Lab 4: Stoichiometry and Green Chemistry

Goals:
- Learn about the philosophy of green chemistry
- Determine the composition of a mixture using stoichiometry
- Learn what is important in a good laboratory report

Introduction

Green chemistry seeks to reduce the use and generation of hazardous material through control of the design and processes of chemical synthesis. Green chemistry, the use of chemistry for pollution prevention, is distinct from environmental chemistry which focuses on pollution mitigation. Green chemistry has the power to transform all areas of chemistry into a far safer enterprise, while simultaneously challenging widely held perceptions that chemistry on the large scale is a polluting, “dirty” industry and a drain on limited natural resources.

Many experiments used in student laboratory courses are not “green.” Some use toxic materials, others create excess waste, and still others use unnecessary amounts of natural resources. Some might do all three or may violate other tenets of green chemistry. A green chemistry approach to teaching laboratory chemistry meets the same goals as a more traditional approach. Students still do experiments that teach the same concepts, techniques, and skills, but the experiments use green materials and processes.

In this experiment, you will learn about the mass and mole relationships of reactants and products in a chemical reaction, and you will practice communicating with other students in the laboratory both orally and in writing in the way that scientists do. The experiment has been designed in accordance with green chemistry principles. All solid wastes produced in this experiment will be collected and used again next semester for the same experiment. The only gaseous wastes generated by the reaction in the experiment are carbon dioxide and water, which are not harmful.

Green chemistry is based on twelve overarching principles. Three of these principles are addressed in this experiment. Prevention is an extremely important part of the green chemistry philosophy. One of the main things that distinguishes green chemistry from the environmental chemistry of the past is the latter’s focus on treatment and cleanup of waste after it is created. Very often, current (non-green) cleanup efforts involve merely placing hazardous waste in containers for indefinite storage or simply diluting them with water or other safe substances and then releasing them into the environment. Frequently these policies of containment and dilution fail because of spills, long-term build-up of toxic materials in the environment, and other problems. By contrast, green chemistry emphasizes the crucial role of prevention as an easier, cheaper and ultimately safer way of avoiding harm from chemical waste. After all, if hazardous waste is never created, then it never has to be stored, treated, or otherwise dealt with. There are often many different ways of creating a chemical
to serve a particular purpose. Green chemists consider all the alternatives available, and the long-term effects of each alternative, before selecting a chemical reaction to carry out.

**Atom economy** is a very important measure used in assessing how “green” a chemical process is. Although the atom economy calculation is usually applied to organic synthesis processes, it can be calculated for any chemical reaction. All chemical reactions have the form

\[ \text{Reactants} \rightarrow \text{Products} \]

The products of the reaction can either be desired products or undesirable waste. Green chemistry seeks to minimize undesirable waste (or not generate it in the first place, if possible). You can think of a reaction instead as

\[ \text{Reactants} \rightarrow \text{(Desirable Products)} + \text{(Undesirable Waste)} \]

The atom economy calculation measures what part of the original input is converted to desirable products. In essence, atom economy measures how well the process conserves input.

\[
\text{Atom economy} = \left( \frac{\text{Mass of all desired products}}{\text{Mass of all reactants}} \right) \times 100\%
\]

Atom economy can be calculated from actual laboratory data or it can be a theoretical prediction. The theoretical atom economy for a reaction can be calculated using molar masses instead of actual masses measured in the laboratory. For example, for the reaction

\[ \text{Fe}_2\text{O}_3 + 3 \text{ CO} \rightarrow 2 \text{ Fe} + 3\text{CO}_2 \]

the desired product is iron metal, and the undesirable waste is carbon dioxide.

The theoretical sum of the molar masses of the reactants is:

\[
\begin{align*}
\text{Mass of all reactants} &= \text{mass of 1 mol of Fe}_2\text{O}_3 + \text{mass of 3 mol of CO} \\
&= \left( 1 \text{ mol Fe}_2\text{O}_3 \times \frac{159.7 \text{ g}}{\text{mol}} \right) + \left( 3 \text{ mol CO} \times \frac{28.02 \text{ g}}{\text{mol}} \right) \\
&= 243.8 \text{ g}
\end{align*}
\]

The theoretical mass of the desired product is:

\[
\begin{align*}
\text{Mass of desired product} &= \text{mass of 2 mol of Fe} \\
&= 2 \text{ mol Fe} \times \frac{55.85 \text{ g}}{\text{mol}} \\
&= 111.7 \text{ g}
\end{align*}
\]

Therefore, the theoretical atom economy is:

\[
\text{Atom economy} = \frac{\text{Mass of all desired products}}{\text{Mass of all reactants}} \times 100%
\]

\[= \frac{111.7 \, g}{243.8 \, g} \times 100\% = 45.82\%
\]

In principle, a reaction with higher atom economy is preferable to one with lower atom economy, because higher atom economy means less waste produced for a given amount of product produced. However, it is important to realize that atom economy is only one measure of a reaction’s greenness. Atom economy tells what fraction of the original materials ends up in the desired product, but says nothing about what the original materials or desired product are and whether they are green or not. A reaction that uses highly toxic materials can have high atom economy, and that reaction still would not be green.

The use and production of non-toxic materials whenever possible is another vital principle in green chemistry. The toxicity of a material is a measure of both the potential harmful effects of that material on people or other organisms, and the amount of the material required to produce harm. A small amount of a highly toxic material can severely harm or kill a person, while a non-toxic material causes no harm to people even in fairly large doses. Different substances range over a continuum from extremely toxic to entirely non-toxic. The toxicity of many thousands of substances has been studied. Green chemists use this information to select the reactants and products that are lowest in toxicity while still allowing them to achieve their goals. In the past, chemists frequently considered many factors when developing a process, such as availability and cost of materials, but they often ignored toxicity. By contrast, green chemists are mindful of toxicity at each step of any process.

Putting green chemistry into practice is more complex than just understanding these three principles, as well as the nine other fundamental principles not discussed here. Often, one of the alternative chemical reactants and pathways to a particular goal is not obviously preferable to other options in terms of greenness. For example, one choice may be better in terms of atom economy, while another is preferable regarding the toxicity of wastes. In such cases, green chemists carefully analyze the relative merits and drawbacks of each choice before making decisions.

**Lab Instructions**

You will be required to analyze a sample made up of sodium carbonate and sodium bicarbonate. You have been provided with the laboratory reports of students who have done this experiment. There are several versions of the laboratory report and in order to fully understand the report, you may need to consult with your laboratory mates.

You are to conduct the experiment described in the laboratory report and write up the introduction, results, discussion and conclusion. The laboratory report will be turned in a week after the laboratory exercises are completed. Your results should address the following points:

1. The total mass of water and carbon dioxide lost in each trial

2. The moles of water lost in each trial
3. The mass of sodium bicarbonate originally present in the sample in each trial
4. The percent composition by mass of the original sample in each trial

In addition to the accuracy of the experiment, the discussion should address how the experiment adheres to the principle of green chemistry (e.g., the atom economy of the experiment).

Questions:

1) How could the student whose report you received have improved his or her lab report?
2) Why do scientists, and science students like you, write lab reports?
3) What did you learn from talking with other groups during the lab that you would not have been able to learn if you weren’t able to talk with other groups?
4) How do scientists communicate with each other
   a) Formally?
   b) Informally?
5) What do you think makes a good lab report?

The Report

The report this week will be focused on the Introduction, Calculation and Experimental Error

Pre-lab Assignment

A mixture of sodium carbonate and sodium bicarbonate is heated. Sodium carbonate does not undergo any chemical reaction, while sodium bicarbonate loses CO2 and H2O.

1. Write a balanced equation for the reaction.
2. What is the theoretical atom economy for the reaction? Sodium carbonate is the desired product and water and carbon dioxide are the waste products.
3. A student heats 0.682g of a mixture of sodium carbonate and sodium bicarbonate to a constant mass of 0.467g. What is the mass of sodium bicarbonate in the mixture? What is the percentage mass of sodium bicarbonate in the mixture?
References
4.