eyes, therefore, correct PPE is vital. If there is any confusion regarding the correct PPE for certain substances ensure the MSDS is consulted [3].

4. Procedure

4.1. Preparation

- 4.1.1. Collect and put on correctly fitting PPE equipment relevant to the experiment (see 5.3).
- 4.1.2. Wash equipment with a small amount of each chemical that is to be used within that piece of equipment, the pipette HCl, Burette – NaOH (ensure to use a funnel to avoid spillage) and Erlenmeyer flask – a small amount of distilled water (using distilled water so the molar quantity is not affected). All substances used in cleaning are to be discarded.

4.2. Execution

- 4.2.1. Fill the burette with the NaOH standard solution using a funnel, run some of the solution through the tap to allow the lowest point of the meniscus to A-line with “zero level.” Gently tap the burette to allow air bubbles to escape.

Record the initial reading.

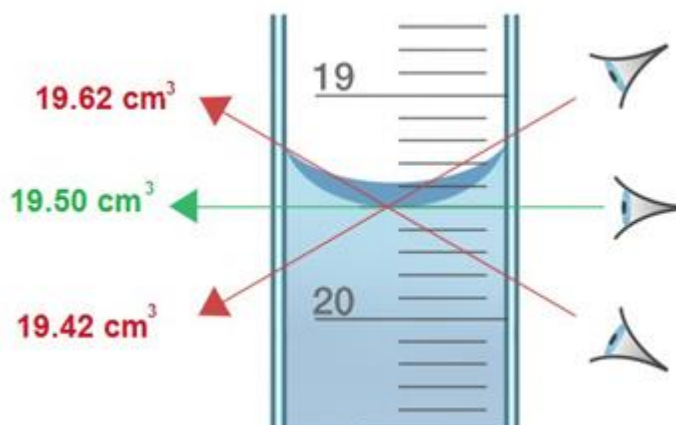


Figure 1 – Correct meniscus reading [4]

- 4.2.2. Fill an Erlenmeyer flask with 25ml of HCl using pipette and record exact amount in table.
- 4.2.3. Using the phenolphthalein indicator, add 3 drops to the same flask and mix via gentle swirling.
- 4.2.4. Using the burette, slowly open the tap to allow the NaOH solution to run into the Erlenmeyer flask, mix throughout, continue until the solution turns to a light pink colour – **record the final Burette level (4 S.F.)**.
- 4.2.5. Repeat steps 2-4
- 4.2.6. As per step 6.2.4 however, run the tap fully open until the volume is 2-3 ml above the rough volume, then run the tap as slow as possible (drops of 0.05ml) until the solution lingers pink for at least 30 seconds, then record as per 6.2.4.
- 4.2.7. Repeat 6.2.5 and 6.2.6 until a set of 3 results are within 0.10cm³ of one another.

5. Observations

- 5.1. Due to time constraints the lab technicians gained three sets of data, but they were not within the specified guideline of 0.10cm^3 . However, it was confirmed with the laboratory supervisor that titration 2 shown in **figure 4** was visually satisfactory as per procedure.
- 5.2. It was observed that the burette provided would not fully close, allowing an approximate volume 0.05ml of NaOH through the nozzle every 20-30 seconds. This meant procedure had to be changed slightly to allow a drop to fall out onto blue roll, replacing the flask under the burette, and then recording the burette initial volume at this point to allow for any loss prior to the start of titration. If this were not accounted for, NaOH added to the volume of HCl would not have been accurate to what was recorded.
- 5.3. Due to the need of removing the flask from under the burette outlined in 7.2, on some occasions this would cause a small volume of NaOH to get onto the side of the flask. Meaning it was necessary for the lab technicians to wait for the drop to contact the HCl before adding any further NaOH to not breach the equivalence point.
- 5.4. All observations made could have caused an error in results, so with each issue that was discovered the lab technicians ensured to check with the laboratory supervisor to determine the deviations would not affect the final outcome to a margin that would affect results.

6. Calculations

6.1. What was calculated

6.1.1. The moles for both substances

6.1.2. The molarity of HCL

6.2. Standard equations and necessary definitions/units

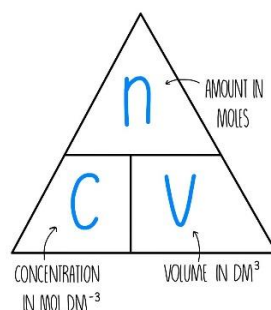


Figure 2 - $n = C V$ [5]

6.2.1. **Figure 2** shows the relationship between concentration, moles and volume

6.2.2. Molarity – M (mol/L), the moles of a solute / volume of the solution

6.2.3. Moles – mol, molarity of solution * volume (litres – SI unit)

6.2.4. Following the above rules [moles solute = $M * V$] [moles acid = $M_A * V_A$]

[moles base = $M_B * V_B$]

Calculation example for Titration number 2

$$M_A \times V_A = M_B \times V_B$$

$$0.1002_{\text{mol/L}} \times 0.01620 = M_B \times 0.02500\text{L}$$

$$\frac{0.1002_{\text{mol/L}} \times 0.01620}{0.025\text{L}} = 0.06490_{\text{mol/L}} - \text{HCL}$$

$$0.06490_{\text{mol/L}} \times 0.025\text{L} = 1.6225 \times 10^{-3} \text{mol} - \text{HCL}$$

$$0.1002 \times 0.01620 = 1.62324 \times 10^{-3} \text{mol} - \text{NaOH}$$

Figure 3 – calculations titration 2

6.3. As Titration 2 was assessed and verified as acceptable by the laboratory supervisor, this will be used as the worked example, the handwritten calculations can be seen in **figure 3** (calculations for Titration 1 and titration 3 can be seen in **figure 5** and **figure 6**).

6.4. Worked example

6.4.1. $M_A \times V_A = M_B \times V_B$

$$0.1002\text{Mol/L} \times 0.01620\text{L} = M_B \times 0.02500\text{L}$$

Rearrange so that M_B is the subject

$$M_B = (0.1002\text{Mol/L} \times 0.01620\text{L}) / 0.025\text{L} = 0.06490 \text{ Mol/L} - \text{HCL}$$

Using the calculated molarity of HCL, the moles of HCL and NaOH were calculated.

$$0.06490 \text{ Mol/L} * 0.025 \text{ L} = 1.6230 * 10^{-3} \text{ mol} - \text{HCL}$$

$$0.1002 * 0.01620 \text{ L} = 1.6230 * 10^{-3} \text{ mol} - \text{NaOH}$$

(All to 4 SF)

Data then applied to corresponding area in data sheet (**figure 2**).

6.4.2. Calculations were then checked using the equivalence point law

moles acid = moles base

So, where both HCl and NaOH mol values are 0.06490 Mol/L (4 S.F) it can

be stated that the equivalence point was reached in the titration, and the final calculations must be correct as it meets the requirements of the above rule.

7. Results and discussion

10.1. Results

STUDENT'S NAME: Owen Miller
 PARTNERS' NAMES: Daniel Gorton

TITRATION DATA SHEET
 Molarity of the standard base solution: $M_{\text{NaOH}} = \underline{0.1002 \text{ mol/L}}$

FLASK	1 rough titration	2	3	4
V_{HCl} (mL) from pipette	25.00	25.00	25.00	
Initial burette reading (mL)	2.200	19.55	21.60	
Final burette reading (mL)	18.95	35.75	38.20	
V_{NaOH} (mL)	16.75	16.20	16.60	
moles of NaOH (mol)	1.680×10^{-3}	1.623×10^{-3}	1.663×10^{-3}	
Moles of HCl (mol)	1.680×10^{-3}	1.623×10^{-3}	1.663×10^{-3}	
Molarity of HCl (mol/L)	0.06713	0.06490	0.06653	

All readings/calculations to 4 Significant Figures

Accuracy
 You should record pipette and burette readings to the nearest 0.05 cm³ (approximately one drop). Consecutive titrations should agree to within 0.10 cm³ and, you should repeat the titration until this is achieved.

8. Figure 4 – Titration Data Sheet

8.1.1. The Data recorded in **figure 4** shows all measured readings taken as well as all calculated data such as molarity and moles of the two substances (exact calculations in section 8).

- 8.1.2. The results of the three titrations show results that confirm the molarity and moles of the unknown HCL solution as well as the molarity of NaOH.
- 8.1.3. As per 8.4.2, the moles of NaOH = moles of HCl shows the titration was successful as the equivalence point had been reached accurate to (4s.f).
- 8.1.4. The moles of both substances across all three titrations are equal to 2s.f (0.0016 mol). The molarity of HCl is equal across the three titrations to 1s.f; this is not as accurate as hoped due to the human factors presented within titration procedures. Refer to 8.3 for details on resolution.
- 8.1.5. Titration 2 was confirmed as the best titration and this data should be used as the satisfactory for all values and should be the titration used for any further investigation.

8.2. Discussion

- 8.2.1. Titration is an effective means of finding the molarity and amount/moles of a known substance with unknown values as it allows for an effective means of neutralisation with minimal equipment outside of standard calibrated laboratory equipment. Personnel with minimal, but satisfactory, training in correct health and safety procedures can complete it to a satisfactory standard [6].

- 8.2.2. The issues with titration were prevalent to the lab technicians throughout this experiment, as human error caused titration 3 to overextend the equivalence point (burette tap opened for an extended period). As well as equipment issues outlined in 7.2, causing significant deviation from Standard operating procedure (SOP) [7].
- 8.2.3. Titration has been tried and tested throughout many different industries and has many industrial uses. Meaning the capability has been created to filter out the errors associated with titration, such as using electrical censoring and mechanical burettes to measure equivalence points to an exact degree. Furthermore, the food processing industry uses titration on a constant basis to measure salt levels in foodstuffs, consequently, the extended period that titration has been used means that it is one of the most effective and only practical ways to measure unknown amounts of a known substance [8].
- 8.2.4. Due to 8.2.3, automation processes for titration where human input can be removed may be worth further investigation as this is the primary point of errors.

9. Conclusion

9.1. To conclude, the theory of titration was applied to successfully carry out the neutralisation of an unknown molarity of HCl using a known molarity of NaOH. The deviation in method caused some variation in results and highlighted the possibilities of human error within the titration process. To reduce human error, it was shown many industry examples use automated censoring and base feeds. The deviation in process due to equipment failure was accepted by laboratory supervisor and caused a small deviation to the required results, nevertheless, the result values were confirmed as acceptable by the laboratory supervisor, showcasing other equipment failure methods and the importance of consulting the subject authority available.

The rule of moles acid = moles base was vitally important for calculated results checking, as these values were equal it is determined the calculated results are correct.

Overall, this showcases why titration is the most commonly used method of finding unknown molarity and molar values in acids, as it is a simple task to carry out, requiring little training and basic equipment. As well as having a critical value that can easily be calculated to check results, as long as the rules shown in Section 6 are followed.

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7. Appendix

Calculations for Titration Number 1:

$$M_A \times V_A = M_B \times V_B$$

$$0.1002 \text{ Mol/L} \times 16.75 \text{ L} = M_B \times 0.25 \text{ L}$$

Convert to SI unit

$$0.1002 \text{ Mol/L} \times 0.1675 \text{ L} = M_B$$

$$0.02500$$

$$M_B = 0.067134 \text{ Mol/L} - \text{HCL}$$

$$\text{Mol}_{\text{HCL}} = C \times V$$

$$\begin{aligned} \text{Mol}_{\text{HCL}} &= 0.067134 \text{ Mol/L} \times 0.02500 \text{ L} \\ &= 1.67835 \times 10^{-3} \text{ Mol} \end{aligned}$$

$$\begin{aligned} \text{Mol}_{\text{NaOH}} &= 0.01675 \text{ L} \times 0.1002 \text{ Mol/L} \\ &= 1.67835 \times 10^{-3} \text{ Mol} \end{aligned}$$

Figure 5 – Calculations Titration 1

Calculations for titration 3

$$\frac{0.1002 \text{ Mol/L} \times 0.01660 \text{ L}}{0.02500 \text{ L}} = 0.0665328 \text{ Mol/L HCL}$$
$$\text{Mol HCL} = 0.0665328 \text{ Mol/L} \times 0.02500 \text{ L}$$
$$= 1.66332 \times 10^{-3} \text{ Mol}$$
$$\text{Mol NaOH} = 0.1002 \text{ Mol/L} \times 0.01660 \text{ L}$$
$$= 1.66332 \times 10^{-3} \text{ Mol}$$

Figure 6 – calculations titration 3