Effervescence Laboratory Experiment – Instructor's Version

Developed by: Alex Jannini, David Krause, Heather Malino and Kevin Sweeney, Rowan University, Department of Chemical Engineering
Edited by: C. Stewart Slater and Mariano Savelski, Rowan University, Department of Chemical Engineering

Date of Experiment:

OBJECTIVES

- Students will perform a basic mass balance on an effervescence reaction in pharmacology
- Students will conduct theoretical stoichiometric calculations and compare to experimental results
- Students will learn about the equilibrium constants and other fundamental aspects of reactions

INTRODUCTION

Alka-Seltzer® is an effervescent antacid ($NaCO_3$, KCO_3 plus anhydrous citric acid) containing acetylsalicylic acid (aspirin), which is an analgesic, antipyretic, and anti-inflammatory drug. Simply put, Alka-Seltzer® relieves upset stomach, provides pain relief, breaks fevers, and reduces inflammation.

Figure 1. Standard original strength packet

The effervescence allows for a faster rate of drug dissolution into a liquid medium (water in this case) by increasing the surface area of the drug exposed to solution and by "bubbling" the mixture, causing a stirring effect. The effervescence reaction is:

$$C_6H_8O_7(aq) + NaHCO_3(aq) \rightarrow H_2O(l) + CO_2(g) + Na_3C_6H_5O_7(aq) \quad (1)$$

Figure 2. Weighing the tablets

In this lab you will determine how much CO_2 is generated and released to the atmosphere by taking the initial and final weights of an Alka-Seltzer® solution. This is an introduction to mass balances, an important concept for engineers. This experimental value will then be compared to the theoretical amount of CO_2 mass generated, found through stoichiometry.

MATERIALS NEEDED

- 2 Alka-Seltzer® tablets (1 packet)
- Analytical scale (+/- 0.0001 g)
- Weigh boat
- Graduated cylinder
- 200 mL plastic beaker
- Timer

PROCEDURE

1. Make sure safety glasses and examination gloves are on before entering the lab.
2. Remove both Alka-Seltzer® tablets from the packet. If the tablets are broken, be careful to not lose any pieces. How do you think a broken tablet will affect the rate of the tablets dissolving?
3. Place a weigh boat on the scale. Tare the instrument so it calibrates to zero with the added weight of the boat.
4. Weigh the Alka-Seltzer® tablets and record in your notebook.
5. Alka-Seltzer® is supposed to be dissolved in 4 oz. (118.3 mL) of water according to the manufacturer's directions. Using deionized water, measure out this volume of water with a graduated cylinder and add it to the beaker.
6. Weigh the beaker plus the added water and record it in your notebook. This weight plus the weight of the Alka-Seltzer® tablets is your initial weight.

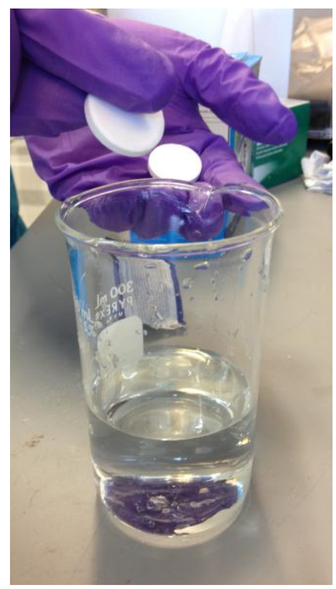

Figure 3. Creating the solution

7. Drop both tablets into the beaker.
8. For the first five minutes, take a weight every 60 seconds. After five minutes have passed, measure the weight every five minutes until an hour has elapsed. Tap the bubbles off of the sides of the beaker as they form.
9. Dispose of the solution down the sink.

PART II

10. Fill the beaker back up with the same amount of deionized water and weigh the water and the beaker.

11. On a weigh boat, measure out 2.0 g citric acid and 3.832 g sodium bicarbonate.
12. Drop the powder into the beaker and record weights at the same time intervals as Part I.
13. Dispose of the solution down the sink and clean up the lab area.

QUESTIONS

1. Fill in the tables shown on the next page:

Solution over time	**Weight**	**Time**
Initial:		0 m
		1 m
		2 m
		3 m
		4 m
		5 m
		10 m
		15 m
		20 m
		25 m
		30 m
		35 m
		40 m
		45 m
		50 m
		55 m
Final:		60 m

Solution over time	**Weight**	**Time**
Initial:		0 m
		1 m
		2 m
		3 m
		4 m
		5 m
		10 m
		15 m
		20 m
		25 m
		30 m
		35 m
		40 m
		45 m
		50 m
		55 m
Final:		60 m

2. You should notice that the initial weights of the two solutions are different.
   a. What may cause this?
   b. To fix this, take the difference between the two sets, find the difference between the two initial points. This difference will need to be subtracted from the solution with the higher weights. Find the new weights and record them in the table below.

Solution over time-Fixed	**Weight**	**Time**
Initial:		0 m
		1 m
		2 m
		3 m
		4 m
		5 m
		10 m
		15 m
		20 m
		25 m
		30 m
		35 m
		40 m
		45 m
		50 m
		55 m
Final:		60 m

c. Please graph the revised data set along with the other set that was not changed.

3. Determine the experimental amount of CO_2 generated and released to the atmosphere by subtracting the initial weight from the final weight.

4. Balance the reaction given in the beginning of the laboratory.

5. According to the manufacturer's website, each tablet contains 1000 mg of citric acid and 1916 mg of sodium bicarbonate. Determine the moles of each reactant.

6. Determine which reactant is the limiting reactant. What is the percent excess? Why do you think there is extra added?

7. Using the effervescence reaction given in the beginning of the lab, determine the moles produced of CO_2 gas.

8. How many milligrams of CO_2 were made in both reactions?

9. What is the theoretical final weight of each solution? Use the weight of the beaker and water measured in the lab.

10. Determine your percent error at each point with the given equation:

$$\%_{Error} = \left(\frac{\left(M_{theoretically\ lost} - \left(M_{experimental}^{inital} - M_{experimental}^{point\ in\ time}\right)\right)}{M_{theoretically\ lost}}\right) x\ 100 \qquad (3)$$

11. What were some sources of error in this lab?

12. Was there if a difference in the way the pure components dissolved versus the tablets? Why do you think they behaved the same/differently? Do you think that the use of milling the powders when forming the tablets adds into the difference in behavior?

13. What is a different way that this experiment can be designed so that the gas released could be directly measured?

14. When designing a reactor, chemical engineers must take into consideration reaction equilibria. The equilibrium constant, Kc, can be used to determine the extent of a reaction at equilibrium. For a given constant temperature reaction at equilibrium:

$$\propto\ A_{(aq)} + \beta B_{(aq)} \leftrightarrow \gamma C_{(aq)} + \delta D_{(aq)}$$

an equilibrium constant can be calculated using the formula:

$$K_c = \frac{[C]^{\gamma}[D]^{\delta}}{[A]^{\propto}[B]^{\beta}}$$

Where [A], [B], [C], and [D] represent the equilibrium concentrations of each component, usually in molarity (mol/L). Pure liquids, like water, and solids are not taken into consideration when determining an equilibrium constant. For example, for the reaction:

$$HCl_{(aq)} + NaOH_{(aq)} \leftrightarrow NaCl_{(aq)} + H_2 0_{(l)}$$

The equilibrium constant, Kc, would be:

$$K_c = \frac{[NaCl]^1}{[HCl]^1[NaOH]^1}$$

Using data collected, an engineer or chemist can determine the value of Kc by using a RICE (Reagent, Initial Concentration, Change in Concentration, Equilibrium Concentration) table. A RICE table shows the initial and equilibrium concentrations of a chemical reaction. For the reaction,

$$\propto A_{(aq)} + \beta B_{(aq)} \leftrightarrow \gamma C_{(aq)} + \delta D_{(aq)}$$

a generic rice table would look like

R	A	B	C	D
Initial	X M	Y M	0	0
Change	-(α)x(z M)	-(β)x(z M)	+(γ)x(z M)	+(δ)x(z M)
Equil.	X - (α)x(z) M	Y -(β)x(z M)	+(γ)x(z M)	+(δ)x(z M)

Where X is your initial concentration of component A, Y is your initial concentration of component B, z is the concentration of reactants used up during the reaction, in molarity. For example, using the reaction above, a process starts out with 1 M of HCl and 1 M of NaOH. At equilibrium the concentration of NaCl is .98M. Using a RICE table, the amount of each component can be determined.

R	HCl	NaOH	NaCl
Initial	1.0M	1.0M	0
Change	-(1)x(.98M)	-(1)x(.98M)	+(1)x(.98M)
Equil.	.02M	.02M	.98M

a. If you were designing a reactor for the balanced effervescence reaction from Question 3, what would your equilibrium constant equation look like?
b. Using the data obtained from Part II of the experiment, create a RICE table, assuming that the reaction reaches equilibrium after 1 hour. Assume no water leaves the system.
c. Calculate the Kc at room temperature. Is Kc above or below 1.0? Comment on what that means about which is favored, reactants or products.

ANSWER KEY

1. Fill in the table:
   Ans: Data will vary depending on the team. However, the table should have data similar to the set shown below:

Solution over time	**Weight**	**Time**
Initial:	123.1220	0 m
	122.4068	1 m
	122.2695	2 m
	122.2130	3 m
	122.1810	4 m
	122.1624	5 m
	122.1017	10 m
	122.0683	15 m
	122.0376	20 m
	122.0133	25 m
	121.9917	30 m
	121.9694	35 m
	121.9462	40 m
	121.9228	45 m
	121.8983	50 m
	121.8742	55 m
Final:	121.8485	60 m

Solution over time	**Weight**	**Time**
Initial:	119.9593	0 m
	119.7013	1 m
	119.4425	2 m
	119.3279	3 m
	119.2654	4 m
	119.2233	5 m
	119.1223	10 m
	119.0740	15 m
	119.0437	20 m
	119.0232	25 m
	119.0066	30 m
	118.9913	35 m
	118.9780	40 m
	118.9654	45 m
	118.9531	50 m
	118.9412	55 m
Final:	118.9294	60 m

2. You should notice that the initial weights of the two solutions are different.
   a. What may cause this?
      Ans: This may be due to the aspirin in the Alka-Seltzer® tablets. However, this would only account for roughly 0.6 g of difference. The other difference in mass could be due differences in the volume of water. Human error could have led to the difference in water volume between the two trials.
   b. To fix this, take the difference between the two sets, find the difference between the two initial points. This difference will need to be subtracted from the solution with the higher weights. Find the new weights and record them in the table below.

Ans: The difference found between the two starting points was 3.163 g. The first trial (Alka-Seltzer® tablets) had to have this difference subtracted from all points taken during experimentation. Below is the corrected data set.

Solution over time-Fixed	**Weight**	**Time**
Initial:	119.9593	0 m
	119.2441	1 m
	119.1068	2 m
	119.0503	3 m
	119.0183	4 m
	118.9997	5 m
	118.9390	10 m
	118.9056	15 m
	118.8749	20 m
	118.8506	25 m
	118.8290	30 m
	118.8067	35 m
	118.7835	40 m
	118.7601	45 m
	118.7356	50 m
	118.7115	55 m
Final:	118.6858	60 m

c. Please graph the revised data set along with the other set that was not changed.
Ans: The following graph was made using the fixed Alka-Seltzer® data and the pure components.

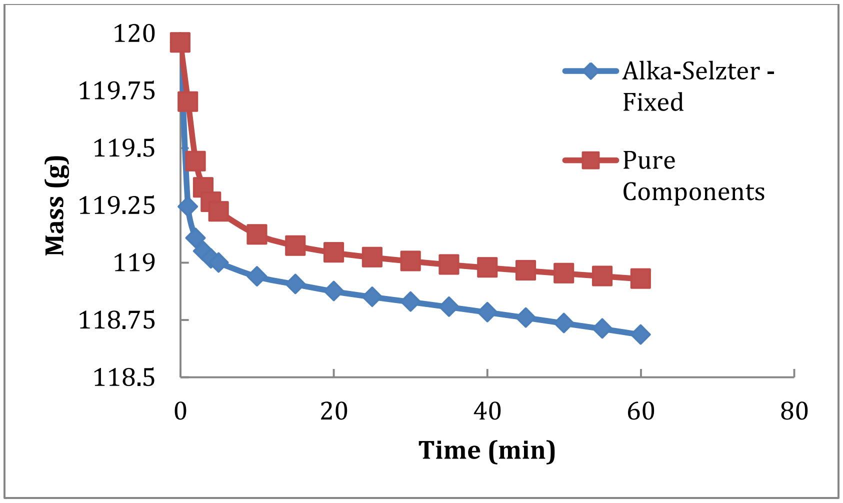

Figure 4. Mass lost over time during the effervescence reactions.

3. Determine the experimental amount of CO_2 generated and released to the atmosphere by subtracting the initial weight from the final weight.
Ans: With the data obtained above for part I, it was determined that the mass lost was 1.36 grams.

$$148.501 - 147.14 = 1.36\ g$$

The amount of mass lost in Part II was 0.338 grams.

$$145.504\ g - 145.166\ g = 0.338\ g$$

4. Balance the reaction given in the beginning of the laboratory.
Ans:

$$C_6H_8O_{7(aq)} + 3NaHCO_{3(aq)} \rightarrow 3H_2O_{(l)} + 3CO_{2(g)} + Na_3C_6H_5O_{7(aq)}$$

5. According to the manufacturer's website, each tablet contains 1000 mg of citric acid and 1916 mg of sodium bicarbonate. Determine the moles of each reactant by converting each mass.
Ans:

$$(1\ g)\left(\frac{1\ mol}{192.124\ g}\right) = 5.21x10^{-3}\ moles\ citric\ acid$$
$$(1.916\ g)\left(\frac{1\ mol}{84.007\ g}\right) = 2.28x10^{-2}\ moles\ NaHCO_3$$

6. Determine which reactant is the limiting reactant. How much of the other reactant is left over? Why do you think there is extra added?

   Ans:

$$(5.21x10^{-3} mols\ of\ citric\ acid)\left(\frac{3\ mols\ NaHCO_3}{1\ mol\ citric\ acid}\right)$$
$$= 1.563x10^{-2}\ moles\ of\ NaHCO_3\ required$$

Therefore, citric acid is the limiting reactant

$$0.0228\ mol\ total - 0.01563\ mol\ required = 0.00717\ mol\ remaning$$

   There is extra sodium bicarbonate added. In addition to driving the reaction, it also acts as an antacid when it enters the stomach.

7. Using the effervescence reaction given in the beginning of the lab, determine the moles produced of CO_2 gas.
   Ans:

$$(5.21x10^{-3} mols\ of\ citric\ acid)\left(\frac{3\ mols\ CO_2}{1\ mol\ citric\ acid}\right)$$
$$= 1.563x10^{-2}\ moles\ of\ CO_2\ produced$$

8. How many milligrams of CO_2 are made in this reaction?
   Ans:

$$(1.563x10^{-2} mols\ CO_2)\left(\frac{44010\ mg}{1\ mol\ CO_2}\right) = 687.8763\ mg\ theoretically\ lost$$

9. What is the theoretical final weight of the solution? Use the weight of the beaker, water, and tablets measured in the lab.
   Ans:
   Part I

$$(116.6280\ g) + \left[6.4940\ g - \big((0.68788\ g)(2\ tablets)\big)\right] = 121.75\ g$$

   Part II

$$(114.1293\ g) + \left[\ 5.8300 g - \big((0.68788\ g)(2\ tablets)\big)\right] = 118.58\ g$$

10. Determine your percent error at each point with the given equation:
    Ans: A sample calculation for this is shown. Using this, the table was filled out:

$$\%_{Error} = \left(\frac{\left(M_{theoretically\ lost} - \left(M_{experimental}^{inital} - M_{experimental}^{point\ in\ time}\right)\right)}{M_{theoretically\ lost}}\right) x\ 100$$

$$\%_{Error} = \left(\frac{\left(1.376\ g - (123.1220\ g - 121.8485\ g)\right)}{1.376\ g}\right) x\ 100 = 7.433$$

Time (min)	Alka-Seltzer difference from theoretical	Pure difference from theoretical
0	100	100
1	48.014	81.247
2	38.034	62.435
3	33.927	54.105
4	31.601	49.562
5	30.249	46.502
10	25.837	39.161
15	23.410	35.650
20	21.178	33.448
25	19.412	31.958
30	17.842	30.751
35	16.221	29.639
40	14.535	28.672
45	12.834	27.756
50	11.053	26.862
55	9.3010	25.997
60	7.4330	25.140

A graph of this was made:

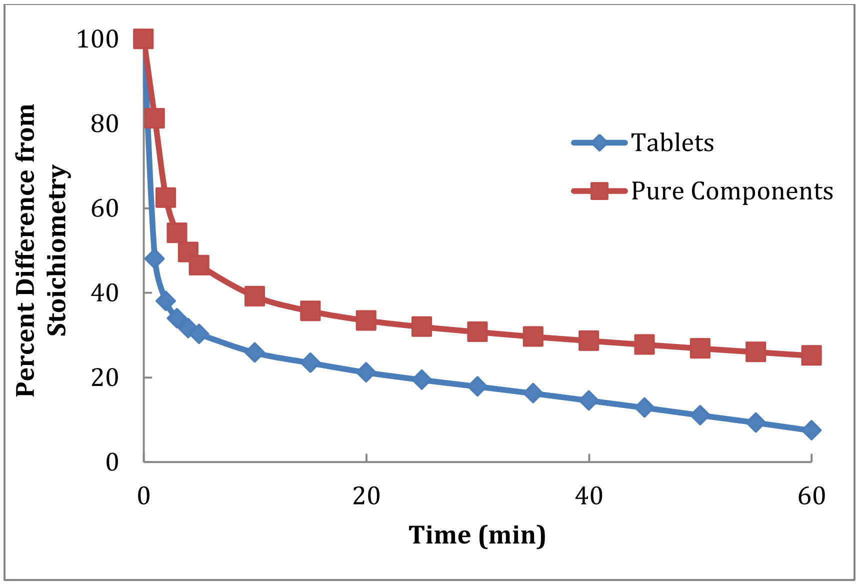

Figure 5. The percent difference from stoichiometry seen in the effervescence reaction.

11. What were some sources of error in this lab?
    Ans. Some sources of error in this lab include (most obviously) not all of the CO_2 leaving solution. In addition, a portion of CO_2 could have been absorbed by the water, as described by Henry's Law. The addition of aspirin (an acid) could have had some effect on the pH of the system, which could affect the rate and extent of the reaction. The pure powder may have not been well-mixed, which may have caused the reaction to not occur in optimal conditions.
12. Was there if a difference in the way the pure components dissolved versus the tablets? Why do you think they behaved the same/differently? Do you think that the use of milling the powders when forming the tablets adds into the difference in behavior?
    Ans: The pure components will dissolve at a much slower rate if not properly mixed. It is not specified in the procedure to thoroughly mix the components together, so it is expected of students to realize why this case dissolves slower. The milling of the powder, the first step listed in the Handbook of Pharmaceutical Manufacturing Formulations[1] for the creation of effervescent tablets, will of course affect the behavior of the reaction. Milling the powder creates particles of smaller size, and the smaller the particle, the greater the surface area for the reaction to take place. Since the powder is finer in the tablets, the powder will dissolve quicker, which is shown above in Question 10.
13. What is a different way that this experiment can be designed so that the gas released could be directly measured?
    Ans: If the reaction is carried out in a container that has a flow meter attached to it than the amount of CO_2 released can be directly

measured. A similar, but more crude method, would be to attach a balloon to the top of a flask then estimate the volume occupied by the gas and density of CO_2 at experimental conditions to find a mass released

14. When designing a reactor, chemical engineers must take into consideration reaction equilibria.
a) If you were designing a reactor for the balanced effervescence reaction from Question 3, what would your equilibrium constant equation look like?
Ans: The following reaction is what we will model in the equilibrium equation:

$$C_6H_8O_7(aq) + 3NaHCO_3(aq) \rightarrow 3H_2O(l) + 3CO_2(g) + Na_3C_6H_5O_7(aq)$$

So, our equilibrium equation is:

$$K_c = \frac{[CO_2]^3[Na_3C_6H_5O_7]^1}{[C_6H_8O_7]^1[NaHCO_3]^3}$$

b) Using the data obtained from Part II of the experiment, create a RICE table, assuming that the reaction reaches equilibrium after 1 hour. Assume no water leaves the system. Make sure all concentrations are in the units of M (mol/L).
Ans: We will conduct this RICE table experiment for part II, as it was the trial that seemed to reach equilibrium over part I. To begin, we find molar concentrations of citric acid and sodium bicarbonate using the molar mass. An example using citric acid is shown below:

$$moles_{\ C_6H_8O_7} = \frac{mass_{C_6H_8O_7}}{molar\ mass_{C_6H_8O_7}} = \frac{2.0003\ g}{192.124\ {}^{g}/_{mol}} = 0.0104\ mol$$

$$Concentration = C_{C_6H_8O_7} = \frac{mol_{C_6H_8O_7}}{volume} = \frac{0.0104\ mol}{0.1183\ L} = 0.0880\ M$$

Then, the RICE table looks as such:

R	$C_6H_8O_7$	$NaHCO_3$	CO_2	$Na_3C_6H_5O_7$
I	0.0880	0.3856	0.0000	0.0000
C	-	-	-	-
E	-	-	-	-

Now, determine how much CO_2 was generated. Do this by determining the loss in mass throughout the session, which is assumed to be how much CO_2 was generated. Then, that is converted into concentration:

$$mass_{CO_2} = m_{CO_2} = mass\ start - mass\ finish$$

$$= 119.9593\ g - 118.9294\ g = 1.0299\ g$$

$$C_{CO_2} = \frac{m_{CO_2}/_{molar\ mass}}{volume} = \frac{1.0299\ g/_{44.01\ g/_{mol}}}{0.1183\ L} = 0.1978\ M$$

This is how much CO_2 was created during the reaction. From stoichiometry, we know this is how much sodium bicarbonate was lost during the reaction. We can also determine the amount of citric acid lost and the amount of sodium citrate created through stoichiometry:

$$C_6H_8O_{7\,lost} = Na_3C_6H_5O_{7\,created} = \frac{1}{3}\,C_{CO_2} = \frac{1}{3}0.1978M = 0.0660\ M$$

With this information, we can fill in the “C” row of the RICE table:

R	$C_6H_8O_7$	$NaHCO_3$	CO_2	$Na_3C_6H_5O_7$
I	0.0880	0.3856	0.0000	0.0000
C	-0.0660	-0.1978	0.1978	0.0660
E	-	-	-	-

Lastly, to determine the “E” row, you take the “C” row and add to the “I” row, as seen below for citric acid:

$$C_6H_8O_{7_E} = C_6H_8O_{7_I} + C_6H_8O_{7_C} = 0.0880\text{ M} - 0.0660\text{ M} = 0.0220\text{ M}$$

This gives:

R	$C_6H_8O_7$	$NaHCO_3$	CO_2	$Na_3C_6H_5O_7$
I	0.0880	0.3856	0.0000	0.0000
C	-0.0660	-0.1978	0.1978	0.0660
E	0.0220	0.1878	0.1978	0.0660

c) Calculate the Kc at room temperature. Is Kc above or below 1.0? Comment on what that means about which is favored, reactants or products.
Ans: Using the RICE table and the equilibrium equation, we get the following:

$$K_c = \frac{[CO_2]^3[Na_3C_6H_5O_7]^1}{[C_6H_8O_7]^1[NaHCO_3]^3} = \frac{[0.0649]^3[0.0216]^1}{[0.0224]^1[0.1279]^3}$$
$$K_c = 0.1266$$

We see here that the equilibrium constant is below 1.0. This means that the reaction favors the reactants. This means that there are more reactants than products.

REFERENCES

1. Niazi, S.K. Handbook of Pharmaceutical Manufacturing Formulations: Compressed Solid Products. Volume One. 2009. New York. INFORMA Healthcare USA, Inc.