

Middle School Experiment Lab Manual

Introduction

States of Matter

There are three primary states of matter: solids, liquids, and gases. Solids are the densest, meaning that molecules and atoms in solids exist in fairly close proximity. Solids retain their shape regardless of the container holding them. Examples of solids include steel, wood, and rubber.

Liquids are less dense than solids and assume the shape of their container. Examples of liquids include water, vinegar, and rubbing alcohol.

Gases are even less dense than liquids, with gaseous molecules far apart. Like liquids, they retain the shape of their container. Air is a common example of a gas, but as you'll learn today there are many other interesting examples of gases.

Solubility refers to the ability for these different states of matter to form solutions, which are homogeneous and uniform. Solids can form solutions called alloys (such as brass or stainless steel) and liquids can also dissolve solids to form solutions (such as salt or sugar water). Interestingly, gases can also dissolve in liquids! Today, we'll use the ability for gases to dissolve in liquids to identify the products of a chemical reaction.

Ammonia

In fact, one of the most important chemicals to helping crops grow, ammonia, is a gas! The chemical formula for ammonia is NH_3 , which indicates that ammonia is composed of one nitrogen atom (N) and three hydrogen atoms (H). Currently, most ammonia is produced via the Haber-Bosch process. Here are some fun facts about this chemical process:

- Fertilizers produced from Haber-Bosch are responsible for feeding half of humanity.
- About $\frac{1}{2}$ of the nitrogen atoms in your body originate from ammonia made by Haber-Bosch.
- Ammonia is a gaseous compound under standard conditions, but even gases can dissolve. In fact, nearly 500 liters of ammonia will dissolve in a single liter of water!
- (Not so fun) fact: Carbon dioxide is another gas produced in the process of industrial ammonia production. Carbon dioxide is a major contributor to climate change.

This last fact shows that Haber Bosch is itself a major contributor to climate change, which is going to affect our planet in profound ways. It is estimated that billions of people may be displaced from their homes due to climate change over the next 50 years. We are already seeing climate change disasters such as wildfires, hurricanes, and refugees forced to migrate due to dwindling food supply.

Obviously, we need to develop ways to minimize climate change as much as we possibly can. As chemists interested in sustainably producing ammonia, we spend a lot of time thinking about this research question:

What alternative methods can we use to make ammonia?

Scientific Method

Actually, this research question represents the beginning of our entrance into the scientific method. You may have heard of this concept before!

The scientific method starts with a question. This question can come from a variety of places, including observations that we make ourselves or from ideas that we have based on the observations that we see other scientists making.

Some big questions that a scientist might aim to answer using the scientific method include the following:

- How can I make fuel that doesn't pollute the atmosphere when I use it to run my car?
- How can I build a more compact and efficient computer?
- ***What alternative methods can we use to make ammonia?***

The next step of the scientific method is centered upon trying to explain these observations based on our own chemical intuition. This explanation is called a hypothesis.

After we formulate our hypothesis, we finally get to the part where we get to do an experiment. Experiments in chemistry can vary a lot, but they generally involve mixing chemicals together, heating them, or shining a light on them. Once we set up an experiment, it's important to record your observations as changes occur. A few changes that you might see are:

Visual. This can include things like a color change or bubble formation.

Odor. New smells can also be a sign that a chemical reaction is happening.

Next, we analyze our results. To do this, we can compare the observations we made to our hypothesis in order to reach a conclusion. If our hypothesis matches our observation, we may have answered an important question, synthesized an exciting new molecule, or discovered a new solution to a big problem. If it doesn't, we can revise our hypothesis/reasoning and perform a modified experiment based on our previous results!

In this sense, the scientific method rarely ever ends. There's always more to learn from our experiments, which gives us a brilliant opportunity to continue the cycle by proposing more hypotheses based on the results from our first experiment!

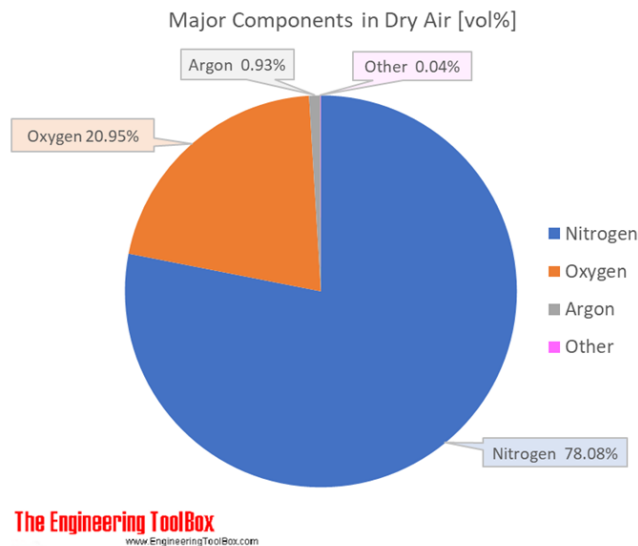
Forming Our Hypothesis

Now that we have solidified our research question, let's formulate a hypothesis.

As a reminder, our question is: ***What alternative methods can we use to make ammonia?***

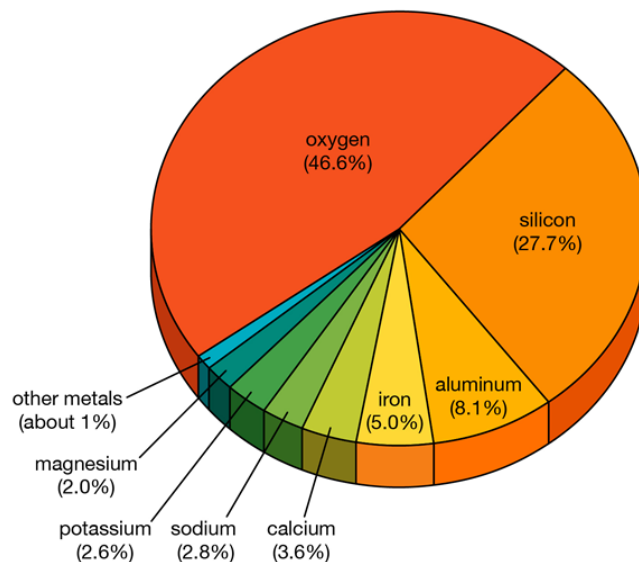
As mentioned before, one major goal we have in studying this question is choosing ways to make ammonia which are sustainable. That means choosing compounds which are plentiful and do not produce environmentally harmful products when we have them undergo reactivity to make ammonia. Let's think about some abundant chemicals on Earth to decide where we can get our nitrogen and hydrogen:

The first is air. Here's a pie chart which shows the composition of Earth's atmosphere. As you can see most is nitrogen, though oxygen and argon also represent a significant percentage as well.



The next is dirt, particularly in the Earth's crust. Here's another pie chart for this natural resource. Most of it is oxygen, with other components being elements such as silicon, aluminum, and iron.

Mineral composition of Earth's crust



© Encyclopædia Britannica, Inc.

Finally, there are other resources that are available. These include plants and water. Water is frequently denoted with the chemical formula H_2O . This means that it contains two hydrogen atoms (H) and one oxygen atom (O).

Do you see a source of nitrogen and hydrogen that we can use for making ammonia?

As you can see, nitrogen is a major component of air and hydrogen is a major component of water! These two both could be useful in making ammonia. In fact, one major source of ammonia in nature comes from lightning strikes providing electrical energy necessary for ammonia production from air and water.

It is useful to note that organisms are capable of making ammonia from natural resources as well! Plants sometimes have bacteria growing in their roots which make ammonia that helps support the plants during their life.

Now let's revisit our question again. We've agreed that air and water are fantastic candidates for making ammonia. Now the question is how we can get them to react.

What source of energy might we be able to use?

As mentioned before, lightning is a source of electrical energy which produces ammonia in nature. It's impractical to summon lightning on command to do this reaction, so let's think about how we can supply electrical energy to a system to make ammonia.

A battery is a fantastic option for this! Now that we have all of the components we need, let's write down a possible answer to our research question. This will be our hypothesis.

Constructing the Electrolysis Setup

Now that the necessary background is in place and you have a hypothesis to test, you can finally run the experiment. The materials you will need are as follows:

- Colorless plastic cups (2 – one large and one small)
- Syringes (2)
- Flat Metal thumbtacks
- Epsom Salts
- 9V battery
- Cardstock
- Paper towels
- Scissors (not in kit)
- Water (not in kit)
- Marker/Sharpie/writing utensil (not in kit)

Safety note: Before doing any science experiment, it is vital that possible hazards are considered. This ensures that what we are doing is safe!

- Since batteries provide electrical energy, they can pose a risk of electric shock. To avoid this, try not to touch both terminals of the battery at once! However, the amount of electric current produced by a 9V battery is not enough to be extremely dangerous.
 - Another important note is that batteries can sometimes leak, and it's important to avoid contact with any leaking batteries. If your battery is leaking, find a different one!
 - Minimize contact of any chemicals that you handle. This means avoiding consumption of our solution, as well as the salt being dissolved in water. Again, the chemicals that you'll use in this experiment are not incredibly dangerous, BUT any compound in an experiment should be handled with caution.
1. Stack the small cup on top of the 9V battery. Center the battery underneath the cup and use the marker to note where the battery terminals are.
 2. Remove the stacked plastic cup and puncture the markings with two thumbtacks. The sharp ends of the thumbtacks should sit inside the cup. Use a marker to push the cup down onto the thumbtacks to avoid poking yourself. Make sure that the thumbtacks do not touch, but are close enough together to touch both terminals of the 9V battery. Label the cup "Electrolysis Cell – MgSO_4 in H_2O ".
 3. Take your piece of cardstock and center the battery on top of it. Mark the two terminals on the piece of cardstock. Use your pencil to puncture through the cardstock to create two holes at the terminal sites; these will end up being about the same size as our syringes.

4. Carefully trim off the narrower ends of both syringes using a pair of scissors (the plastic may be difficult to cut, so go slowly!). Push the syringes through the holes in the card stock, to about the 1.0 mL line and set aside.
5. Add approximately 15 mL (1 Tbsp) of Epsom salt (MgSO_4) to the large cup followed by 120 mL (1 cup) of water. Stir the solution until the salt dissolves in the water.
6. Pour the electrolyte solution into the small cup containing your thumbtacks until the cup is about $\frac{3}{4}$ full. Discard the rest of the electrolyte solution (the drain is fine because the solution is just MgSO_4 which is non-toxic and water) and dry out the cup.
7. Next, place the cardstock/syringe apparatus over the cup and line up the syringes over the top of the thumbtacks. Pull solution up into the syringes to the 0.8 – 0.9 mL mark, making sure to avoid getting any bubbles in your syringe. If you do get bubbles, push the plunger all the way down and draw up fresh solution. You may need to repeat this a few times to get rid of all the bubbles. Push the syringes down until they cover the sharp ends of the thumbtacks.
8. Now take the 9 V battery and place in the bottom of the large (and dry!) cup and pack around it with paper towels to snugly place the battery in the middle of the cup. **Notify the teacher if the battery is leaking/corroded as battery acid is corrosive.**

Running the Electrolysis

1. Record the liquid level in the syringes at both the (–) and (+) terminals on your worksheet.
1. Having made our hypotheses, stack the two cups, connecting the thumbtacks to the two terminals on the 9V battery. Write down your observations of what happens on your worksheet.
2. After approximately 1-2 minutes, or when you can clearly measure a large difference in the water level in each syringe. Record any changes on your worksheet.

Now that you've run the experiment, think about whether any of the gases in the bubbles we saw forming were ammonia. Based on the chemicals available inside our cell, there are several possible reactions that could happen:

- Water Oxidation: $6 \text{H}_2\text{O} \rightarrow 3 \text{O}_2 + 12 \text{H}^+ + 6 \text{e}^-$
- Nitrogen Reduction: $\text{N}_2 + 6 \text{H}^+ + 6 \text{e}^- \rightarrow 2 \text{NH}_3$
- Proton Reduction: $6 \text{H}^+ + 6 \text{e}^- \rightarrow 3 \text{H}_2$

The products of these reactions—oxygen, ammonia, and hydrogen—are all gases at room temperature and atmospheric pressure. However, remember that ammonia is VERY SOLUBLE in water, the liquid inside of our electrochemical cell. Oxygen and hydrogen are less soluble. If we were making ammonia, would you expect to see gas produced at both electrodes? Does your answer to this question suggest that ammonia is being produced?

It doesn't! Does this result confirm your original hypothesis?

Because this result is potentially unexpected, it's important that we try to explain what actually happened. What gases could have been formed instead of ammonia?

Hydrogen (H_2) and oxygen (O_2)!

These gases are not as water soluble as ammonia, suggesting that they would produce bubbles as they were being produced. Ammonia production would have resulted in a uniform solution instead!

Conclusions

Now that you've studied your hypothesis, you can move to the last segment of the scientific method where we figure out what to do with our new knowledge! We also want to revisit the experiment we did to see if we can potentially envision other ways of answering our guiding question.

We didn't make ammonia using a 9V battery today, but we did make hydrogen!

This is an interesting result, because hydrogen is a clean, carbon-free fuel. While this may not solve our specific question, this result may nevertheless be interesting for its potential application in fuel cells which also help to mitigate climate change!

It's important to know that in science, this experimental outcome is quite common and acceptable. As long as you made sure that your experiment tested your original hypothesis, you learned something anyway. This is the most important part of following the scientific method—learning something about your original research question.

Finally, let's think about what we might do differently based on what we learned today. If we were to do this experiment again, what could we change to try to lead to a different result?

- Trying a different solvent than water!
- Trying a different material than a thumbtack as our electrode!
- Trying to do the same experiment in an atmosphere of 100% nitrogen!