Analysis of Sodium Hydrogen Carbonate

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Introduction:

Sodium hydrogen carbonate (NaHCO3), also known as baking soda, is a chemical salt that can be used for both domestic and medicinal purposes. In baking it causes batter mixtures to rise. The sodium hydrogen carbonate reacts with an acid (H+) to form carbonic acid H2CO3 which can readily bifurcate into H2O and CO2.

NaHCO3(*aq*) + H+(*aq*)→ H2CO3(*aq*) + Na+(*aq*)

H2CO3(*aq*) → H2O(*l*) + CO2(*g*)

The CO2 produced from this reaction gets trapped within the batter mixture and these trapped gases expand to allow the batter to rise (2).

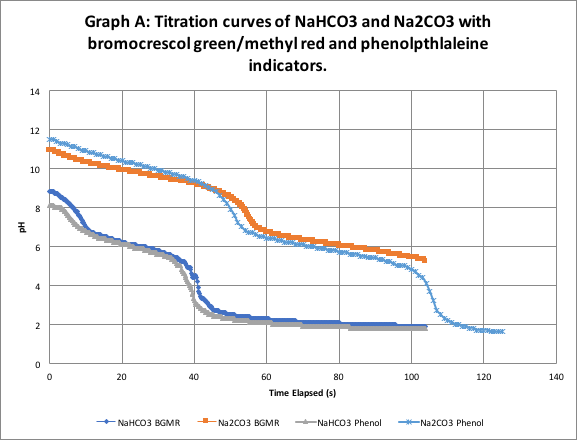
Sodium hydrogen carbonate is also used as an intravenous solution to treat build of of acid from metabolic processes (i.e. metabolic acidosis). Metabolic acidosis is induced by an imbalance of acids and bases within the body- the body either produces excess quantity of acids or the kidneys cannot neutralize enough acid which lead to this buildup (4). This buildup depending on the severity, could lead to shock or death (4). While treatments against metabolic acidosis are focused on the cause of the metabolic acidosis, intravenous injection of sodium hydrogen carbonate can be used as an immediate solution towards raising blood pH levels. The pH in the bloodstream is regulated by a buffer of carbon dioxide, bicarbonate anion, and carbonic acid, that follows the equilibrium reaction:

CO2(*aq*) + H2O(*l*) ⇄ H2CO3(*aq*) ⇄ H+(*aq*) + HCO3–(*aq*) (3)

When there is too much CO2 in the bloodstream, the reaction leans to the right due to Le Chatelier's principle and the concentration of H+ ions increase, lowering the pH. If the body does not produce enough bicarbonate anion, the reaction leans right and the concentration of H+ increases, lowering the pH. When intravenous sodium bicarbonate solution is injected into the bloodstream of a person diagnosed with acidosis, the increase in the amount of bicarbonate anion causes the reaction to lean to the right, decreasing the H+ concentration and bringing the pH back up to safe levels.

In both usages of sodium hydrogen carbonate, the purity of sample becomes a critical factor to consider. Too much ammonium chloride or too much sodium carbonate present in baking soda will decrease the effectiveness of the decomposition of CO2 as sodium carbonate is an end product of heating sodium hydrogen carbonate, so it does not decompose any further. For an intravenous sodium hydrogen carbonate solution, the presence of sodium carbonate under a certain amount would positively impact the effectiveness of the solution in treating acidosis, as the carbonate anion would bond dissociate into CO32– and 2 Na+, so for each mole of sodium carbonate in the solution counts for an extra mole of sodium hydrogen carbonate. However, if there is too much sodium carbonate, there will be too much Na+ in the blood would increase blood sodium levels and cause blood cells to shrivel up due to the transfer of water via hydrolysis. Having as pure a sample as possible is desirable as it allows for the simplest dosage calculations. As such we wanted to evaluate the purity of the sodium hydrogen carbonate sample, with the objective point at 90% purity- NaHCO3 makes up more than 90% of the mass of the sample.

Experimental procedures:

The sample of sodium hydrogen carbonate in this experiment was obtained from samples made earlier in the semester through the Solvay process involving solid carbon dioxide, saline solution, and ammonia. Sodium hydrogen carbonate made in this way is likely to have contaminants from the products of intermediate reactions, which could consist of sodium chloride, ammonium chloride, water, and sodium carbonate. This determined the direction of our experimental procedure. In an earlier investigation, sodium carbonate and sodium hydrogen carbonate were both titrated with HCl using phenolphthalein and bromocresol green/methyl red indicators separately. The indicator became clear/grey at the first equivalence point of both solutions (see Graph A), however the sodium carbonate solution had a higher initial pH than the sodium hydrogen carbonate solution, making the pink to grey transition much easier to see. The phenolphthalein indicator was visible in both solutions before titration, and continued to be visible after the first equivalence point. The indicator turned to clear/grey at the second equivalence point of the titration. This meant that the amount of sodium carbonate present in the sample could be determined by titrating the sample in solution with HCl using phenolphthalein indicator, and the amount of sodium hydrogen carbonate present in the sample could be determined by subtracting the volume of titrant used at the first endpoint from the volume of titrant used at the second endpoint based on the titration equations equations:

Na2CO3(*aq*) + 2 HCl(*aq*) → 2 Na+(*aq*) + HCO3–(*aq*) + HCl(*aq*) → 2 NaCl(*aq*) + 2 H2CO3(*aq*)

NaHCO3(*aq*) + HCl(*aq*) → NaCl(*aq*) + H2CO3(*aq*)

To analyze the composition of sodium hydrogen carbonate and sodium carbonate, 0.3 Grams of sample were weighed and dissolved with DI water in an Erlenmeyer flask. Phenolphthalein indicator was added and the solution was titrated with 0.1000M HCl up to the phenolphthalein endpoint. Bromocresol green/methyl red indicator was added, and the solution was titrated close to the BGMR endpoint. The solution was boiled to achieve a sharper endpoint, and then was carefully titrated to completion.

The chloride analysis ascertains the amount of chloride ions in terms of mass present in the sodium hydrogen carbonate sample by evaluating the mass of AgCl precipitate produced through a gravimetric approach. Roughly 0.25 grams of the sodium hydrogen carbonate sample first was weighed out to the nearest 0.0001g and added to a beaker. 50 mL of deionized water was then poured to dissolve the sample. Adding HNO3 to the beaker caused the solution to bubble and was added drop by drop until the bubbling ceased. Since the amount of chloride ions present in the sample was undetermined, an excess volume of 0.1M AgNO3 of about 20 mL were added to the solution. The mixture was boiled using a Bunsen burner for roughly 2 minutes to coagulate any AgCl particles and then set to rest. The mass of a dried crucible was weighed to the nearest 0.0001g before use. Using vacuum filtration, the AgCl particles were filtered out (Lab manual, Section V, Appendix III). The filtered precipitate was then dried in an oven of 40°C for 15 minutes before taken out and weighed again. This process was repeated twice. The moles of AgCl with the mass of the sample determined how many Cl- ions were present in the sample.

To verify if ammonium chloride is present in the sample, 0.50 grams of the sodium hydrogen carbonate sample was weighed out to the nearest 0.0001g and added to a beaker. It was then dissolved using roughly 20 mL of deionized water. 10 mL of 0.1M NaOH was added to the solution so that it could convert any of the NH4+ into NH3. The beaker was wafted to smell for any signs of ammonia. The ammonia smell would indicate presence of NH4+ in the sodium hydrogen carbonate sample. If ammonia smell is present, this means that there is some NH4+ in our sample, meaning that the percent composition of ammonium chloride would have to be considered in the total composition of the sample.

The water test analyzed if the mass of the sodium hydrogen carbonate sample was affected by presence of water molecules. 0.25g of the sodium hydrogen carbonate were weighed and added to the a beaker. The beaker containing the sample was then weighed to the nearest 0.0001g and then placed into an oven of 40°C. Between 5 minute intervals the beaker was taken out, cooled for 30 seconds, and then measured to detect whether the mass decreased or remains the same. This process was continued until the mass of the beaker containing the sodium hydrogen carbonate sample does not change. Three water tests were taken of the sample.

Tabulated Results:

Percentage of Sodium of sodium hydrogen carbonate sample:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Mass of Sample (g) | Vi (initial volume of HCl in titration stand) (mL) | V1 (volume of HCl in titration stand at Na2CO3 endpoint) (mL) | V2 (volume of HCl in titration stand at NaHCO3 endpoint) (mL) | %Na2CO3 | %NaHCO3 |
| 0.3005 | 0.0015 | 0.0038 | 0.03758 | 8.1122 | 88.0036 |
| 0.3001 | 0.00239 | 0.00445 | 0.0386 | 7.2754 | 89.8285 |
| 0.3008 | 0.00451 | 0.00768 | 0.0406 | 11.1696 | 83.0844 |
| 0.3035 | 0.00475 | 0.008 | 0.04124 | 11.3496 | 83.0096 |
| % Mean: | | | | 9.4767 | 85.9815 |
| % Relative Average Deviation: | | | | 18.8134 | 3.4130 |

*Table 1:* Vi refers to the initial volume (mL) of HCl in titration stand. V1 refers to the volume of bicarbonate ions present in the solution and V2 refers to the volume of carbonic acid produced. The %NaHCO3 present in the sodium hydrogen carbonate sample was calculated to be roughly 86%.

Chloride Analysis:

|  |  |  |
| --- | --- | --- |
| Mass of Sample (g) ±0.0001g | Mass of AgCl precipitate (g) | % Cl- |
| 0.2511 | 0.0241 | 2.3765 |
| 0.2516 | 0.0195 | 1.9191 |
| % Mean: | | 2.1478 |
| % Relative Average Deviation: | | 10.6488 |

*Table 2:* Determined % of chloride ions by mass of AgCl precipitated formed in chloride analysis test. Mean % chloride ions yield is 2.1478%.

Water Test Analysis:

|  |  |  |
| --- | --- | --- |
| Weight of sample before | Weight of sample after | % H2O |
| 31.2189 | 31.1351 | 0.2684 |
| 65.2208 | 65.135 | 0.1316 |
| 81.1072 | 81.0085 | 0.1217 |
| % Mean: | | 0.1739 |
| % Relative Average Deviation | | 36.2438 |

*Table 3:* Determined % H2O by differences in mass of sodium hydrogen carbonate sample before and after drying in oven. Mean % H2O yield is 0.1739%.

Discussion:

The percent composition sodium hydrogen carbonate in the sample was determined to be 85.98% with a relative average deviation of 3.413%. The percent composition of chloride in the sample was determined to be 2.148% with a relative average deviation of 10.65%. The percent composition of water in the sample was determined to be 0.1739% with a relative average deviation of 36.24%. The percent composition of sodium carbonate in the sample was determined to be 9.477% with a relative average deviation of 18.81%. These values did not meet the initial purity goal of >90% and with all of the relative average deviations having values >0.3%, the percent compositions are not precise enough to assess the true composition accurately.

Even though the sample was ground with a mortar and pestle, it is possible that the distribution of molecules in the sample was not homogenous. It is also notable that the first two titrations were done on the first day, and the last two were done on the second day. These first two titrations gave very different values for the percent composition of sodium hydrogen carbonate and sodium carbonate, however the second two titrations had percent compositions that had a relative average deviation of >0.1% relative to each other, and were much less than the percent compositions from the titrations of the first day. This is most likely to have been caused by the concentration of the hydrochloric acid being unequally distributed in solution during the first set of titrations, and being much more equally distributed in solution during the second set of titrations. Another possibility, is that the distribution of possible contaminants within the sample was unequal within the sample, allowing for different “chunks” of sample with different percent compositions to be present in the total sample, and if one of these chunks were used in the titrations their distinct percent compositions would be reflected in the results, however this is much less likely due to the sample being ground prior to the use of any analytical methods and due to the consistency seen in the second set of titrations.

Within the chloride analysis, the reaction between the sample in aqueous solution and the HNO3 to produce CO2 and protonate all the carbonate and bicarbonate in the solution might not have been complete. It should be noted that that Ag2CO3 is also insoluble, so carbonate or bicarbonate of the sample must be protonated so that it doesn’t form Ag2CO3. Not adding enough of the HNO3 so that the carbonate or bicarbonate was all protonated, could have yielded above average mass of the precipitate and lowered the purity of the sample.

Measurements of the water test varied greatly by >36% deviation. This is primarily due to the change in mass between immediate extraction from the oven to around 1 minute after. Before it was understood that such difference existed, the execution of the first water test took roughly 45 minutes whereas the other two took roughly 20 minutes. Measurement of the sample promptly after it had been in the oven for an interval of time displayed lower mass, but the measurement should have been taken after a short period of cooling down. These variances might have impacted the % H2O composition and contributed to the wide deviations.

The test for ammonium in the sample was negative, so all the chloride detected from the chloride test was assumed to be from sodium chloride present in the sample.

Conclusion:

The results of this experiment reveal the shortfall of laboratory synthesized sodium hydrogen carbonate for applications in domestic settings like baking and for remedial purposes like intravenous sodium hydrogen carbonate. These four analysis tests demonstrated: a) percent composition of Na2CO3 and NaHCO3 present within the sample via volumetric analysis or titration with HCl, b) percent composition of chloride ions within the sample, c) whether or not the ammonia ions were present in the sample, and d) a rough estimate of the mass of water that contributed to the overall mass of the sodium hydrogen carbonate sample. Although the % NaHCO3 failed to reach the 90% critical value, the 85.98% composition still relatively close to 90%.

In both uses of NaHCO3 the purity of sample is typically >90%, so our sample could not even be considered for these uses. Typical baking soda has a purity of ~99% (1), so the sample would not perform well if used in baking. However, were the entire sample heated so that all sodium hydrogen carbonate decomposed into sodium carbonate, a relatively pure sample of sodium carbonate could be formed. Sodium carbonate has been used intravenously to buffer changes to blood pH caused by CO2 (6). Assuming the sample of sodium carbonate was of good quality after heating, it could be used as an alternative for intravenous sodium hydrogen carbonate in an emergency to treat acidosis. This investigation introduced the process of analysis on the sodium hydrogen carbonate prepared via the Solvay process. The analysis tests indicate presence of above average percent impurities within the laboratory synthesized sample. As such, it would require more quality lab control or an alternative mode (i.e. the mining of the trona ore) to generate a purer sample of sodium hydrogen carbonate.

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Appendix 1: Calculations