The Chemical History of a Candle by Michael Faraday

Study Guide

Introduction for Parents: Material for this guide has been taken from the website of Mr. Kevin A Boudreau, chemistry instructor at Angelo State University http://www.angelo.edu/faculty/kboudrea/index.htm. In fact, if you want dramatic demonstrations of some of the reactions described in this book, check out his demo page.

Many of the demonstrations will require some purchases from a science supply store. Everything I use I get at HomeScienceTools.com. They are a terrific company to work with, and very reasonably priced. You can get a basic set of glassware for about $30, and the chemicals are usually less than $5 for the amounts you will use in these activities.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Lab Equipment</th>
<th>Chemicals</th>
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<tbody>
<tr>
<td>Taper candle(s)</td>
<td>glass tube</td>
<td>Brandy or denatured alcohol</td>
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<tr>
<td>matches (short and taper)</td>
<td>test tubes (2) with stoppers</td>
<td>table sugar</td>
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<tr>
<td>paper towel</td>
<td>sacrificial pan with lid</td>
<td>potassium chlorate</td>
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<td>flashlight</td>
<td>dropper</td>
<td>sulphuric acid</td>
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<td>white paper</td>
<td>Narrow neck bottle</td>
<td>hydrochloric acid (a.k.a.</td>
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<td>muriatic acid at the hardware</td>
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<tr>
<td>three empty soda cans</td>
<td>Ring stand with test tube</td>
<td>water &amp; ice</td>
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<td></td>
<td>clamp</td>
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<tr>
<td>balloon</td>
<td>beaker or wide mouth jar</td>
<td>rock salt</td>
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<tr>
<td>rubber band</td>
<td>rubber tubing</td>
<td>olive oil</td>
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<tr>
<td>9 volt battery</td>
<td>rubber stopper with hole</td>
<td>zinc or aluminum filings</td>
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<tr>
<td>2 liter bottle</td>
<td></td>
<td>calcium hydroxide</td>
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<tr>
<td>cornstarch or custard powder</td>
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<td>Epsom Salt</td>
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<td></td>
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<td>manganese dioxide</td>
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Safety equipment: lab coat or equivalent, eye protection, gloves.
What you hope to have happen when your student reads these is that he or she comes to you and narrates what Faraday did and then asks “Can I try that?” You will then pull out a box of supplies and say, “Go for it.” Well, for some things. Not everything will be reproducible at home. If you’re like me, some of the experiments will not work the first time, or the second time. Keep trying. Problem solve if it doesn’t work the first time, see if there are variables that can be changed: amounts of chemical, purity and concentration, environmental conditions, containers, technique, and then try it again. All of the demonstrations “work.”

**IMPORTANT SAFETY NOTE!!** Some of the demonstrations are hazardous - there are always hazards inherent in combustion. If you are not comfortable performing these experiments there are videos available on the internet for all of them. Always wear and make your students wear appropriate clothing, gloves, and splash goggles when performing an experiment. Eyeglasses are not sufficient. Clothes should not be loose, they should fit tight to the body. If an experiment should be done under a fume hood, and you don’t have one, that means “take it outside.” For any chemicals you purchase, print out an MSDS (Material Safety Data Sheet) which will tell you how to safely store and discard the chemicals you use.**

I include equations for many of the reactions Faraday describes in his lectures. I leave them for the student to balance, because I assume that you read Mystery of the Periodic Table, and learned about stoichiometry - balancing chemical equations based on the law of conservation of mass. If your student has not learned this, it is easy to pick up and really quite fun to do - like solving a puzzle. Khan academy lectures covering beginning stoichiometry can be found at [http://www.khanacademy.org/science/chemistry/chemical-reactions-stoichiometry/v/balancing-chemical-equations](http://www.khanacademy.org/science/chemistry/chemical-reactions-stoichiometry/v/balancing-chemical-equations). The complete and balanced equations are provided at the end of the guide.

When a candle burns, there are two kinds of change taking place with the wax. First, the wax turn to liquid. That is a physical change: the wax is still wax. Second, the wax is changed into the products you will discover in these lectures. When the wax is no longer wax, we say that a chemical change has taken place. Remind your student of the difference between the two types of change.

Lecture 1: Part 1

Materials: Taper candle, matches, paper towel, glass tube, test tube or similar narrow necked glass container, food coloring (optional).

Read from the beginning to: “The fluid has risen by the capillary attraction of the piece of cane, just as it does through the cotton in the candle.”

A fun way to begin this study would be to make your own candles. Faraday prefered the natural tallow dip candle for this demonstration. A site with instructions is here: [Making Hand Dipped Tapers](#)
Always light your candle at the beginning of your readings so you can look at it as you read.

Did you know that everytime something burns a chemical reaction is taking place? **Combustion** is a specific type of chemical reaction known as **oxidation**. It is the same kind of reaction, in fact, that causes steel to rust except that it happens much more quickly, releasing much more heat. This makes it at the same time more useful, and more dangerous.

Combustion requires four elements: fuel, oxygen, the chemical reaction and (usually) an initial source of heat. This is sometimes called the “fire tetrahedron.”

In this first reading, Faraday talks a bit about the manufacture of candles and their fuel, which is wax. There are three main kinds of wax used in candles: beeswax, paraffin, and stearic acid - or beef tallow (fat) candles. Wax, like most fuels we use, is a **hydrocarbon**. The chemical composition of hydrocarbons is remarkably simple as they are made of only two elements: carbon atoms and hydrogen atoms. The molecular formula for stearic acid is $C_{26}H_{52}$, twenty five carbon atoms and 52 hydrogen atoms per molecule (remember a molecule is 2 or more atoms). Methane is $CH_4$, a much smaller hydrocarbon molecule. What we call natural gas and it may be heating your house or cooking your soup. Propane, which comes in bottles and is used in barbeques, is $C_3H_8$.

Let’s think about the three physical states of wax. We appreciate the beauty of a candle when the wax is in its solid form. Faraday spends a bit of time evaluating how the candle is made - why might a beautiful candle burn badly?

Now let’s think about wax in its liquid form. Wax melts at 69.6° C, or 157° F. What are some properties of liquids? How is it that a liquid can defy gravity and travel up the side of a cup? How does Faraday show this? You can do it by getting a paper towel and holding it over a colored liquid so that just the end touches the liquid. You can also take a piece of celery and put it in a cup full of water and food coloring - this will take longer than the paper towel. What happens? Say what is meant by **capillary action** and **adhesion** in your narration. Why is this important to a candle?

Take a glass test tube and fill it halfway with water. You can color it if you like. Is the top of the water flat? No? That downward curve you see is called the **miniscus**, and it is caused by adhesion. As a chemist, when you measure liquids you will line up the bottom of the miniscus with the line closest to it.

We’ll talk more about the physical states of wax in the second half of Lecture 1.

**Lecture 1: Part 2** (read to the end of the lecture)

**Materials:** Candle, flashlight, white wall, brandy or denatured alcohol, raisins or plums (if using
brandy).

Wax in its liquid state will not burn. Once it reaches 383°C (721°F), it will boil and turn to vapor. It is the vapor that burns. However, all liquids and even solids have a layer of vapor around them, which makes it possible for a solid to catch fire before it becomes liquid. This is caused by **vapor pressure**, because molecules are always moving, even in a solid. As your candle is burning, light another match and have it ready. Gently blow out the candle, and see if you can relight it without touching the wick. How far could you get from the candle? Did you light a trail of flame?

Take your flashlight and shine in on the flame. Does it cast a shadow? What does that mean? What happens when you blow on the flame (but not hard enough to blow it out)?

The game of snapdragon that Faraday refers to is a Victorian Christmas game. Fill a shallow dish with raisins or plums. Warm up brandy and put it in the dish. Light the brandy. The fire will be blue and the flames wild. The object of the game is to fish out the burning fruit and put it in your mouth - the one who eats the most wins. Alcohol burns “cooler” than most fuels, but it can still burn you, so be fast and be careful. Here’s a poem to go with the game:

Here he comes with flaming bowl,  
Don't he mean to take his toll,  
Snip! Snap! Dragon!

Take care you don't take too much,  
Be not greedy in your clutch,  
Snip! Snap! Dragon!

With his blue and lapping tongue  
Many of you will be stung,  
Snip! Snap! Dragon!

For he snaps at all that comes  
Snatching at his feast of plums,  
Snip! Snap! Dragon!

But Old Christmas makes him come,  
Though he looks so fee! fa! fum!  
Snip! Snap! Dragon!

Don't 'ee fear him but be bold —  
Out he goes his flames are cold,  
Snip! Snap! Dragon!

You can do a “observation only” version of this by putting denatured alcohol in a dish and lighting it. Alcohol has a high vapor pressure meaning it vaporizes very easily (hence the smell),
so it does not need a wick to draw the liquid up to the flame to vaporize. Note how different air currents give the flames a different shape.

Lecture 2: Part 1

Materials: Candle, glass tube, sacrificial pan with lid, spare wax, white paper, cornstarch or custard powder

Read to: “they are exceedingly bright if they retain their solid state, and that it is to this presence of solid particles in the candle-flame that it owes its brilliancy.”

In this part, Faraday proves to you that it is the vapor that burns. First, take a look at the vapor. Take your glass tube and hold it in the black part of the flame, near the wick. What do you see going into the tube?

Now, Faraday and others have been able to direct the wax vapor through the tube and into a flask to be burnt. If you do that, email me and tell me how you got it to work, because for me the wax simply condensed into liquid when it left the flame. But, you can prove that it is the wax vapor that burns and not the wick. Take your spare piece of wax and heat it until it melts and gives off vapor. Take a match and light the vapor. The whole pan full of wax will burn. Extinguish with the lid. You could even try completely vaporizing your piece of wax, so there is no liquid, and then burning it - that may get exciting. Make sure your hood fan is running.

Take your tube higher up in the candle. What color is your vapor? Why do you think? Will the smoke burn?

Faraday will now prove that the flame is hollow and that a candle needs air to burn. Take a white piece of paper and do as he suggests with it. See the shape on your paper? Now, what is it that turns the paper black? It is Element #12. You can write your name with the candle flame if you like - just don’t hold the paper in the flame too long in one place.

What happens when you put a jar over your candle?

This next demonstration is best done outside on a calm day.

“Lycopodium powder is a fine yellow powder derived from the spores of Lycopodium clavatum (stag’s horn club moss, running ground pine). When a lighted match is dropped into a pile of this powder, it does not burn. However, when the powder is dispersed into a fine mist near a candle flame, it ignites into a spectacular fireball. This results from an increasing the available surface area for combustion: when the powder is dispersed into a mist, the particles are surrounded by enough oxygen to support a combustion reaction.” You can do this with cornstarch or custard powder. Put a spoonful of cornstarch in a paper tube and gently blow it on the flame of your candle. You will get an impressive fireball. But it takes practice. And a calm
day.

“This demonstration illustrates the basic principle behind a grain elevator explosion. Grain dust, like lycopodium powder, is not especially flammable, but when grain is dumped into a grain silo or elevator, some of the finer dust particles can remain suspended in air, surrounded by oxygen. The mixture can be ignited by a spark or flame, resulting in a devastating explosion.” (K. Boudreau) So now, narrate: What is a flame?

Lecture 2: Part 2

Materials: potassium chlorate, table sugar, sulphuric acid

1) Faraday was attempting to create an “invisible flame” by burning a oxyhydrogen (HHO) torch. Because there was no carbon, there were no particles to incandesce, or glow, when heated. Hence there was heat but no flame. When he put lime, and platinum wire, and charcoal in the “flame,” it glowed. This sort of torch can be used to cut metal, it is very hot. It is best to just imagine and narrate what Faraday does with his torch, and when you are done with these lectures, I'll include a link that tells how to make a homemade HHO torch.

2) Another thing Faraday demonstrates is that it is possible to start a fire without heat, that the chemical reaction in the case of some chemicals is enough. “Chlorate of potassa” is potassium chlorate. It is a very strong oxidizer. Faraday mixed his with “sulphuret of antimony” but you can get the same results using table sugar, and a drop or two of sulphuric acid to act as a catalyst.

DO THIS OUTSIDE!!! Hazards !!!

- Potassium chlorate is a powerful oxidizing agent; do not store the mixture of sugar and potassium chlorate since this can detonate unexpectedly.
- Use caution when taking potassium chlorate out of the bottle; scraping the compound roughly can produce sparking, which can cause the bottle to ignite or explode.
- This reaction must be done in a well-ventilated area, or in a fume hood.

Mix equal parts table sugar and potassium chlorate. Add one or two drops of sulphuric acid. Stand back. You will get a large purple flame tower, and it will explode the container it is in. You can also watch this happen through the link above, but what fun is that?

3) Combustion can be complete or incomplete. An orange, smoky flame indicates incomplete combustion. Incomplete combustion produces two products, carbon particles (soot, smoke, and flame) and water. Take your candle now, and put a jar over it, and then shine your flashlight on the jar. You can see the candle is making quite a mess inside the jar. You can see the water by holding a cool spoon over the candle, too. Do you see it fog up? Here is an equation for incomplete combustion. If you have learned stoichiometry, you can balance this equation.
Fortunately for us, combustion is usually quite a bit more complete, and produces less carbon in the form of soot. We will make more combustion equations for you to balance later on.

Lecture 3: Part 1

Materials: Three empty soda cans, ice, rock salt, water, olive oil.

Read to- “by the further application of heat, it would have been blown outwards.”

In this portion of the third lecture, Faraday continues to demonstrate that water vapor is a product of combustion. He shows that potassium can react with water and give off a lot of heat while doing so. Because elemental potassium is so reactive (read: dangerous), it’s not that easy to get, so even if you ask nicely your parents probably won’t get you some to play with. We’re going to instead follow Faraday on his little side trip to show some of the properties of water when it freezes and when it vaporizes.

Fill one soda can with water, to the top, and one with olive oil. Set them in a bowl of ice that you have mixed with rock salt. This will freeze both liquids. Now why do we do this instead of using a freezer? Remember, Faraday did not have a freezer - they had not yet been invented. He used a colligative property of the solution of salt and water. Salt mixed with water lowers the freezing point of the water, which means it will melt the ice, reducing the temperature of the surroundings as it does so. That’s how you can make ice cream in ziploc bags.

While you are making solid ice and solid fat in two cans, take your third can and put a small amount (about ¼ c) of water in it. Set it on a hot plate and bring the water to a boil. When all the water is boiled off, put a piece of clay in the opening to completely seal it off. Take a cup of ice water and pour it on the can. What happens?

When you had water vapor in the can, it replaced the air and filled the can. A gas will expand to fill the space. The pressure of the water vapor inside the can balanced the pressure of the air outside the can. When you lower the temperature of a gas, you lower the pressure as well. The vapor condensed into water again and occupied less space. The pressure inside the can became less than the pressure outside. The pressure of the outside air crushed the can.

Now take a look at your other two cans. What has happened? Compare the can with the ice to the can with the fat. How are they different? Water is the only substance that expands, or becomes less dense, when it freezes. In Faraday’s lecture, it was powerful enough to burst a sealed iron container. Did your pop can burst?

Lecture 3: Part 2
Read to “Mr. Anderson having now been able to get two or three jars of gas…”

Faraday asks: Where does the water come from? Do you know?

How is he going to prove it? First, he’s going to show another kind of oxidation - the rusting of iron. He showed that the oxidation of zinc produced a white powder (zinc oxide) and the oxidation of iron produces an orange powder (ferric oxide or iron oxide - a.k.a. rust).

In his fine furnace (which we won’t reproduce) he will run water vapor over the iron filings to get them to rust. Tell how he does this. Here’s the reaction, balance it:

\[ \text{_____Fe} + \text{____H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + \text{_____} \]

How does he prove what the gas coming out is?

**Lecture 3: Part 3**

**Materials:** Narrow neck bottle, stopper with hole, glass tube, zinc or aluminum filings, hydrochloric acid, balloon.

When you mix hydrochloric acid with metal filings in the bottle, the chlorine combines with the metal and the hydrogen floats free. You can put a balloon over the neck of the bottle to capture the hydrogen. It will be flammable (explosively so), and it will float, so if you want to keep it you will need to tie it down.

Narrate how he makes his hydrogen candle. You can try this by replacing the balloon with the stopper and glass tube. Hydrogen burning in the presence of oxygen makes what? Why do you think car companies are trying to build cars that run on hydrogen cells?

Faraday comments on the weight of hydrogen - it is the lightest element. Take a look at your periodic table. What is its atomic weight? Remember how the weight of different elements was calculated?

The AMU (Atomic Mass Unit) is not a very practical weight. Chemists use instead the mol (pronounced “mole” like the burrowing creature). A mol of a substance weighs the same in grams as its atomic number. So a mol of hydrogen weighs about one gram. To figure out how much a mol of a compound such as water weighs, add up the weights of the elements in its chemical formula. Water, H\textsubscript{2}O, has 2 hydrogen atoms and one oxygen atom. So a mol of water weighs 1g+1g+16g or about 18 grams.

A mol of any substance has been experimentally shown to contain $6.02 \times 10^{23}$ atoms or molecules (That’s 602 followed by 20 zeros, quite a lot). That number is called **Avogadro’s number** after the 18 century Italian chemist Amedeo Avogadro.
Narrate what he does at the end to the battery (“voltaic pile”). No need to do it yourself. You get to destroy a battery in your next lesson.

Lecture 4: Part 1

Read to: “I will take this jar first, and will ask you to be prepared to recognise hydrogen.”

Materials: Ring stand with test tube clamp, 2 test tubes, test tube stoppers, rubber band, distilled water, Epsom Salt (Magnesium sulfate), 9 volt battery, beaker or wide mouth jar

Faraday, being the father of electricity that he is, is playing with his battery and showing what can be done chemically with it. He shows how you can coat a piece of metal with copper through a process called electroplating. You can use electricity to force a reduction reaction (remember that from Mystery of the Periodic Table?) that would not ordinarily happen, simply by adding the electrons needed. The battery produces those electrons.

Electrolysis of water - at first Faraday collects the gas from both electrodes of his battery in order to prove that he is not simply boiling the water with electricity. How could he prove that the gas he collected was not simply water vapor? When he ignites the combination of gasses, what does he get?

Here is the formula for you to balance \(_2H_2 + O_2 \rightarrow \_H_2O\) This is called a composition reaction, when two elements join to make a compound.

Next he collects the gas from each pole separately. You can do this at home.

1. First, make a solution of magnesium sulfate in distilled water in a measuring cup. Use about 15 g of magnesium sulfate to 600 mL of distilled water.
2. Pour most of the solution in the jar, reserving enough to fill the two test tubes.
3. Fill the first test tube with solution, and holding your thumb over the opening immerse it in the jar. Do the same with the second test tube.
4. Secure the test tubes together with a rubber band.
5. Carefully place the jar on the ring stand, and position the clamp to hold the test tubes so that their openings are several inches below the surface of the solution. Place one of the test tubes in the clamp and lock it in place.
6. Gently lower the nine volt battery into the solution, positioning it so that each tube catches a trail of bubbles from one of the electrodes. It may take from 10 to 30 minutes for a test tube to fill with gas.

(Procedure taken from *The Illustrated Guide to Home Chemistry Experiments* by Robert Thompson)

Notice that one test tube has twice as much gas as the other. Take that test tube and stopper it while it is still in the solution. Remove it while keeping the other in place. Light a match and hold
it over the tube as you remove the stopper. What happens?

When the second test tube is full of gas, stopper and remove it. Hold it upside down while lighting a match and letting it burn a second. Blow out the match, unstopper the tube and thrust the match up into the tube. What happens?

**Lecture 4: Part 2**

So now he talks about oxygen, the gas in your second test tube, and its properties. Do you remember how much a mol of oxygen weighs? (Hint, check your periodic table) So, let’s check Faraday’s math. He says that 11.1% of the weight of water is hydrogen, and 89.9% of the weight of water is oxygen. You do the calculation. Is he right?

As with hydrogen, you can use a chemical reaction to make oxygen. Remember the potassium chlorate that made the purple fire? Well, take the amount you did not use and heat it with manganese dioxide in a flask over a gentle flame, probably best over a hot plate. Take the flask off of the heat, and light a taper (long match). Compare how it burns in the air to how it burns when you lower it into the flask. If it burns more brightly, you have pure oxygen.

Here is the formula for the chemical reaction that produces oxygen. This is not an oxidation reaction, it is a **decomposition** reaction. A decomposition reaction happens when a compound simply falls apart into separate elements or compounds. The manganese dioxide acts as a **catalyst**, speeding up the reaction but not changing itself or bonding with any of the products.

\[
2\text{KClO}_3 + \text{MnO}_2 + \text{energy} \rightarrow 2\text{KCl} + 3\text{O}_2 + \text{MnO}_2
\]

And here is the reaction he describes where potassium burns in water, producing potassium hydroxide and hydrogen gas (balance away!):

\[
\underline{\text{K}} + \underline{\text{H}_2\text{O}} \rightarrow \underline{\text{KOH}} + \underline{\text{H}_2}
\]

**Lecture #5: Part 1**

Read to: “A pint of air weighs about 10-7/10 grains, and a cubic foot weighs 1-3/4 ounce.”

Faraday mixes oxygen with nitrous oxide, changing it to nitric oxide. Narrate how he uses this test to determine there is something in air besides oxygen.

Tell something about nitrogen and its properties. Look at your periodic table and tell how many grams a mol of nitrogen weighs.
Lecture 5: Part 2

Read to: “...that wonderful property of the air, its elasticity, its compressibility, and expansibility, to an exceedingly large extent, and which is very essential for the purposes and services it performs in the economy of creation.”

Discuss: how would you weigh a gas?
I have a spring balance, and I decided to see if I could weigh air like Faraday did, only using a bicycle tire and pump. I managed to pump in almost half an ounce of air. What ways can you come up with to weigh air?

Did you try his experiment with the glass of water? Cool trick, right? You can try his experiments with a potato and a straw as well. Just don’t hit your little sister.

The “elasticity” of air. This is Faraday’s way of saying that gases are “compressible” and also that they “expand to fill the space they are confined in.” Seven years prior to giving these lectures, Faraday proved that one could change ammonia (a gas) into a liquid if you put it under enough pressure, and by the end of Faraday’s Christmas lectures a German engineering professor had patented a system for liquefying 3 different gasses by compression to use in refrigeration.

Refrigeration works because the minute you release the pressure on a compressed liquid, it will take heat out of the air as it evaporates.

Lecture 5: Part 3

Materials: calcium hydroxide, water, 2 liter plastic bottle, tubing.

Faraday has already shown two products of combustion: carbon and water. How does he show that there is another gas coming out of the candle?

Build yourself a little contraption to capture the gas that comes out of the flame. You could cut out the bottom of a 2 liter soda bottle and tape a hose to the top. Be sure to set your candle on a stand so that air can reach the candle from underneath.

Faraday uses lime water as an indicator for his gas, which is carbon dioxide. You can make it with calcium hydroxide, 1 tsp per gallon of water.

Carbonic Acid is another name for carbon dioxide, and today generally refers to carbon dioxide that has been dissolved in water. Your cola is full of carbonic acid. There is carbonic acid in your veins.

Light two candles. Put one under your contraption so that air can reach the candle from
underneath. Direct the hose to the other candle. It will put out the candle just as if you were running water through the hose, because the gas will sink as it cools and surround the flame. Aim the hose at a beaker of lime water. Does it turn cloudy? The clouds are calcium carbonate precipitating out of the solution. Here’s the equation for that reaction:

$$\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$$

Another way to produce \( \text{CO}_2 \), which Faraday describes and you probably already know, is to mix an acid (such as vinegar) with a carbon containing material, such as baking soda, chalk, or marble. It is possible to tip the gas out of the bowl in which you do this reaction and put out the candle, because it is heavier than air.

We cannot breath carbon dioxide, and carbon dioxide cannot support combustion. The chemical formula for carbon dioxide is \( \text{CO}_2 \). How many grams does a mol of \( \text{CO}_2 \) weigh? How does he compare the weights of various gasses?

**Lecture 6: Part 1**

Read to: “It is in a fixed, almost unchangeable condition before the combustion; but afterwards it is in the form of gas, which it is very difficult (though we have succeeded) to produce in a solid or a liquid state.”

Here he proves that the \( \text{CO}_2 \) that is a product of the candle’s burning comes from a further chemical reaction, the burning of the carbon particles in the flame. How does he do this? Do you think, based on his experiment, that it is possible to have a smokeless fire?

What happens when he burns phosphorus in \( \text{CO}_2 \)? What happens when he burns potassium in \( \text{CO}_2 \)? (other than the explosion)

So let’s look at the complete process of combustion as an equation, thinking of our candle in a perfectly oxygenated environment (balance away):

$$\text{C}_{25}\text{H}_{52} + \_\text{O}_2 \rightarrow \_\text{H}_2\text{O} + \_\text{CO}_2.$$  

Why is the combustion of carbon containing substances unique, according to Faraday?

There is one more product of incomplete combustion that Faraday may not have been aware of. Sometimes when there is not enough oxygen for the fire, an atom of carbon will combine with only one of oxygen to make \( \text{CO} \), which is carbon **monoxide**. It is a poisonous gas, because our blood tries to use it the same way as oxygen, but cannot. We don’t feel like we are suffocating when we breathe carbon monoxide, but we are. That is why we never, ever burn more than a few candles in the house. We don’t use camp stoves in the house, we don’t make campfires anywhere except in the fireplace, we don’t run the car in a closed garage, because there is
nowhere for that poisonous CO to escape.

Finally, in his last quote he hints that CO₂ can, with difficulty, be made liquid or solid. You may know solid CO₂ as “dry ice.”

Now that you know that water and carbon dioxide are the products of combustion, you can balance the equations using different fuels:

\[
\begin{align*}
\text{CH}_4 + \_\text{O}_2 & \rightarrow \\
\text{C}_3\text{H}_8 + \_\text{O}_2 & \rightarrow \\
\text{C}_2\text{H}_5\text{OH} + \_\text{O}_2 & \rightarrow \\
\text{C}_4\text{H}_{10} + \_\text{O}_2 & \rightarrow \\
\text{C}_8\text{H}_{18} + \_\text{O}_2 & \rightarrow \\
\end{align*}
\]

Answers:

\[
\begin{align*}
\text{CH}_4 + 2\text{O}_2 & \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \\
\text{C}_3\text{H}_8 + 5\text{O}_2 & \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \\
\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 & \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} \\
\text{C}_4\text{H}_{10} + 13\text{O}_2 & \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O} \\
\text{C}_8\text{H}_{18} + 15\text{O}_2 & \rightarrow 16\text{CO}_2 + 18\text{H}_2\text{O} \\
\end{align*}
\]

Lecture 6: Part 2

Materials: Table sugar, sulfuric acid, beaker. Safety equipment: lab coat or equivalent, eye protection, gloves.

How does Faraday prove that our breath is CO₂ with the candle and with the lime water? How is it that we produce CO₂?

SAFETY NOTE - do this outside or under a fume hood!!!

“Oil of Vitriol” is sulfuric acid, H₂SO₄. The chemical formula for sucrose (table sugar) is C₁₂H₂₂O₁₁. This is another rather spectacular reaction that Faraday does to demonstrate what goes on in the body when we process sugar. At first you see a decomposition reaction in which the acid acts as a catalyst. Then you might observe (by smell) a secondary oxidation reaction where the
the sulfuric acid become sulfur dioxide and the oxygen combines with the carbon to make CO2. Do you think you can come up with the formula for the reaction on your own? Be very careful as this is a very exothermic reaction, just like the combustion reactions, except there will not be a flame, just a lot of heat, as in our own bodies. YOU CAN GET BURNED! Wear protective equipment. When you clean up do not touch the carbon “snake” with bare hands, as there may still be acid present - wear heavy gloves. Remove and discard the carbon in the trash, and soak the beaker in acetone before washing it.

Faraday’s final piece of instruction: that carbon’s energy is stored. While combustion is a process that gives off energy, it requires energy to initiate it. This is called the heat of ignition.

And his final point? Compare it to these verses: Matthew 5: 15-17

\[
\text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow 12 \text{ C} + 11 \text{ H}_2\text{O}
\]

This is the decomposition reaction catalyzed by the acid

\[
\text{H}_2\text{SO}_4 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{O}(+) + \text{HSO}_4(-) + \text{heat}
\]

This is what happens when an acid dissolves in water. You will learn more about this reaction later.

\[
2 \text{H}_2\text{SO}_4 + \text{C} \rightarrow \text{CO}_2 + 2 \text{SO}_2 + 2 \text{H}_2\text{O}
\]

This is the action of the acid on the carbon (oxidation) that occurs because of the heat produced in the middle reaction.