Survey of General, Organic and Biochemistry
Laboratory No 5
CHM 108L-01
Spring 2020

Heartburn, Gas Bloating and Indigestion?

A teaching experiment produced by

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Concepts to explore in this lab:

- Acid – base reaction
- Excess and limiting reactant
- Reaction rate
- Order of the reaction
- Effect of temperature on the reaction rate
- Ideal gas equation
- Stoichiometry
- Activation Energy

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Acid-base reactions are very common reactions that we carry out every day without knowing it; for example, when you take TUMS, the calcium carbonate in it acts as a base and reacts with the acid in your stomach. Acids are characterized by releasing protons, H^+, and bases are characterized by accepting protons when dissolved in water. When an acid reacts with a base in stoichiometric amounts, the reaction is called neutralization and not acid nor base remains in solution; the products of this reaction are a salt and water (see example below).

$$\underset{\text{Acid}}{HNO_{3(aq)}} + \underset{\text{Base}}{KOH_{(aq)}} \rightarrow \underset{\text{Salt}}{KNO_{3(aq)}} + \underset{\text{Water}}{H_2O_{(l)}}$$

Chemical reactions occur at different rates, some happen in milliseconds and some take days or even years. Several factors affect the rate of a chemical reaction, among these are:

a. The concentration of reactants
b. Temperature
c. Presence of catalysts
d. The physical state of reactants
e. Pressure (for reactions involving gases).

For the reaction **aA + bB → cC +dD**, the rate of a reaction can be described by the following equations:

Eq 1. $$\boldsymbol{Rate = -\frac{1}{a}\frac{\Delta[A]}{\Delta t} = -\frac{1}{b}\frac{\Delta[B]}{\Delta t} = +\frac{1}{c}\frac{\Delta[C]}{\Delta t} = +\frac{1}{d}\frac{\Delta[D]}{\Delta t}}$$

Eq 2. $$\boldsymbol{Rate = \kappa[A]^x[B]^y}$$

In the first equation, the rate is defined by the change of the concentration of either the reactants or products in time; the negative sign means that the concentration of reactants decreases in time (being consumed) and the positive sign means the concentration of the products increases in time (being produced). In the second equation, [A] and [B] are the concentrations of the reactants **A** and **B**, $\boldsymbol{k}$ is the rate constant, and **x** and **y** are the orders of the reaction with respect to **A** and **B**, respectively. The order of the reaction with respect to a reactant tells you if the rate depends on its concentration; for instance, if **x=0** the rate of the reaction does not depend on the concentration of **A** or if **x=2** the rate of the reaction doubles when the initial concentration of **A** increases. The values for the reaction rate, reaction orders and the rate constant are typically found experimentally.

The rate constant $\boldsymbol{k}$ depends on the temperature according to the following equation:

Eq 3. $$\boldsymbol{k = A'e^{-\frac{E_a}{RT}}}$$

where $\mathbf{A'}$ represents the number of collisions per second (molecules must collide to react!); $\boldsymbol{E_a}$ is the activation energy (J/mol unit), which is the amount of energy the reactants must overcome to become products; R is a constant with a value of 8.314 J/(K·mol); and T is the temperature (in Kelvin).

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PART ONE

Pre-experiment Questions (write answers on your notebook)

1. Find on the web, the active ingredients of the original/regular Alka-Seltzer. Draw the Lewis structure and write the chemical formula (condensed) for each of the active ingredients and classify them as an acid or a base.
2. Identify which of the active ingredients are inorganic and which ones are organic compounds. Identify the functional groups present in the structure of the organic compounds.
3. Find the molar mass for the active ingredients and then calculate the number of moles for each in every pill of Alka-Seltzer.
4. Find on the web the definition for activation energy and find the graphs energy vs reaction progress for both an endo- and exothermic reactions, draw them in your notebook.
5. Analyzing Eqs. 2 – 3, given in the background, how do you expect temperature changes will affect the rate of the reaction?

General Protocol (Read entire protocol before starting the experiment)

<u>Alka-Seltzer reaction:</u>

- Take a packet of Alka-Seltzer which contains two tablets. Write down the brand, list of active ingredients and their amounts.
- Open the packet and take the tablets out of it; then, measure the mass of the two tablets together using a weighing paper.
- Over the weighing paper, break the pills is small pieces such that they fit in the mouth of a 12” balloon. Insert all the pieces of Alka-Seltzer in the balloon and push them in.
- Add approximately 75 mL of water to an Erlenmeyer with a capacity of 100 mL and measure the temperature of the water.
- Carefully, attach the mouth of the balloon to the mouth of the Erlenmeyer keeping the Alka-Seltzer in the balloon.
- Find a flat surface (i.e. a wall) in the lab and tape a piece of millimeter graph paper to it.
- Place the Erlenmeyer in front of the graph paper such that when the balloon gets inflated, you can measure the diameter of the balloon using the graph paper (as shown in the scheme to the right).
- When you have the setup for the reaction ready, pick the balloon up so the pieces of Alka-Seltzer will go in the water; as soon as the reaction begins, start recording the reaction using your cellphone. Keep the camera still and as straight as possible.

Scheme 1. Experimental setup.

<u>Balloon-diameter measurements:</u>

- Download the Alka-Seltzer reaction video to your computer and open it using any software suitable to play videos.
- Advance the video to the first 15 or 21 seconds and take a snapshot or print the screen (ctrl prt scr), copy this to a PowerPoint slide and label it 15 or 20 seconds.
- In the ppt, crop the picture as shown in figure 1 and make it larger so you can see the scale, insert a line and draw it on top of the balloon (edge to edge) in the center of it.
- Move the line up and find the length of the line using the graph paper as shown in Figure 1.

- Then, advance the video 3 seconds, take a snapshot or print the screen (prt scr) and measure the diameter again as you did before. Repeat this process until you get at least 8 values for the diameter.

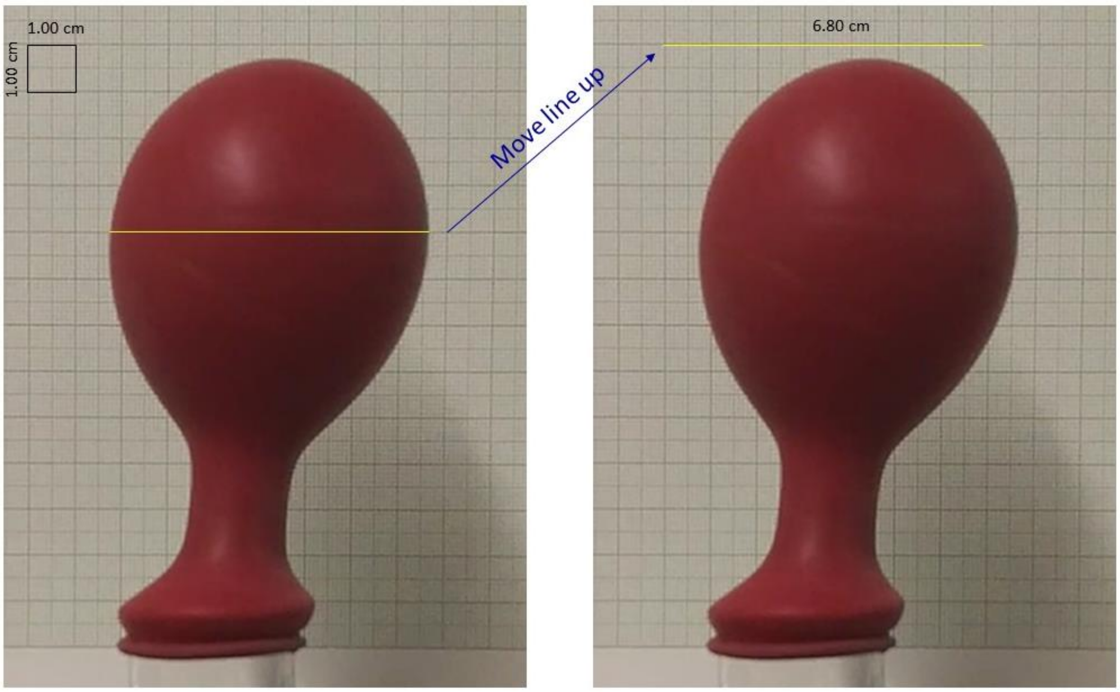

Figure 1. Measurement balloon diameter at 15 seconds after the reaction starts.

<u>Mass measurements:</u>

- Go to the analytical balance that is closer to your bench and press the Tare button to make the balance go to zero (0.000 g).
- If you want to measure the mass of:
  - a powder or granular solid, you can use a watch glass to hold the solid;
  - a liquid, you can use a small beaker or small graduated cylinder to hold the liquid;
  - an object, you can place it directly on the balance plate.
- For **a solid**, open the side or top doors of the balance and place the watch glass in the center, then close the door and tare the balance to get zero. Open the doors and using a spatula start placing the powder or granular solid on the watch glass (do it carefully to avoid spills) until you reach the desired weight. Then close the doors and write in your notebook the number in the digital screen of the balance.
- For **a liquid**, open the side or top doors of the balance and place the empty container (i.e. beaker or graduated cylinder) in the center of the balance, then close the door and write in your notebook the number in the digital screen of the balance. Then, pour the amount of liquid required into the **pre-weighed** container and place it on the balance plate (make sure the balance was zeroed before your measurement). Write the number in your notebook. To find the mass of the liquid, you subtract the mass of the container from the mass of the container with the liquid.
- For a **compact solid or an object**, you can just place the object directly in the balance (make sure the balance is zeroed).

(note: be careful not to spill anything inside the balance, if you do please notify your instructor)

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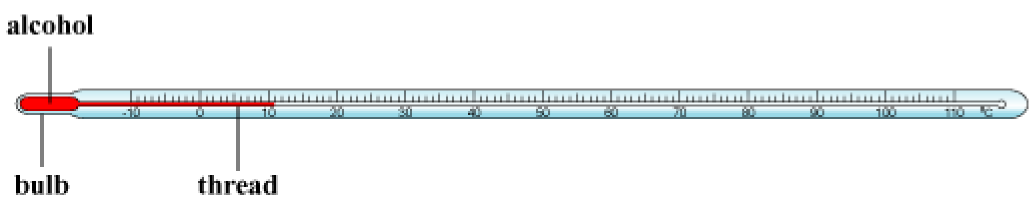
Spring 2020

Temperature measurements:

- Use a thermometer to measure the temperature of:
  - a liquid, to do that you must fully immerse the bulb (without touching the walls of the container) in the liquid and wait until the temperature becomes constant. (note: the red liquid in the thermometer will move up or down but it will stop flowing when it reaches the temperature of the liquid). With the bulb still in the liquid, read the temperature by looking at the mark in the thermometer that matches with the top of the red liquid.
  - the environment, to do that you must hold the thermometer in the air and make sure nothing touches the bulb. Read the temperature by looking at the mark in the thermometer that matches with the top of the red liquid.



Experiment

Temperature effect on reaction rate:

6. Discuss numerals 1-5 with your partner and then with another group. Then discuss with the entire class.
7. Carry out the Alka-Seltzer reaction using water at room temperature (follow the general protocol for the reaction) and write your observations.
8. Similarly, carry out the Alka-Seltzer reaction using water at a temperature below room temperature (at least 10 degrees below) and write your observations.
9. Finally, carry out the Alka-Seltzer reaction using water at a temperature higher than room temperature (at least 10 degrees above) and write your observations.
10. Measure the pH of one of the resulting solutions and dispose of all the solutions in the waste container.

Thinking About the Data

11. Write down the balanced chemical equation of the reaction that is happening as you dissolve the Alka-Seltzer tablets in water. (Note: use Lewis structures for the organic compounds)
12. Find the limiting and excess reactants for the reaction in numeral 11; base your calculations on the number of moles you found in numeral 3.
13. Calculate the number of moles of CO_2 gas you will produce if the Alka-Seltzer reaction will go to completion (use the balanced chemical equation and the limiting reactant). Then, calculate the volume of CO_2 that you expect to be produced by using the ideal gas equation PV=nRT $\left(R = 0.08216\frac{atm*L}{mole*K}\right)$. *(Note: make sure you use the correct units for the variables in the ideal gas equation, assume the temperature is 298.15K)*
14. What type of reaction is the one from numeral 11? Explain.
15. For the reaction carried out in numeral 7, find how the diameter of the balloon changes in time (see general protocol). Using the value of the diameter, calculate the radius of the balloon, $r = \frac{diameter}{2}$, and with that value you can calculate the volume of the balloon assuming the balloon is a sphere

$\left(V_{sphere} = \frac{4}{3}\pi r^3\right)$. Since CO_2 is a gas, the volume of the balloon is the volume of the gas $\left(V_{sphere} = V_{CO_2\,gas}\right)$. Collect the data for the time, diameter, radius and volume in the following table:

Table No 1. Alka-Seltzer reaction at a **T= ____ ºC**

Time (s)	Diameter (cm)	Radius (cm)	Volume (L)	Moles CO_2
15				
18				
21				
24				
27				
30				
33				
36				

16. Using the calculated volume of gas from numeral 15, calculate the number of moles of CO_2 produced at different times employing the ideal gas equation PV=nRT. *(Note: make sure you use the correct units for the variables in the ideal gas equation, assume the temperature is 298.15K)*
17. Repeat numerals 15-16 for the reactions at the other two temperatures (numerals 8 & 9), and create Tables No 2 & 3 for the data of those two reactions and specify the temperature in the table's title.
18. Create **one plot** of the number of moles of CO_2 (y-axis) vs time (x-axis) using the data for the three reactions. You can create the plot using Google Spreadsheets, Excel, Origin or any programming language you may know. If you have never created a plot, you can use this template prepared by your professor using Google Spreadsheets. **Before you do any modifications to it, make a copy of the spreadsheet** (File → Make a Copy) and save it as **Graph1_your initials_your partner's initials.** Then, you will just have to change the values for time and number of moles in that template; to do this, you can select all data and then press the key delete in your keyboard. After that, you can enter the values that you have in Tables 1-3 and the plot will appear again. Copy and paste your graph here for the lab report.
19. Analyze the plot and write your observations in detail about the differences and similarities between the three curves which represent the CO_2 production in time from the Alka-Seltzer reaction at different temperatures.
20. Copy the first four data points for the time and the number of moles of CO_2 (for the three reactions) to this second Google Spreadsheet template. The template is already set up to fit the points to a line, this is called a linear fit; for each curve, the linear fit produces an equation for a line of the form:

$$\boldsymbol{y = m * x + b}$$

Where $\boldsymbol{m}$ is the slope and $\boldsymbol{b}$ is the intercept. The slope represents $\frac{\Delta y}{\Delta x}$; in this case, Δy represents the change in the number of moles and Δx represents the time interval. Therefore, the units of the slope are $\frac{moles\ of\ CO_2}{seconds}$; and represents the rate of production of CO_2 at different temperatures. Complete the following table:

Temperature (K)	Slope $\left(\frac{moles\ of\ CO_2}{seconds}\right)$	Intercept	R^2

The value of R^2 tells us if the linear fit is appropriate for the experimental data points. If you get a number for R^2 between 0.90 and 1.0, it means the data points follow the linear trend.

21. Let's compare the slopes, the slope of the curve represents the rate of the reaction; therefore, if we calculate the ratio between two slopes for two reactions at different temperatures, the value of the ratio can show us how the reaction rate is affected by the temperature.

    So, you will first find the ratio of $\frac{Slope_{T_2}}{Slope_{T_1}}$ and then the ratio between $\frac{Slope_{T_3}}{Slope_{T_1}}$. After you find these ratios, discuss how the temperature affects the rate of the Alka-Seltzer reaction.

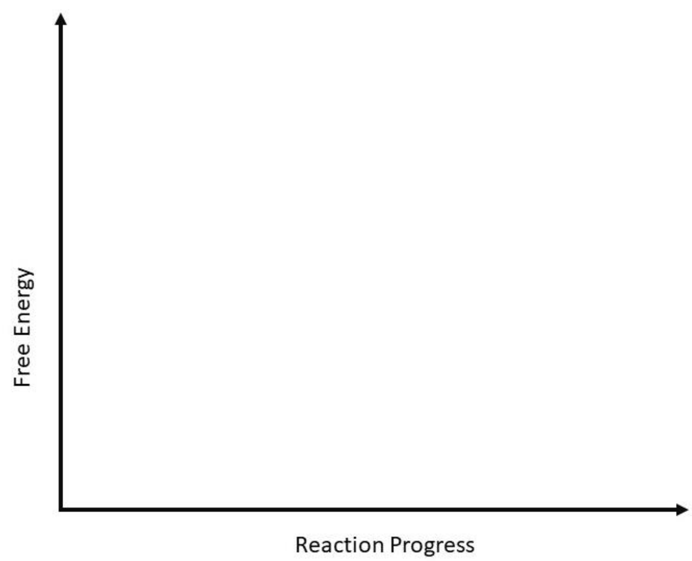
22. Calculate the activation energy for the reaction using the following equations (see appendix to find the derivation of these equations):

$$22a. \qquad E_{a12} = -\frac{ln\left(\frac{Slope_{T_2}}{Slope_{T_1}}\right) \times R}{\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

$$22b. \qquad E_{a23} = -\frac{ln\left(\frac{Slope_{T_3}}{Slope_{T_2}}\right) \times R}{\left(\frac{1}{T_3} - \frac{1}{T_2}\right)}$$

    Then, find the average value for the activation energy, $\overline{E_a} = E_{a12} + E_{23}$, **if and only if the numbers are relatively close to each other**. Otherwise do not do this average calculation.

23. Watch this video to figure out if the Alka-Seltzer reaction is endothermic or exothermic. After that, draw the energy diagram for this reaction. You can use the following template; in it, indicate reactants, products and activation energy with its average value.



24. Write three conclusions of what you learnt in this laboratory (around 250 words). Base your conclusions on the concepts we explored in this lab and your observations.

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Appendix

i. Writing the rate equation for each reaction using Eq 2.:

- $Rate_{T_1} = k_{T_1} * [acid]^x * [base]^y$
- $Rate_{T_2} = k_{T_2} * [acid]^x * [base]^y$
- $Rate_{T_3} = k_{T_3} * [acid]^x * [base]^y$

ii. Taking the ratio between Rates. The $[acid]^x * [base]^y$ in the numerator and denominator cancel out.

- $\frac{Rate_{T_2}}{Rate_{T_1}} = \frac{k_{T_2}*[acid]^x*[base]^y}{k_{T_1}*[acid]^x*[base]^y} = \frac{k_{T_2}}{k_{T_1}}$
- $\frac{Rate_{T_3}}{Rate_{T_2}} = \frac{k_{T_3}*[acid]^x*[base]^y}{k_{T_2}*[acid]^x*[base]^y} = \frac{k_{T_3}}{k_{T_2}}$

iii. Replacing the Rates by the slope from graph#2 (moles of CO_2 vs time) and the constants k by the expression in Eq 3.:

- $\frac{Slope_{T_2}}{Slope_{T_1}} = \frac{A'e^{-\frac{E_a}{RT_2}}}{A'e^{-\frac{E_a}{RT_1}}} = \frac{e^{-\frac{E_a}{RT_2}}}{e^{-\frac{E_a}{RT_1}}} = e^{-\frac{E_a}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)}$
- $\frac{Slope_{T_3}}{Slope_{T_2}} = \frac{A'e^{-\frac{E_a}{RT_3}}}{A'e^{-\frac{E_a}{RT_2}}} = \frac{e^{-\frac{E_a}{RT_3}}}{e^{-\frac{E_a}{RT_2}}} = e^{-\frac{E_a}{R}\left(\frac{1}{T_3}-\frac{1}{T_2}\right)}$

iv. Taking natural logarithm on both sides of the previous equation:

- $ln\left(\frac{Slope_{T_2}}{Slope_{T_1}}\right) = -\frac{E_a}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$
- $ln\left(\frac{Slope_{T_3}}{Slope_{T_2}}\right) = -\frac{E_a}{R}\left(\frac{1}{T_3}-\frac{1}{T_2}\right)$

v. Rearranging the equation to find the value of E_a:

- $E_a = -\frac{ln\left(\frac{Slope_{T_2}}{Slope_{T_1}}\right) \times R}{\left(\frac{1}{T_2}-\frac{1}{T_1}\right)}$
- $E_a = -\frac{ln\left(\frac{Slope_{T_3}}{Slope_{T_2}}\right) \times R}{\left(\frac{1}{T_3}-\frac{1}{T_2}\right)}$