International Research Journal of Pure and Applied Chemistry

Volume 25, Issue 4, Page 116-120, 2024; Article no.IRJPAC.120793
ISSN: 2231-3443, NLM ID: 101647669

Study of Nature of Chemical Reactions using pH –Meter

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: https://doi.org/10.9734/irjpac/2024/v25i4870

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/120793

Original Research Article

Received: 08/06/2024
Accepted: 10/08/2024
Published: 13/08/2024

ABSTRACT

In general, nature of chemical reactions are studied by separating the products followed by analyzing the products using different methods like spectroscopic method, chromatohgraphic method etc. The objective of the present study is to investigate nature of chemical reactions using pH –meter. Two types of reactions are studied: (a) neutralization of a given Na_2CO_3 solution by HCl solution and (b) neutralization of a given $NaOH$ solution by oxalic acid solution. In both the cases, one component is acid and the other component is base. So, a salt is produced as the main product but the nature of the reaction, i.e., whether the reaction occurs in single step or multiple steps, cannot be identified by any standard methods.

In the present study the reaction is closely monitored using pH –meter. The detailed investigation clearly indicates that the neutralization reaction of a given Na_2CO_3 solution by HCl solution occurs in two steps while neutralization reaction of a given $NaOH$ solution by oxalic acid solution occurs in a single step.

On the basis of experimental studies, the probable steps of each reaction are proposed to explain the above neutralization reactions.

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Cite as: *Mallick, Abhijit. 2024. "Study of Nature of Chemical Reactions Using PH-Meter". International Research Journal of Pure and Applied Chemistry 25 (4):116-20. https://doi.org/10.9734/irjpac/2024/v25i4870.*

Keywords: Na_2CO_3; *oxalic acid;* $NaOH$; HCl; pH *–meter.* $NaHCO_3$; *sodium oxalate.*

1. INTRODUCTION

pH –metric study is very useful to measure the acidity or alkalinity of different type of solutions. In acid-base titrations also pH meter is used to find out neutralization volume. pH –metric study is also useful in determining water quality as documented by several scientists [1-2]. Hossain et al. [3] and Kim et al. [4] studied the change in pH during different phases of waste water treatment process. pH –metric study of soil pH and quality of soil is reported by several authors [5-6]. Tania et al. [7] documented that pH – metric study is useful to determine pK_a value of mangosteen extract. pH –metric study in acid-base system has been reported by different authors [8,9]. Ishikawa et al. [10] reported that pH – metric method is useful to study the chemical interaction between solute and membrane. pH metric studies of interaction among biomolecules are also documented in the literature [11,12]. Stacy et al. reported complex pH-dependent interactions between Weak Polyelectrolyte Block Copolymer Micelles and Molecular Fluorophores [13].

The present work deals with study of nature of chemical reaction in acid-base system using pH –metric titration method. In strong acid-weak base neutralization reaction an acidic salt is produced. In case of Na_2CO_3 and HCl neutralization reaction carbonic acid (H_2CO_3) is formed. The pH – metric study of the reaction shows that neutralization reaction occurs in two steps. Sodium carbonate is first converted to sodium bicarbonate, which is eventually converted to carbonic acid. However, in case of $NaOH$ and oxalic acid neutralization reaction, pH – metric study clearly reveals that the reaction occurs in a single step. No sodium bi-oxalate is formed during the reaction.

2. MATERIALS

Following chemicals are used for this experiment.

1. Laboratory Grade Na_2CO_3 crystals.
2. Laboratory Grade $NaOH$ beads.
3. Laboratory Grade 12 $(N)HCl$.
4. Laboratory Grade oxalic acid dihydrate crystals.

3. APPARATUS

1. 10 ml pipette
2. 50 ml burette,
3. 250 ml glass beaker
4. pH –meter (EI-make)

4. METHODS

1. 100 ml of $\left(\frac{N}{10}\right)$ Na_2CO_3 solution is prepared using double distilled water.
2. 100 ml of 0.9384 $\left(\frac{N}{5}\right)$ HCl solution is prepared using double distilled water.
3. 100 ml of $\left(\frac{N}{10}\right)$ $NaOH$ solution is prepared using double distilled water.
4. 100 ml of 0.9835 $\left(\frac{N}{5}\right)$ oxalic acid solution is prepared using double distilled water.
5. In the first set of experiment, freshly prepared 0.9384 $\left(\frac{N}{5}\right)$ HCl solution is poured in a 50 ml burette. 10 ml freshly prepared $\left(\frac{N}{10}\right)$ Na_2CO_3 solution is taken in a 250 ml beaker by a 10 ml pipette. 90 ml distilled water is added into it. The electrode-set of pH – meter is immersed into the solution. The pH –meter reading is noted. 0.5 ml HCl solution is added to it from the burette. Gently stir the solution and corresponding pH reading is noted. Then continue addition of 0.5 ml HCl solution and take the pH reading in each case. The process is continued until pH reading shows around 2.5.
6. In the 2nd set of experiment, freshly prepared 0.9835 $\left(\frac{N}{5}\right)$ oxalic acid solution is poured in a 50 ml burette. 10 ml freshly prepared $\left(\frac{N}{10}\right)$ $NaOH$ solution is taken in a 250 ml beaker by a 10 ml pipette. 90 ml distilled water is added into it. The electrode-set of pH – meter is immersed into the solution. The pH –meter reading is noted. 0.5 ml oxalic acid solution is added to it from the burette. Gently stir the solution and corresponding pH reading is noted. Then continue addition of 0.5 ml oxalic acid solution and take the pH reading in each case. The process is continued until a constant pH reading is observed.

5. RESULTS AND DISCUSSION

5.1 Na_2CO_3 Versus HCl Titration

In case of Na_2CO_3 versus HCl titration process, the recorded pH – values are given in the

Table 1. pH −values are plotted against volume of HCl solution added. It is shown in the Fig. 1.

Two sharp decrease in pH (one around $pH = 9$ and another around $pH = 5.7$) are quite discernible in the Fig.1. It is evident from the figure that initially pH decreases slowly on addition of HCl solution as the system contains sufficient amount of Na_2CO_3. Later on around $pH = 9$, almost all Na_2CO_3 is consumed and hence pH starts decreasing. This sharp decrease in pH is observed in alkaline region, indicating that neutralization reaction is only partially completed. It is believed that during this sharp decrease total Na_2CO_3 is converted to $NaHCO_3$, which is still alkaline and hence the sharp decrease is observed in alkaline pH range. The following reaction is believed to take place during 1st phase of neutralization process.

$$Na_2CO_3 + HCl \longrightarrow NaHCO_3 + NaCl$$

2nd sharp decrease is observed in acidic region, indicating that the reaction is completed and it is believed that total $NaHCO_3$ is converted to H_2CO_3. The following reaction is believed to take place during 2nd phase of neutralization process.

Table 1. Change in pH −values on addition of HCl solution to Na_2CO_3 solution

Volume of HCl solution added (ml)	pH	Volume of HCl solution added (ml)	pH	Volume of HCl solution added (ml)	pH
0	10	4.5	6.6	9	3.1
0.5	9.8	5	6.4	9.5	3
1	9.7	5.5	6.2	10	2.9
1.5	9.5	6	6		
2	9.3	6.5	5.7		
2.5	9	7	5.2		
3	8.5	7.5	3.7		
3.5	7.3	8	3.3		
4	6.8	8.5	3.2		

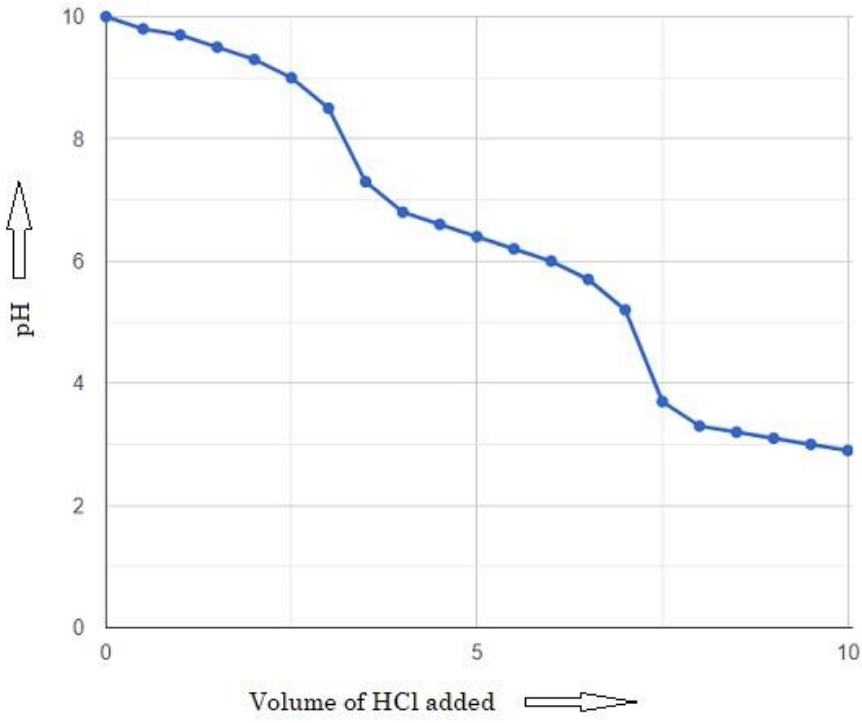

Fig. 1. Change in pH values during reaction between Na_2CO_3 and HCl

$$NaHCO_3 + HCl \longrightarrow H_2CO_3 + NaCl$$

As the neutralization is completed in the 2nd phase, neutralization volume should be calculated on the basis of 2nd sharp decrease in acidic region.

5.2 $NaOH$ Versus Oxalic Acid Titration

In case of $NaOH$ versus oxalic acid titration process also, it may be assumed that oxalic acid reacts with $NaOH$ in two steps as given below.

Step-1 $NaOH + (COOH)_2 \longrightarrow HOOC - COONa\ (Sodium\ bi-oxalate) + H_2O$

Step-2 $HOOC - COONa + NaOH \longrightarrow (COONa)_2\ (Sodium\ oxalate) + H_2O$

The recorded $pH-$ values during titration process are given in the Table 2. pH –values are plotted against volume of oxalic solution added. It is shown in the Fig. 2.

The Fig. 2 shows only one sharp drop in pH in alkaline region, indicating that the neutralization reaction occurs in one step. The following reaction is believed to take place during neutralization process.

Table 2. Change in pH –values on addition of oxalic acid solution to $NaOH$ solution

Volume of oxalic acid solution added (ml)	pH
0	11.4
0.5	11.2
1	11.1
1.5	11
2	11
2.5	10.8
3	10.7
3.5	10.5
4	10.2
4.5	9.4
5	5.8
5.5	4.8
6	4.5
6.5	4.2
7	4
7.5	4
8	4

$$2NaOH + (COOH)_2 \longrightarrow (COONa)_2 + 2H_2O$$

So, unlike $Na_2CO_3\ /HCl$ titration, no sodium bi-oxalate is formed during $NaOH/Oxalic\ acid$ titration process. Only sodium oxalate is formed. There are no existences of Step-1 and Step-2 as shown above. It is a single step reaction.

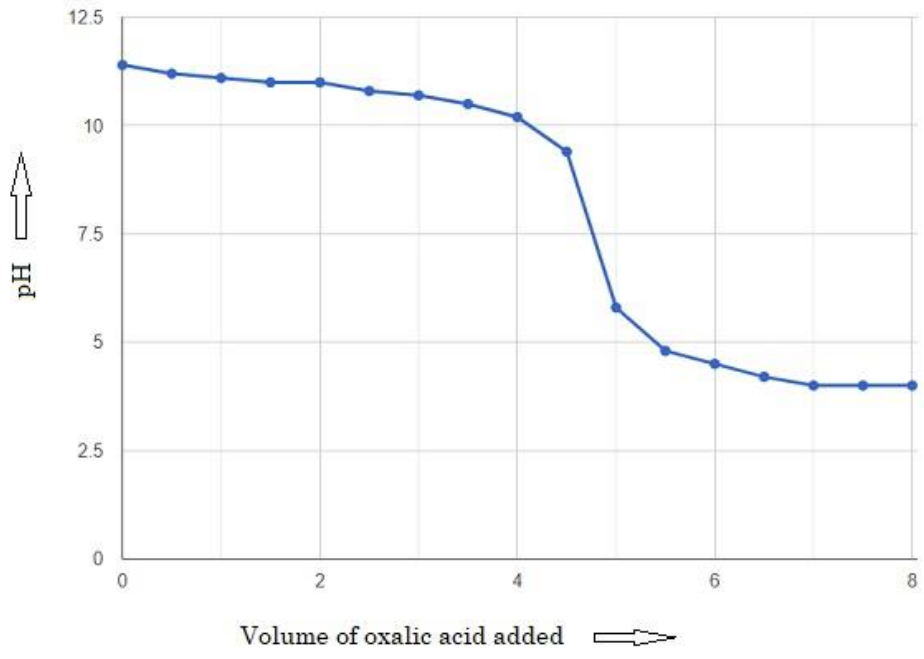

Fig. 2. Change in pH values during reaction between sodium hydroxide and oxalic acid

6. CONCLUSION

The reaction between Na_2CO_3 and HCl occurs in two steps. In the 1st step sodium bicarbonate ($NaHCO_3$) is formed. It is alkaline and finally sodium bicarbonate is converted to carbonic acid (H_2CO_3) on further addition of HCl. However, the reaction between $NaOH$ and oxalic acid occurs in one step without formation of any sodium bi-oxalate. The present work shows a novel method to study the nature of chemical reactions and it opens up the scope of future research works.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ACKNOWLEDGEMENT

The author is indebted to Mr. Rahul Chacraborty, our Laboratory Assistant, whose active participation in experimental works helped the author complete this research paper.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Peer-review history:
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