Analysis of an Antacid Using the Ideal Gas Law

Learning Objectives

Apply the Ideal Gas Law to calculate the mass percent of a carbonate in an antacid.

Gas collection from a chemical reaction.

Introduction

Antacids are a class of medications, often sold over-the-counter, and most commonly used to treat heartburn and acid indigestion. But why? What makes these medications effective? It all boils down to acid-base neutralization! Heartburn is chest pain that occurs when excess stomach acid backs up into the esophagus. The active ingredient in an antacid is a base, which offers relief to the user by effectively neutralizing the excess stomach acid. There are many brands of commercially available antacids and they use a variety of bases as the active ingredient Table ANT.1.

Table ANT.1: Commercially Available Antacids and Active Ingredients

Commercial Antacid	Active Ingredient (Base)
Alka-Seltzer	$NaHCO_3$
Amphojel	$Al(OH)_3$
Digel	$CaCO_3$
Maalox	$Al(OH)_3$, $Mg(OH)_2$
Milk of Magnesia	Mg(OH2
Mylanta	$Al(OH)_3$, $Mg(OH)_2$
Tums	$CaCO_3$
Rolaids	$AlNa(OH)_2CO_3$
Sodium-Free Rolaids	$CaCO_3$, $Mg(OH)_2$

Note that many of the active ingredients contain the carbonate ($CO_3{}^{2-}$) ion, or bicarbonate ($HCO_3{}^-$) ion. Both of these ions are bases and react with acids to evolve carbon dioxide gas, water, and a salt:

$$Ca(CO)_3(aq) + 2\,HCl(aq) \rightleftharpoons CO_2(g) + H_2O(l) + CaCl_2(aq) \quad \text{(Reaction ANT.1)}$$

$$NH_4CO_3(aq) + H_2SO_4(aq) \rightleftharpoons CO_2(g) + H_2O(l) + NH_4SO_4(aq) \quad \text{(Reaction ANT.2)}$$

$$NaHCO_3(aq) + HNO_3(aq) \rightleftharpoons CO_2(g) + H_2O(l) + NaNO_3(aq) \quad \text{(Reaction ANT.3)}$$

$$Ca(HCO_3)_2(aq) + H_2SO_4(aq) \rightleftharpoons 2\,CO_2(g) + 2\,H_2O(l) + CaSO_4(aq) \quad \text{(Reaction ANT.4)}$$

Gas-evolution reactions such as these can be easily followed in the laboratory by collecting the gas that is produced "over water." This is achieved using an apparatus such as the one shown in the Experimental Procedure. In this experiment, you will react a small sample of an Alka-Seltzer tablet with hydrochloric acid and collect the carbon dioxide gas that is produced. The volume of the carbon dioxide gas can be used to determine how much bicarbonate (HCO_3^-) was present in the sample, and thus determine the amount of active ingredient ($NaHCO_3$). In order to carry out these calculations, we must combine what we know about acid-base neutralization with the ideal gas law. Recall that the ideal gas law allows us to relate the volume of a gas to both the pressure and the moles of that gas.

Calculations

When collecting a gas (like carbon dioxide) over water, we must consider that there will be some amount of water vapor mixed in with the gas collected. This water vapor must be accounted for, since it contributes to the total pressure of the gas in the system. In order to find the pressure of the carbon dioxide alone, we can use Dalton's Law of Partial Pressures (Equation ANT.1):

$$P_{\text{total}} = P_1 + P_2 + P_3 + \dots \quad \text{(Equation ANT.1)}$$

Since the experiment is being carried out under atmospheric conditions, the total pressure of the system is simply equal to the atmospheric pressure, which can be easily measured with a barometer (Equation ANT.2):

$$P_{\text{total}} = P_{\text{atm}} \quad \text{(Equation ANT.2)}$$

To isolate the pressure of just the CO_2 in the system, we subtract out the pressure due to water vapor (Equation ANT.3):

$$P_{CO_2} = P_{atm} - P_{H_2O} \qquad \text{(Equation ANT.3)}$$

The pressure due to water vapor depends only on the temperature of the system, and can be easily found on any constants table for the Vapor Pressure of Water (Report Table ANT.1).

Table ANT.2: Vapor Pressure of Water at Various Temperatures

Temperature (°C)	**P_{H_2O} (Torr)**	**Temperature (°C)**	**P_{H_2O} (Torr)2**
0.0	4.6	26.0	25.2
5.0	6.5	27.0	26.7
10.0	9.2	28.0	28.3
15.0	12.8	29.0	30.0
16.0	13.6	30.0	31.8
17.0	14.5	35.0	42.2
18.0	15.5	40.0	55.3
19.0	16.5	45.0	71.9
20.0	17.5	50.0	92.5
21.0	18.7	60.0	149.4
22.0	19.8	70.0	233.7
23.0	21.1	80.0	355.1
24.0	22.4	90.0	525.8
25.0	23.8	100.0	760.0

In today's experiment, you will be reacting Alka-Seltzer ($NaHCO_3$) with hydrochloric acid (HCl). In order to get you ready for the calculations to come, let's walk through a similar reaction together. Consider the reaction of an antacid with calcium carbonate ($CaCO_3$) as its active ingredient, with hydrochloric acid:

$$\mathrm{Ca(CO)_3(aq) + 2\,HCl(aq) \rightleftharpoons CO_2(g) + H_2O(l) + CaCl_2(aq)} \qquad \text{(Reaction ANT.5)}$$

Let's suppose that a 0.250 g portion of the antacid tablet is reacted with excess hydrochloric acid and results in 28.15 mL of carbon dioxide gas collected over water. The atmospheric pressure and temperature are measured to be 741.1 Torr and 24.10°C, respectively.

We first find the partial pressure of CO_2 alone by subtracting the vapor pressure of the water (from Report Table ANT.1) at the temperature closest to the measured temperature from the atmospheric pressure:

$$P_{\mathrm{CO_2}} = P_{\mathrm{atm}} - P_{\mathrm{H_2O}} = 741.1 - 22.4 Torr = 718.7 Torr \qquad \text{(Equation ANT.4)}$$

The ideal gas law (Equation ANT.5),

$$PV = nRT \qquad \text{(Equation ANT.5)}$$

where P is pressure in atmospheres (atm), V is volume in liters, n is number of moles of gas, R = 0.082057 $\frac{L*atm}{mol*K}$ (called the ideal gas constant), and T is temperature in Kelvin. In order to use this equation, the units of all the parts need to match the units of the ideal gas constant. At this point in your chemistry course, you should be comfortable performing these conversions. Rearranging the ideal gas law to solve for moles gives us (Equation ANT.6):

$$n_{\mathrm{CO_2}} = \frac{PV}{RT} \qquad \text{(Equation ANT.6)}$$

Using the balanced chemical equation for the reaction (Reaction ANT.5), we see that the mole-to-mole ratio for carbon dioxide gas to calcium carbonate is 1:1, so the number of moles of calcium carbonate is equal to the number of moles of carbon dioxide gas (Reaction ANT.6).

$$\mathrm{1\ mole\ CaCO_3 = 1\ mole\ CO_2} \qquad \text{(Reaction ANT.6)}$$

Using the molar mass of calcium carbonate (100.09 g/mol), we can now calculate the mass of calcium carbonate that must have been present in the antacid tablet. Finally, we can determine the mass percentage of calcium carbonate in the original sample (Reaction ANT.7).

$$\text{mass percentage of CaCO}_3\text{ in tablet} = \frac{\text{mass of CaCO}_3}{\text{mass of sample}}\, x\, 100 \qquad \text{(Reaction ANT.7)}$$

The Apparatus

Your experimental apparatus is shown in Figure ANT.1.

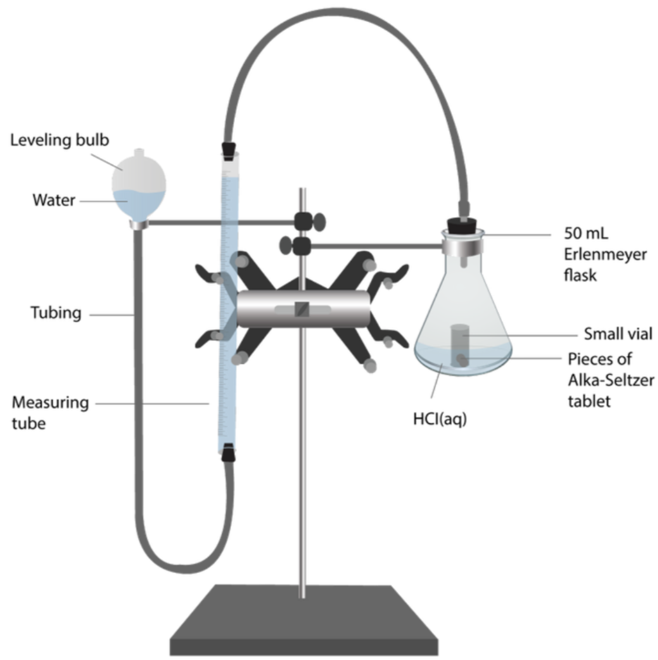

Figure ANT.1: Apparatus for antacid experiment

Your reaction will take place in the Erlenmeyer flask, where the acid will be located along with a small vial holding the antacid sample. The reaction is started by tipping the flask to allow acid to flow into the vial. As the reaction progresses, the carbon dioxide produced flows upwards through the tubing, and into the measuring tube. The measuring tube is marked to the tenth of a mL, so you will be able to read the volume of the gas produced to the hundredth of a mL (0.01 mL) by estimating one digit past the markings.

Before beginning the reaction, you will need to adjust the water level in the measuring tube to be near the 0.00-mL mark. To do this, the top of the measuring tube must be open to atmospheric pressure (not connected to the reaction vessel yet). To raise or lower the water level in the measuring tube simply move the leveling bulb up or down until the water level in the bulb is close to the zero mark on the measuring tube.

Once the system is closed (i.e., with all hoses and stoppers connected), the pressure in the system can be greater than, less than, or equal to the atmospheric pressure, as shown in Figure ANT.2.

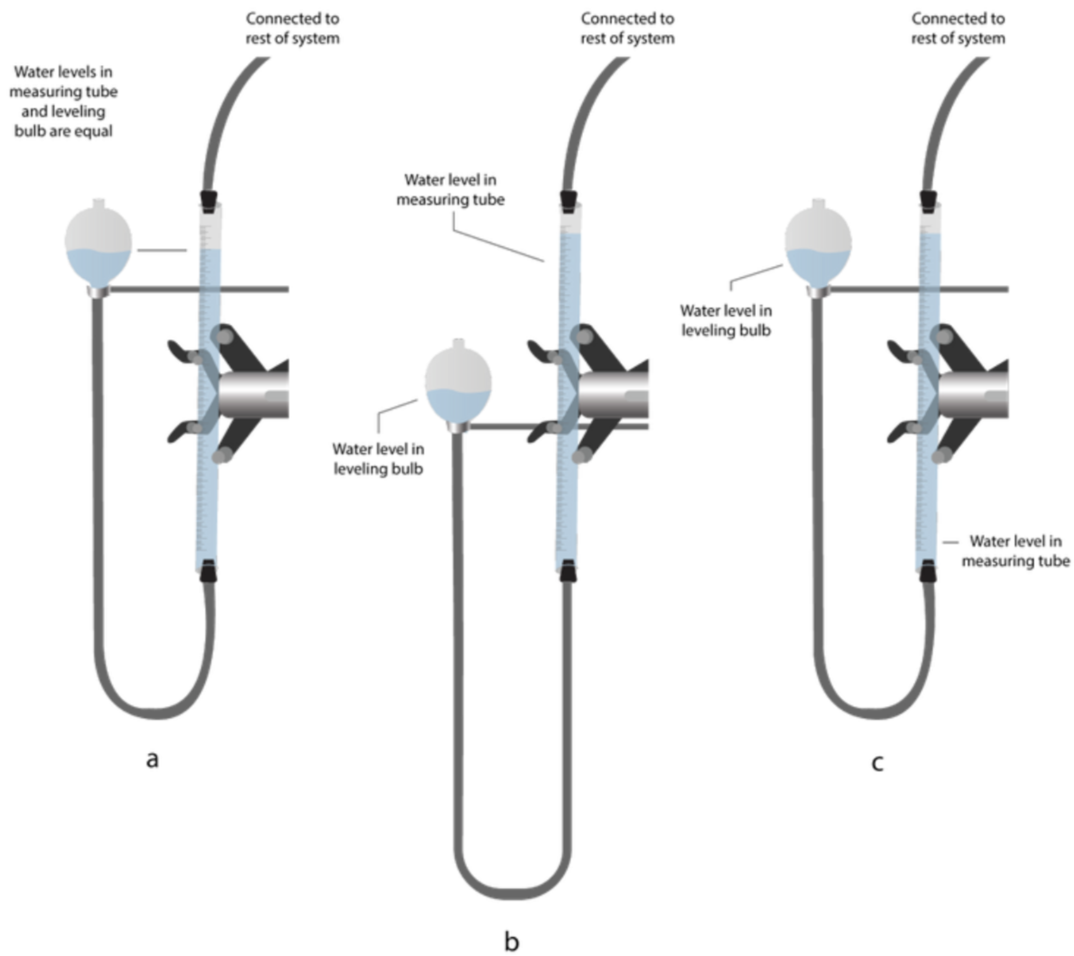

Figure ANT.2: Possible pressure conditions (system is closed). a. Pressure is equal to atmospheric pressure. b. The atmospheric pressure is greater than the pressure in the system. c. The pressure in the system is greater than the atmospheric pressure.

Because the only pressure being measured is atmospheric pressure, we must ensure that the pressure within the measuring tube is equal to atmospheric pressure whenever volume measurements are taken. To do this, the leveling bulb must be moved up and down next to the measuring tube until the two water levels are equal. Once the levels are equal, the volume of water from the measuring tube can be read and recorded.

Experimental Procedure

Safety Precaution

Wear safety goggles and a lab apron/lab coat when performing this experiment.

1. Your instructor will measure the atmospheric pressure of the room from a barometer, and write it on the white board. Record this value in Report Table ANT.1.

2. Assemble the apparatus, as shown in Figure ANT.1, **leaving the reaction chamber disconnected for now.**

Safety Precaution

Be careful inserting tubing and rubber stoppers as glassware breakage can lead to puncture wounds.

3. Fill the system with deionized water until the leveling bulb is approximately 1/2 full by pouring the water into the open hole at the top of the leveling bulb. Raise or lower the leveling bulb in order to get rid of any air bubbles trapped in the rubber tubing. Note that while the reaction chamber is not connected, the water levels in the measuring tube and leveling bulb should remain equal. If they are not, there are air bubbles in the tubing. Remove any air bubbles before continuing. Have your instructor check the system for leaks before proceeding.

4. Wash and dry your 50 mL Erlenmeyer flask. This will be your reaction chamber. Obtain a 1-dram glass shell vial from the stockroom window and make sure it is completely dry. The Alka-Seltzer will be placed in the vial and will react with any residual water.

Safety Precaution

Do not under any circumstances put any Alka-Seltzer in your mouth. Anything that has been in the laboratory has been contaminated with chemicals present in the lab.

5. Your instructor will break up one packet of Alka-Seltzer per bench, and you will share the pieces with your lab mates. Use a piece of weighing paper, tared on a precision balance, to weigh out about 0.15 to 0.20 grams of an Alka-Seltzer tablet (a piece about the size of a pea should be in this range) and record the mass (±0.001 g) on Report Table ANT.2. Carefully transfer the Alka-Seltzer sample into the dry shell vial.

6. Place approximately 6 mL of 3 M HCl solution into the Erlenmeyer flask and carefully slide the shell vial down the side of the flask. It is important that no HCl enter the vial prematurely, or the reaction will begin before your system is closed and ready. Clamp the reaction chamber onto the ring stand, as shown in Figure ANT.1.

Safety Precaution

CAUTION: The hydrochloric acid (HCl) is corrosive and can cause chemical burns and damage to clothes. Handle it with care. Any corrosive chemicals spilled on your skin must be rinsed immediately with water for 15 minutes. Any corrosive chemicals spilled on the lab benches should be neutralized with baking soda, the area rinsed with water and wiped clean. Inform your instructor of any large spills.

7. Adjust the water level in the measuring tube to be between 0 and 15 mL by raising the leveling bulb. When the water level is between 0 and 15 mL, connect the measuring tube to the reaction chamber by inserting the rubber stopper into the reaction chamber. Note that the water levels in the measuring tube and in the leveling bulb are now different. *If they are equal, there is a leak in your system. Correct the leak before continuing.*

8. Raise or lower the leveling bulb to equalize the pressures in the two ends of the system. Record the volume from your measuring tube as the initial volume ($V_{initial}$) for Trial 1 on Report Table ANT.2

9. Initiate the reaction by unclamping the flask and slowly tilting the reaction chamber until the HCl runs into the vial, taking care that the HCl does not go up into the rubber stopper. Be careful not to disconnect the tubing connecting the reaction chamber to the rest of the system. IT IS NOT NECESSARY FOR ALL OF THE ACID TO ENTER THE VIAL. You just need enough to generate the reaction.

10. Observe the reaction and the change in the water level. Once the volume of the water in the measuring tube has stopped changing, equalize the pressures again using the leveling bulb. Read and record the volume from the measuring tube as the final volume (V_{final}) for Trial 1 on Report Table ANT.2

11. Measure the temperature of the water in your leveling bulb and record it in Figure ANT.1 (You only need to record this for the first trial.)

12. Disconnect your reaction chamber, dispose of the contents down the drain, and rinse out the chamber with water. *Next, ensure the vial is dry, and repeat the procedure to obtain a total of two good sets of data.* NOTE:

You are given room for 4 runs in Report Table ANT.2. It is not necessary to complete all four runs - you just need 2 GOOD sets of data.

13. Read the label on the Alka-Seltzer package and confirm the list of ingredients indicated.

14. Disassemble your apparatus and wash the flask and vial.

15. Return the leveling bulb apparatus and vial to the stockroom window. Don't forget your ID card!

Safety Precaution

Dispose of all chemicals in the proper waste container.

Be sure to wash your lab bench after completing the experiment to remove all traces of any spilled chemicals and to eliminate potential hazards for other students.

Data

Report Table ANT.1

Atomospheric pressure, mmHg	____________
Temperature of H_2O, °C	____________
Vapor pressure of H_2O at this temperature	____________
Calculated pressure of CO_2 in the system, mmHg	____________
Average mass of whole Alka-Seltzer tablet given by instructor	____________

Write a balanced reaction of $NaHCO_3$ and HCl.

Report Table ANT.2

Trial	**Run 1**	**Run 2**	**Run 3**	**Run 4**
Mass of sample (g)	____	____	____	____
$V_{initial}$ (mL)	____	____	____	____
V_{final} (mL)	____	____	____	____
V_{total} (mL)	____	____	____	____

Calculations

Report Table ANT.3

Trial	**Run 1**	**Run 2**	**Run 3**	**Run 4**
Moles of CO_2	_____	_____	_____	_____
Moles of $NaHCO_3$	_____	_____	_____	_____
Mass of $NaHCO_3$ in sample (g)	_____	_____	_____	_____
Mass % of $NaHCO_3$ in sample (%)	_____	_____	_____	_____

Average mass % of $NaHCO_3$ in Alka-Seltzer ____________

Show your calculations for Trial 1 below. Submit these calculations with your DATA.

Questions to Consider

1. Write balanced chemical equations for each of the following descriptions:

   a. potassium carbonate reacts with nitric acid

   b. calcium bicarbonate reacts with sulfuric acid

   c. strontium bicarbonate reacts with hydrochloric acid

2. Calculate the mass percent of $NaHCO_3$ based on the manufacturer's list of ingredients: 325 mg aspirin, 1000 mg citric acid, 1916 mg $NaHCO_3$. Use the average mass of a whole tablet provided by your instructor.

   a. Show your calculation for the mass percent of $NaHCO_3$ in a commercial Alka-Seltzer tablet.

   b. Compare this value with the average mass percent of $NaHCO_3$ in your sample of Alka-Seltzer. How close was your experimental value to the mass percent calculated from the ingredients? Explain possible sources of error that could explain any differences.