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Manufacture and Use of an Effervescent Antacid
- Information and Questions for Students
By Professor David Cash

Background Information

Sodium bicarbonate is a major industrial chemical with many uses. These include amongst many others food and beverages, personal care, cleaning and household products, agriculture, and pharmaceuticals. It is produced globally in mega-tonne quantities with a total value into the mid-billions of dollars (US) in 2023. It can be considered a natural product, since its use produces no toxic residues or non-natural substances. There are many niche markets, such as dry fire extinguishers and acid spill neutralizers.

There are many routes by which it may be produced. Most of world production involves either sodium carbonate or sodium hydroxide. These are both produced and used in immense quantities annually.

Sodium bicarbonate is used in the food and beverage industry as a leavening agent, pH regulator, and flavor enhancer. In the pharmaceutical and healthcare sectors it is used as an antacid to alleviate heartburn and indigestion, a buffering agent in pharmaceutical formulations, and as a component in intravenous solutions. It is used as a flue gas desulfurization agent to reduce sulfur dioxide emissions from power plants, as a cleaning and degreasing agent, and in water treatment processes.

The main reaction of sodium bicarbonate on which most of the uses depend is the neutralization reaction with acids. This reaction is responsible for the effervescence of antacid products. This reaction will be the focus of Part 2 of this question set.

A second reaction of importance is the thermal decomposition into sodium carbonate, water, and carbon dioxide. This reaction occurs at very low temperature, beginning at 80 °C. This reaction may be useful, or it may be an aggravation. The decomposition reaction is useful when solid sodium bicarbonate powder is used as an extinguisher of electrical fires. The carbon dioxide produced will exclude air from the fire.

The decomposition reaction is an aggravation for the users of pharmaceutical sodium bicarbonate. You will encounter this aspect in Part 1 of this question set. All pharmaceutical powders must be dried as part of their manufacturing process. Drying with heat is the least costly method, and in this process, some of the sodium bicarbonate decomposes into sodium carbonate. This must be kept to a minimum.

Sources

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Questions

Part 1. The Manufacture of an Effervescing Antacid

In the manufacturing stage of a solid pharmaceutical product the ingredients are powdered and dried using various methods. A dried powder flows smoothly. This allows the later operations of formulating, blending, transporting, and dispensing into unit doses to be carried out efficiently. Adsorbed moisture may also alter physical properties, interfere with chemical analysis, or cause undesired chemical reactions in storage. Some solids cannot be dried using elevated temperature (heat-drying) for a variety of possible reasons. More complex and costly methods may be used if necessary.

Sodium bicarbonate cannot be dried as a pure substance using heat-drying by heating to above 100 °C due to its decomposition reaction. Sodium bicarbonate begins to decompose at 80 °C. The consequence of heat-drying the sodium bicarbonate at a temperature above 100 °C is a partial decomposition into sodium carbonate.

This does not always prevent using the method, as the presence of some sodium carbonate does not necessarily cause a problem. In particular, the presence of sodium carbonate as a minor component of an effervescent antacid formula is allowed. The amount of sodium carbonate in a sample of heat-dried sodium bicarbonate can be calculated if sufficient information about the sample is known.

In Part 1 you will apply your knowledge of chemistry to the reaction occurring when sodium bicarbonate is heated to dryness. First you will assemble the information required for writing equations and performing calculations.

Overall Objective of Part 1

A Scientific American article for young scientists (source # 3 above) describes in semi-quantitative terms how heating solid sodium bicarbonate causes a decrease of mass of the solid to occur. You will write a balanced chemical equation for this process and use the mass – mass relationships of the equation to predict whether a particular sample is completely or partially decomposed. More importantly, you will learn how to determine the composition of the mixture of sodium bicarbonate and sodium carbonate formed by an incomplete reaction.

Preliminary Steps

1. a. Write the formula of sodium bicarbonate (sodium hydrogen carbonate).
   Add together the atomic masses of each atom present to calculate the molar mass of this compound.

   b. Calculate the percentage by mass of sodium in sodium bicarbonate.
   Convert the percentage to a decimal fraction.
   Example: the decimal fraction of 12.34 % is 0.1234.

2. a. Write formulas for sodium carbonate, water, and carbon dioxide.
   Add together the atomic masses of each atom present to calculate the molar masses of these compounds.

   b. Calculate the percentage by mass of sodium in sodium carbonate.
   Convert the percentage to a decimal fraction.

3. Fill in the table with the required information.

Name	Sodium Bicarbonate	Sodium Carbonate	Water	Carbon Dioxide
Formula				
Molar Mass				
Sodium Content (percent)			X	X
Sodium Content (decimal)			X	X

4. Write the balanced equation for the decomposition of solid sodium hydrogen carbonate into solid sodium carbonate, water vapor, and carbon dioxide gas.

   Check that the atom counts on the left side and right side of the equation are equal.

Why do we refer to molecules of water in the gas phase as a vapor, but refer to molecules of carbon dioxide in the gas phase as a gas?

5. Under each substance in the balanced equation, write the molar mass of the substance, multiplied by the coefficient.

   Check that the total masses on the left side and right side of the equation are equal.

Exercise 1 – Partial Decomposition of a Sample of Sodium Bicarbonate

Objective: Determine the percentage composition of the solid remaining after incomplete decomposition of a heat-dried sample of sodium bicarbonate, given the initial and final mass of the solid.

A **147.92 g** mass of solid sodium bicarbonate was briefly heated to above 100 °C in a stream of warmed air. After cooling to room temperature, the solid remaining had a mass of **138.65 g**. What is the composition of this 138.65 g of solid?

Is the decomposition reaction complete? Is the final mass entirely converted to sodium carbonate, or is it a mixture of product and unreacted starting material?

6. Use your balanced equation and the relative masses under each reagent to calculate the theoretical 100 % yield of sodium carbonate. Is the decomposition reaction complete?

You should find that the decomposition is incomplete. How is the composition of this mixture to be determined? Recognize that the decrease in mass occurring is due to the loss of volatile products – water and carbon dioxide. Treating the mass of volatile products as if they were a single product of the reaction, calculation of other reactant quantities is possible.

7. Rewrite the balanced equation and its mass information by adding the water and carbon dioxide masses together as ‘mass of volatiles’.

8. Subtract the final mass after heating from the starting mass. This is the mass of volatile products produced by the decomposition. Treat this mass ('mass of volatiles') as if it were a single product of the decomposition.

9. Use your new balanced equation and the relative masses under each reagent to calculate the mass of sodium carbonate produced when the mass of volatiles (from Question 8) was formed.

10. Use your new balanced equation and the relative masses under each reagent to calculate the mass of sodium bicarbonate that was decomposed when the mass of volatiles (from Question 8) was formed.

11. Subtract the mass of sodium bicarbonate that decomposed from the starting mass of sodium bicarbonate to determine the amount of sodium bicarbonate remaining in the final mixture.

12. Add the calculated amount of sodium carbonate formed to the calculated amount of sodium bicarbonate remaining. The total must equal 138.65 g. If not, there is an error in your calculations that must be corrected.

13. Calculate the percentage by mass of sodium bicarbonate that has decomposed.

14. Calculate the percentage by mass of sodium carbonate in the final mixture.

    Are the percentage values of these last two questions equal? Should they be?

Exercise 2 - Sodium Content of the Sample Before, During, and After Decomposition

Objective: Calculate and compare the mass of sodium present in the sample of Exercise 1 at each stage of the reaction occurring.

15. Calculate the sodium content of the initial mass of sodium bicarbonate, using the percentage sodium value for sodium bicarbonate in your table.

16. Calculate the sodium content of the theoretical yield amount of sodium carbonate (Question 6 above), using the percentage sodium value for sodium carbonate in your table.

17. Calculate the mass of sodium in each of the two components of the final mixture (Questions 9 and 11 above) and add them together to find the total mass of sodium in the final mixture.

    The answers to these three questions must agree except for rounding differences in the last digit. Why?

Summing Up Exercises 1 and 2

A sample of solid sodium bicarbonate is heated to above 100 °C in a stream of warmed air. The mass of the sample is followed in real-time using a digital balance.

- Over time the mass of the sample goes: up / down / stays constant.
- Over time the mass of sodium in the sample goes: up / down / stays constant.
- Over time the percentage by mass of sodium in the sample goes: up / down / stays constant.
- The minimum percentage by mass of sodium in the sample is _______ % at the: start / end.
- The maximum percentage by mass of sodium in the sample is _______ % at the: start / end.

Formulation of a Fictitious Effervescent Antacid

Here is the formulation or ingredient list for a fictitious pharmaceutical effervescent antacid.
It is based closely on the formulation of an antacid that has been available commercially for many years.

Effervescent Antacid Formulation (per dose)
ASA (acetylsalicylic acid) 0.325 g
Anhydrous citric acid 1.000 g
Heat-dried sodium bicarbonate 1.932 g
Sodium content 0.578 g
(There is no other ingredient containing sodium.)

The amount of sodium present in an antacid formulation is a very important and useful piece of information. Since this is a pharmaceutical that will be ingested, the manufacturer is required by regulation to provide the sodium content of the dosage to the consumer.

The mass of sodium present can be used to determine if the sodium bicarbonate listed in the formulation or on a product label is pure or partially decomposed into a mixture of sodium bicarbonate and sodium carbonate. If it is a mixture, the initial mass of sodium bicarbonate can be calculated even when it is not stated or otherwise known.

Exercise 3

Objective: Determine from the given mass and sodium content of a heat-dried sample of sodium bicarbonate that it is a mixture. If it is a mixture, calculate the initial mass of the sample and then use the method of Exercise 1 to calculate the percentage composition of the mixture.

18. Calculate the percentage by mass of the sodium (0.578 g) in the heat-dried sodium bicarbonate (1.932 g) of the fictitious formulation.

19. Is the percentage value calculated in Question 18 between 27.366 % (100.0 % sodium bicarbonate) and 43.381 % (100.0 % sodium carbonate)?
If so, this is a mixture of sodium bicarbonate and sodium carbonate.

20. Calculate the mass of sodium bicarbonate that contains the mass 0.578 g of sodium. This calculated mass is the initial value for determining the composition of the mixture.

21. Subtract the mass of heat-dried sodium bicarbonate in the formulation (1.932 g) from the initial mass calculated in Question 20. This is the mass of volatile products produced by the decomposition.

22. Use the balanced equation and the relative masses under each reagent to calculate the mass of sodium carbonate produced when the mass of volatiles (from Question 21) was formed.

23. Use your balanced equation and the relative masses under each reagent to calculate the mass of sodium bicarbonate that was decomposed when the mass of volatiles (from Question 21) was formed.

24. Subtract the mass of sodium bicarbonate that decomposed from the initial mass of sodium bicarbonate to determine the amount remaining in the end heat-dried mixture.

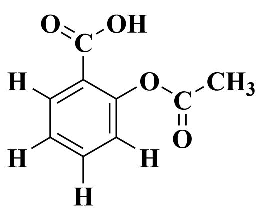
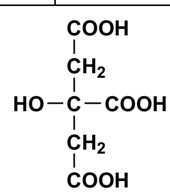
25. Add the calculated amount of sodium carbonate formed to the calculated amount of sodium bicarbonate remaining. The total must equal 1.932 g. If not, there is an error in your calculations that must be corrected.

26. Calculate the percentage by mass of sodium bicarbonate that has decomposed.

27. Calculate the percentage by mass of sodium carbonate in the heat-dried mixture.

Part 2. The Addition of an Effervescent Antacid Dosage to Water

Organic Compound Structures (D. Cash/ChemDraw)

	Acetylsalicylic Acid (a monoprotic acid) $C_9H_8O_4$ or $HC_9H_7O_4$ = 180.17 g / mol	Citric acid and acetylsalicylic acid react immediately with sodium bicarbonate and/or sodium carbonate in aqueous solution. The products are carbon dioxide, water and sodium citrate or sodium actetylsalicylate respectively.
Citric Acid (a triprotic acid) $C_6H_8O_7$ or $H_3C_6H_5O_7$ = 192.1 g / mol		pK_a Values 3.14 4.75 6.40

What processes occur when the fictitious effervescent antacid dosage is added to water?

The active ingredients dissolve into water solution and the acidic substances react with the alkaline substances. Since there are two acids and two alkalis present there are four reactions occurring simultaneously.

28. Write the balanced equation for the reaction of acetylsalicylic acid and sodium bicarbonate. Write the formula of the acetylsalicylic acid as $HC_9H_7O_4$ to emphasize that this is a monoprotic acid. The products are sodium acetylsalicylate, carbon dioxide, and water.

29. Write the balanced equation for the reaction of citric acid and sodium bicarbonate. Write the formula of the citric acid as $H_3C_6H_5O_7$ to emphasize that this is a triprotic acid. The products are sodium citrate, carbon dioxide, and water.

30. Write the balanced equation for the reaction of acetylsalicylic acid and sodium carbonate. The products are sodium acetylsalicylate, carbon dioxide, and water.

31. Write the balanced equation for the reaction of citric acid and sodium carbonate. The products are sodium citrate, carbon dioxide, and water.

Exercise 4

32. Which is the excess reagent type in the fictitious antacid dosage – acidic components or alkaline components?

    To answer this question, you will have to do some quantitative calculations. Fill in the table below, including the calculated values required.

N.B. One equivalent of acid is the amount providing one mol of ionizable hydrogen ions. One equivalent of alkali is the amount that neutralizes one equivalent of acid.

Table of Reactants in Each Dosage of Fictitious Antacid				
	Citric acid	**Acetylsalicylic acid**	**Sodium bicarbonate**	**Sodium carbonate**
Formula				
Molar mass (g)				
Mass per dose (g)				
mol per dose				
mol of hydrogen ion equivalents per mol				
mol of hydrogen ion equivalents per dose				
mol of alkali equivalents per mol				
mol of alkali equivalents per dose				

33. a. Calculate the total of mol of acid equivalents in each dose.

    b. Calculate the total of mol of alkali equivalents in each dose.

    c. Which component type is in excess?

A solution of excess citric acid in carbonated water will be acidic and taste like a lemon-lime soft drink. A solution of excess alkali will be alkaline and taste unpleasant, like medication.

If you have access to a pH meter and the required chemicals, you can check the pH of the following solutions: 0.015 molar citric acid; 0.050 molar sodium bicarbonate; 0.025 molar sodium carbonate; one regular-strength effervescent antacid dosage and one extra-strength effervescent antacid dosage each fully dissolved in 250 mL of water.

The Effect of Heat Drying of Sodium Bicarbonate on Neutralizing Ability and Carbon Dioxide Generation

Look at the balanced equation for the decomposition of sodium bicarbonate into sodium carbonate:

Compare the number of moles of alkalinity on the left side and the right side of the equation.

Compare the number of moles of carbon dioxide that will be generated from the left-side reagents to that from the right-side reagents when neutralized by acid.

A sample of solid sodium bicarbonate is heated to above 100 °C in a stream of warmed air.

- Over time the moles of alkalinity of the sample goes: up / down / stays constant.
- Over time the carbon dioxide generating ability of the sample goes:

  up / down / stays constant.

Commercial Effervescent Antacid Questions

Company **X** is a very large, multi-national pharmaceutical company. This company owns the brand name of an iconic effervescent antacid. In Canada, this brand is sold by the Canadian consumer products division of company **X**. Recently, the company added two new products to its popular product **X-1** (regular strength original formula). These are **X-2** (new regular strength lemon-lime flavour) and **X-3** (new extra strength).

These products are sold in tablet form. The adult dosage is one or two tablets, fully dissolved in one cup (about 250 mL) of water before ingestion. Product details in the table below are per tablet quoted from the US online drug facts sheets for these products.

The Antacid Products of Company X (Label Information)				
Product	**Anhydrous Citric Acid**	**Sodium Bicarbonate**	**Sodium Content**	**Percent Sodium by Mass**
X-1	**1000 mg (also contains 325 mg ASA)**	**1916 mg**	**567 mg**	
X-2	**1000 mg**	**1650 mg**	**489 mg**	
X-3	**1000 mg**	**1976 mg**	**586 mg**	

34. Calculate the percentage by mass of sodium in the sodium bicarbonate in each of the three products in the table.

    If the three values obtained are equal to within ± 1 % then the two new products contain heat-dried sodium bicarbonate with the same composition as that in the original product.

35. Use the method of Exercise 3 to calculate the mass of sodium bicarbonate and the mass of sodium carbonate in each of X-2 and X-3.

36. Use the method of Exercise 4 to determine whether total acid or total alkali is limiting or in excess in each of X-2 and X-3.

    If citric acid is in slight excess in product X-2, it should taste like a lemon-lime flavoured, carbonated drink. If alkali is in slight excess in product X-3, it should taste like a medicated seltzer.

Company **Y** is a very large, multi-national pharmaceutical company. This company owns the brand name of an effervescent antacid. In Canada, an imported product bearing this brand name is sold by the Canadian consumer products division of company **Y**. This is product **Y-1** in the table.

The product is sold in powder form. The adult dosage is 5.0 g fully dissolved in a small glass of water before ingestion. Product details in the table below are per dose quoted from the packaging material of the product.

Because the product sold in Canada has so little information about its contents, a search was conducted. Information was located about a discontinued product formerly sold in Europe by the European consumer products division of company **Y**. This is product **Y-2** in the table.

The Antacid Products of Company Y	
Product	**Known Information**
Y-1	**Information from the package:** • **Individual doses of 5 g of powder.** • **Dissolve completely in 6 oz of water before ingesting.** • **When dissolved, each dose provides 2680 mg of sodium citrate.** • **Each dose contains 855 mg of sodium.** • **Does not contain ASA, preservatives, dyes, sugar, or flavourings.** • **Do not consume if allergic to sodium bicarbonate, citric acid, or sodium carbonate.**
Y-2	**From a European medical information web page:** • **Individual doses of 5 g of powder.** • **Each dose contains 0.85 g of sodium.** • **Each dose contains 2.32 g sodium bicarbonate, 2.18 g citric acid, and 0.50 g anhydrous sodium carbonate.**

Although product **Y-1** does not have a content list, the allergy alert implies that it contains sodium bicarbonate, sodium carbonate and citric acid. It is reasonable to assume that **Y-1** and **Y-2** are identical. Also, it is reasonable to assume that the sodium bicarbonate and sodium carbonate content are present together as a heat-dried sodium bicarbonate mixture.

The information for product Y-2 does not state whether the citric acid is anhydrous. The other possibility is citric acid monohydrate. The latter is produced in huge quantities and used in the production of processed foods and beverages. But it cannot be heat-dried as it decomposes at 100 °C. It can be dried by other means, such as using vacuum or freeze-drying (see source 1 above).

37. Calculate the percentage by mass of sodium in the heat-dried sodium bicarbonate of products **Y-1** and **Y-2**.

    If the value obtained is close in value to that for the percentage of sodium in the three products of company **X** this supports the hypothesis that this is a heat-dried sodium bicarbonate.

38. The information for product Y-1 states that when dissolved in water a solution containing 2680 mg of sodium citrate is formed.

    a. Calculate the theoretical yield of sodium citrate (molar mass 358.1 g) formed from 855 mg of sodium.

    b. Calculate the theoretical yield of sodium citrate (molar mass 358.1 g) formed from 2.18 g of anhydrous citric acid (molar mass 192.1 g).

    c. Calculate the theoretical yield of sodium citrate (molar mass 358.1 g) formed from 2.18 g of citric acid monohydrate (molar mass 210.1 g).

Option c gives the stated result!! This is an unexpected discovery. It seems that company Y has developed a means of using the less costly citric acid monohydrate in the product, even though it cannot be heat dried.

39. All effervescing antacids of the sodium bicarbonate – citric acid type generate a solution of sodium citrate which the patient ingests. If the sodium bicarbonate has already been neutralized, how does this act as an antacid?

    a. Write the balanced equation for the reaction of sodium citrate with hydrochloric acid (stomach acid).

    b. Calculate the mass of HCl neutralized by 2680 mg of sodium citrate.

40. Chemistry teachers love doing demonstrations with effervescing antacids. There is an excellent YouTube video of an experiment in which such an antacid is reacted with excess acetic acid and the mass of carbon dioxide evolved is measured as a mass decrease:
    https://www.youtube.com/watch?v=LIPeiZxzn2s (starts at 4 min 20 sec).

Suppose you want to update this experiment using one tablet of product X-3. In Question 35 above you calculated the mass of sodium bicarbonate and the mass of sodium carbonate in this tablet. Use these values here.

a. Write balanced chemical equations for the reaction of each component of the tablet with acetic acid (CH_3COOH).

b. Calculate the theoretical yield of carbon dioxide for each reaction, and the total theoretical yield of carbon dioxide expected for the experiment.