



How Do We Use Energy?

One of the best ways to establish a concept is to provide multiple examples of the concept in action. In this section we present a number of activities where students investigate energy through chemical and physical reactions. The activities present chemical processes that will be familiar to students through their everyday lives, but focus on how energy is involved in the changes they observe. These ideas are reinforced with a chemical demonstration, a video, and an article on the chemistry of explosives.

- Lab Investigation—Combustion & Burning
- Demo—Soda Can Steam Engine
- Lab Investigation—Preparation & Combustion of Biodiesel
- Demo—Electrolysis of Water
- Video—Temperature & Energy
- *ChemMatters* Reading—The Explosive History of Nitrogen

Combustion & Burning | A Lab Investigation

Summary

In this investigation, students are challenged to make careful observations about a burning candle to discover the chemical and physical changes that make it work.

Objective

Students will describe their observations about a burning candle to discover the chemical and physical changes that make it work.

Safety

- Be sure to wear safety goggles while making close observations, tie your hair back if you have long hair, and always be aware of where the flame is with respect to your clothing—do not lean over the flame.
- Burning candles are open flames that can cause burns. Liquid wax is hot and can cause burns to the skin.

Materials for Each Group

- Tea light candle
- Matches
- Small beaker or evaporating dish (such as 50 mL or 100 mL)
- Balance
- Ruler or meter stick
- String (for measuring circumference)
- Stopwatch

Time Required

One class period, approximately 45–50 minutes.

Lab Tips

Tea candles can be purchased in large quantities, as can tapered candles from hardware stores. Candles of different colors, sizes, and shapes can enrich the observations made by the class.

Integrating into the Curriculum

This investigation could fit into a unit on chemical reactions.

PREPARING TO INVESTIGATE

We are all familiar with burning candles, but how much have we really seen while looking at one? In this exercise you will be challenged to observe a burning candle through the lens of chemistry. You may be surprised by how much is really happening in what seems like a familiar process!

First we will try to observe details beyond our usual way of looking at a candle, and then we will look for evidence of the physical or chemical nature of any changes that are taking place. Take care in recording your observations—try to imagine that you have never seen a burning candle before!

GATHERING EVIDENCE

Obtain a tea light candle, matches, and any measuring equipment available to you. Before lighting the candle, make three qualitative observations and three quantitative observations of the candle.



Qualitative observations describe qualities or characteristics, quantitative observations involve quantities, or measurements. You may choose among many properties to observe: color, texture, mass, physical dimensions, density, aroma ... or any others you can think of. Use as many of your physical senses as possible, and be sure to include units for any of your quantitative observations.

Record your observations below:

Qualitative observations	Quantitative observations

Use a match to carefully light the candle.

Repeat the process of making qualitative and quantitative observations of the burning candle, this time making six of each kind of observation. (Some of your observations may relate to properties you have already recorded, that may be changing now that the candle is burning.) Once again use all your senses to make qualitative observations. Ask yourself what you can measure for the quantitative observations.

For your observations and measurements, consider not only the physical candle, but also consider its influence on the air in the space surrounding it. Record your observations below:

Qualitative observations	Quantitative observations

Now sketch a detailed drawing of the burning candle, an enlargement of the portion about a centimeter from the top of the candle to the topmost tip of the flame:



Label the following regions of the candle in your drawing: solid wax, liquid wax, region of wick without flame, region of wick with flame, and region of the wick that glows.

Now distinguish as many different aspects of the flame itself and label them in the drawing. When you have completed recording your observations and drawings, prepare to blow out the candle, and be ready to make further observations as you do this!

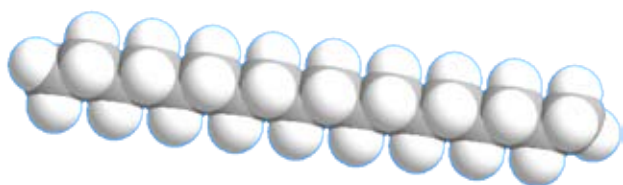
Blow out the candle and record two qualitative and two quantitative observations of the candle immediately after it is extinguished:

Qualitative observations	Quantitative observations

INTERPRETING EVIDENCE

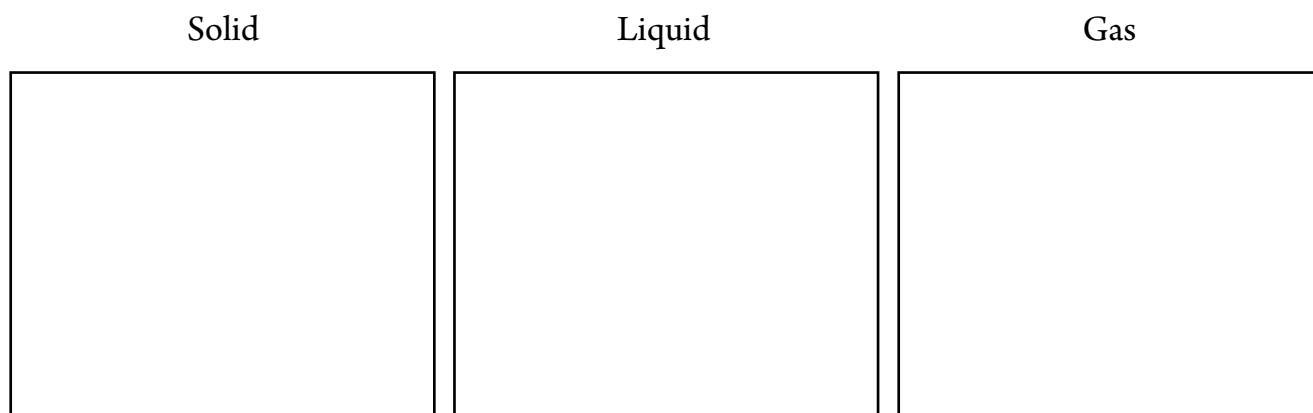
Now that we have paid close attention to the properties of a burning candle, we can begin to interpret what we've seen in terms of phase changes and chemical reactions.

In a phase change (from solid to liquid or from liquid to gas) the particles of a substance (in this case the molecules of wax) will change the arrangement they have with each other. As a solid they will be closely packed together and unable to move freely. In the liquid they will be able to flow around each other but will still be close together, and as a gas they will fly freely apart but they will still be wax molecules and will have the same structure they had as molecules in the solid and the liquid phases:



Waxes from plants and animals have different structures. Here is a molecule similar to wax, $C_{18}H_{38}$ — a material that is normally a major component of the candle wax.

In the boxes below, use small, single shapes to represent entire wax molecules, and sketch their arrangement in the three physical phases:



Based on your observations of the burning candle, did you find evidence for the change from the solid wax phase to the liquid wax phase?



Describe this evidence as specifically as possible:

Did you find evidence for the change from the liquid wax phase to the gaseous wax phase?



Describe this evidence as specifically as possible:

A physical candle is composed of wax surrounding a wick. Look up the definition of the verb “to wick,” and write it below:

Describe the wicking process in the burning candle, and be sure your description includes the physical state of the wax and the wick:

As a candle burns, the wax gradually disappears from sight. Is there a physical change in the wax that would account for this disappearance?

If the wax was simply undergoing physical change, would you expect the candle to produce heat and light as it does when a candle burns?

The process of burning (as opposed to evaporating) is a chemical reaction, a chemical change. The wax molecules are undergoing a chemical change; they are changing into different molecules by reacting with a substance in the air. What is this substance in the air that a candle needs to burn?

Interestingly, a candle releases energy through the same kind of reaction that your body uses to obtain energy. Hold your breath for a moment. What is your body craving? This is the same substance the candle needs to burn in a chemical change that we call combustion.

We can represent the combustion of a candle like this:



Complete the following sentence that restates this equation:

Two molecules of wax react with _____ molecules of oxygen to produce _____ molecules of _____ and _____ molecules of _____.

We are not aware of oxygen in the air because it is an odorless and colorless gas, and at the temperature of a burning candle, both the CO_2 and the H_2O are also gases that are invisible to us. We can see evidence of chemical change, however, if we restrict the amount of oxygen that is allowed to react with the wax.

If less oxygen is available, one possible outcome in the combustion of wax is



Relight the candle and lower the bottom of a small beaker or a clear watch glass into the flame so that the flame touches the surface of the glass. Hold it there for a moment (where it restricts some of the air flow to the flame) and then remove it.

What do you observe on the bottom of the beaker? What could this substance be and where did it come from?

How does this provide evidence that a chemical reaction is taking place?

Wipe the bottom of the beaker clean and place an ice cube inside it. Hold the beaker several centimeters above (not in) the flame and allow the candle to burn. Can you see a substance forming on the bottom of the beaker? What could this substance be and where did it come from? Could it have come from the melting ice inside the beaker?

Consider the flame itself. Is the flame a substance produced by the candle? What observations lead you to think that the flame is matter? In what ways does the flame seem like energy?

Is the following statement true or false: "As a candle burns, wax turns into fire."

If this isn't an accurate statement, can you restate it correctly below?

Finally, let us consider the physical phase of the wax as it reacts with the oxygen to produce carbon dioxide and water. Prepare to observe carefully! Blow out the candle and very quickly bring a match close to the wick. Try to notice exactly where the lit wooden splint is with respect to the wick when the candle reignites.

Do this several times to see if you observe something interesting. Note any evidence you have observed that helps to determine the physical phase of the wax when it reacts with oxygen.

REFLECTING ON THE INVESTIGATION

1. What phase is the wax in when it mixes with oxygen in the air and undergoes a chemical change?
2. Based on your observations, in which phase (solid, liquid, or gas) is the wax most likely to undergo a chemical change?
3. Explain why this is the case based on your sketches of wax in solid, liquid, and gas phases.
4. How might this (your answer to question 3 above) explain a sign that says NO SMOKING near the pumps at a gas station?
5. Look back at your diagrams of the candle flame. Can you identify the region where the wick itself is undergoing combustion? Where is this region?
6. What is fire? Is it matter or is it energy? Explain your answer.
7. In a short paragraph, summarize the changes that a candle undergoes when it burns. Incorporate the following words into the paragraph in a meaningful way: wax, wick, phase change, chemical reaction, vaporize, melt, transforms, solid, liquid, gas, energy, light, and heat.

Extension

Further analysis problem using stoichiometry:

Given the reaction that we are using for the combustion of wax:



Use stoichiometry relationships to calculate:

1. The volume of oxygen gas needed at STP to burn 37.5 g of wax.
2. The mass of carbon dioxide released when 37.5 g of wax burns.

If less oxygen is available, one possible outcome in the combustion of wax is



If this were to happen, what mass of soot (carbon) is produced for every 1.0 g of wax that burns?

Can you think of another gas that could be produced when there is insufficient oxygen to produce CO_2 ?

The following links provide further inquiry in different aspects of burning candles:

- This site from NASA helps students gain insight into the characteristic shape of a candle flame by observing how a candle burns in zero gravity.
 - <http://bit.ly/highschoolnrg3>
 - <http://bit.ly/highschoolnrg4>
- Diagrams and explanations of candle combustion from the National Candle Association:
 - <http://bit.ly/highschoolnrg5>
- A *Journal of Chemical Education* article on observing candles that includes a demonstration of the scorch marks left on an index card held in a flame:
 - <http://bit.ly/highschoolnrg6>

TEACHER'S KEY

Reflecting on the Investigation

1. What phase (solid, liquid, or gas) is the wax in when it mixes with oxygen in the air and undergoes a chemical change?

Gas

2. Based on your observations, in which phase (solid, liquid, or gas) is the wax most likely to undergo a chemical change?

In the gas phase surrounding the wick.

3. Explain why this is the case based on your sketches of wax in solid, liquid, and gas phases.

In the gaseous phase the wax molecules have more freedom to mix and collide with oxygen molecules in the air, and react with them to produce water and carbon dioxide.

4. How might this (your answer to question 3 above) explain a sign that says NO SMOKING near the pumps at a gas station?

Gasoline that has vaporized near the pumps may react with oxygen if exposed to an open flame or a lit cigarette.

5. Look back at your diagrams of the candle flame. Can you identify the region where the wick itself is undergoing combustion? Where is this region?

At the very tip of the wick, where it is glowing orange, the wick itself is burning, or reacting with oxygen in the air. Melted wax (in the process of changing into gaseous wax) coats the rest of the wick.

6. What is fire? Is it matter or is it energy? Explain your answer.

Both. What we call fire is what we see and feel when the gaseous reactants and products of combustion release energy in the form of light and thermal energy that heats the surroundings.

Extension

Further analysis problem using stoichiometry:

Given the reaction that we are using for the combustion of wax:



Use stoichiometry relationships to calculate:

1. The volume of oxygen gas needed at STP to burn 37.5 g of wax.

90.8 L O₂

2. The mass of carbon dioxide released when 37.5 g of wax burns.

117 g CO₂

If less oxygen is available, one possible outcome in the combustion of wax is



If this were to happen, what mass of soot (carbon) is produced for every 1.0 g of wax that burns?

0.42 g C

Can you think of another gas that could be produced when there is insufficient oxygen to produce CO₂?

CO

Soda Can Steam Engine | A Demonstration

Summary

In this demonstration, students consider the concepts of energy transformations and conservation as they observe a simple steam engine made from an aluminum soda can.

Objective

Students learn about energy transformations and the concept of conservation of energy.

Safety

- Be sure you and the students wear properly fitting goggles.
- Handle the hot soda can with tongs. Steam from the can could scald your hand and skin.

Materials

- Unopened 12-oz aluminum soda can (using diet soda will help avoid potential stickiness)
- Thumbtack
- Access to a sink
- Wash bottle
- Water
- 10-mL graduated cylinder
- String
- Ring stand
- Ring
- Bunsen burner or hot plate
- Tongs

Time Required

Part of one class period, approximately 10–15 minutes.

Integrating into the Curriculum

This demonstration could fit into a unit on phase changes, thermochemistry, or technology.

PREPARATION

1. Working over a sink, create a hole in the middle of the side of an unopened soda can using a thumbtack. Continually shake the can, using the pressure generated by carbonation to force the soda out through the hole.
2. When the can is empty, create a second hole on the side opposite the first.
3. Rinse the can with a wash bottle, squirting water into one of the two holes.
4. Once you have emptied and rinsed the can, use the wash bottle to add about 10 mL water (or enough so you hear it sloshing around inside the can).
5. Use the thumbtack to slant each of the two holes in the same direction, tangential to the can's surface. These holes act as "jets" in order to propel the can.

DEMONSTRATION

1. Shake the can so that students can hear the water sloshing around inside the can. Allow them to observe that the pull tab is unopened and that there are two holes in opposite sides of the can.
2. Tie a string to the can's unopened pull tab and secure the can to a ring attached to a ring stand at a height that allows a Bunsen burner or hot plate to warm it.
3. While waiting for the can and water to heat, ask students to predict what will happen.
4. Gently warm the can and water. Water vapor will eventually exit both holes and should result in a net force that sets the can spinning.

DISCUSSION WITH STUDENTS

1. Ask students to describe any energy transformations present in the demonstration.
2. Challenge students to explain why the can behaves as it does. As long as the water is heated gently, no condensed water vapor is visible as steam exits the can.

EXPLANATION

Energy may go through several conversions before we actually use it to do work. Energy is not "used up" in any conversion; it is simply changed from one form to another. Like matter, the total energy is conserved.

Several energy conversions are involved in the demonstration. Chemical energy from the fuel used in the Bunsen burner or the source that produced the electricity (some possibilities are hydroelectric, solar, wind, geothermal, nuclear, and petroleum energy sources) powering the hot plate is used to warm the water and can. Some of the energy goes to overcoming the attractions among the liquid water molecules so they vaporize to produce warm water vapor. The molecules

of the warm water vapor have high kinetic energy, which increases the pressure inside the can and thus forces some of the gas out through the holes in the sides of the can. As these jets of gas leave the can, they push on the air outside the can and create an opposite push on the can, which then is partially converted to kinetic energy as the escaping water vapor causes the can to rotate. Some of the energy from the escaping water vapor is also partially converted to potential energy as the string attached to the spinning can twists.

EXTENSIONS

Instructors may also wish to discuss the idea that no energy conversion is 100% efficient in transforming one form of energy to another desirable form. Thus, some useful energy is always “lost” whenever energy is converted from one form to another. The energy itself is not destroyed, but becomes unavailable to do useful work. For example, some of the electrical energy used in the operation of a hair dryer is converted to sound energy, which does not help to perform the work of drying your hair.

Students can investigate energy conversions in everyday items. Some suggestions are light bulbs, batteries, toys, car engines, etc.

Students could research the early steam engine invented by Hero of Alexandria in the first century A.D. and compare it to the soda can steam engine.

ADDITIONAL RESOURCE

“Demonstration Idea,” *Chemistry in the Community*, 6th ed., Teacher’s ed., New York: W. H. Freeman and Company/BFW, 2012, p 361.

Preparation & Combustion of Biodiesel | A Lab Investigation

Summary

In this investigation, students use canola oil, typically used in the kitchen, to produce biodiesel by reacting it with methanol using a potassium hydroxide catalyst. They then burn a sample of the biodiesel produced. The sample is placed underneath a soda can that contains a measured amount of cold water. The initial and final temperatures of the water are recorded. The collected data is used to calculate the heat of combustion of the biodiesel, which is compared to the theoretical heat of combustion of diesel fuel from crude oil. The concepts of renewable and non-renewable fuels are also discussed.

Objective

Students learn about a reaction used to produce biodiesel, heat of combustion, and the concepts of renewable and non-renewable fuels.

Materials for Each Group

- 25-mL graduated cylinder
- 10-mL graduated cylinder
- Canola oil (25 mL)
- Methanol (4 mL)
- Plastic container with a screw-top lid (needs a capacity of at least 50 mL)
- Dropper
- 9 M potassium hydroxide (KOH) (12.5 g KOH in 25-mL solution)
- Sodium chloride (0.5 g)
- Large test tube (needs a capacity of at least 30–35 mL)
- Cork or stopper to seal large test tube
- Test tube rack
- 12-oz empty, clean aluminum soft drink can with pull tab
- Ring stand
- Ring
- Thermometer
- Stirring rod
- Matches
- Balance
- Tea light candle with metal cup and wick
- Watch glass

Safety

- Be sure you and the students wear properly fitting goggles.
- Burners must not be used, since many reagents are flammable.
- Methanol particularly poses a serious fire hazard, and its flame is almost invisible. Avoid flames or sparks. Methanol is also toxic by ingestion. Skin contact causes dermatitis. Work in a well-ventilated area.
- When working with alcohols such as methanol, the National Science Teachers Association recommends that “the primary reagent alcohol container be kept in the chemical storeroom. The minimum quantity of alcohol needed for the experiment should be available to students”:

<http://bit.ly/highschoolnrg7>

- *Extreme caution* should be used with 9 M KOH. It is caustic and corrosive. The instructor must dispense drops of the concentrated base directly into each group’s container. 9 M potassium hydroxide is caustic and corrosive. Avoid skin contact. In the event of skin or eye contact, rinse well with water. Have contact area evaluated by qualified medical personnel.
- Instructors should follow their own state’s rules for proper disposal of waste. The waste layer in the investigation contains mostly glycerol, excess methanol, and potentially unreacted potassium hydroxide. A useful document is “Biodiesel Safety and Best Management Practices for Small-Scale Noncommercial Use and Production” from Penn State’s College of Agricultural Sciences:

<http://bit.ly/highschoolnrg8>

Time Required

Two class periods, approximately 45–50 minutes each. The biodiesel reaction mixture must sit for at least 30 minutes or overnight.

Pre-Lab Discussion

This investigation introduces the concept of heat of combustion of a fuel. It also highlights the difference between renewable and non-renewable fuel sources, in particular, biodiesel and diesel obtained from crude oil. A discussion of the basic organic structures presented in the investigation would be helpful.

Lab Tips

Instead of shaking the bottle with the reaction mixture for 10 minutes, a magnetic stir bar apparatus could be used.

One option for the plastic containers with screw-top lids are “baby soda bottles,” also known as soda bottle preforms. These are sold by science supply companies and look like large plastic test tubes with 2-liter soda bottle screw-top lids.

The reaction mixture is transferred to a test tube after mixing so it is easier to see the two layers separated and to decant the top biodiesel layer. Separatory funnels could be used instead if available. The time needed for the investigation can be shortened if a centrifuge is available; portions of the reaction mixture can be centrifuged to obtain the two separated layers rather than leaving them to separate overnight.

Chilled water should be used in the combustion portion of the investigation. Ice can be added to cool the water if needed. However, unmelted ice should be removed from the water before using it in the soft drink can.

Instructors may wish to use only a few 25-mL graduated cylinders that would be reserved for this activity, as they will become coated with oil and may be difficult to clean thoroughly. Student groups can share the cylinders.

Integrating into the Curriculum

This investigation would fit into units on chemical reactions, thermodynamics, combustion, and green chemistry.

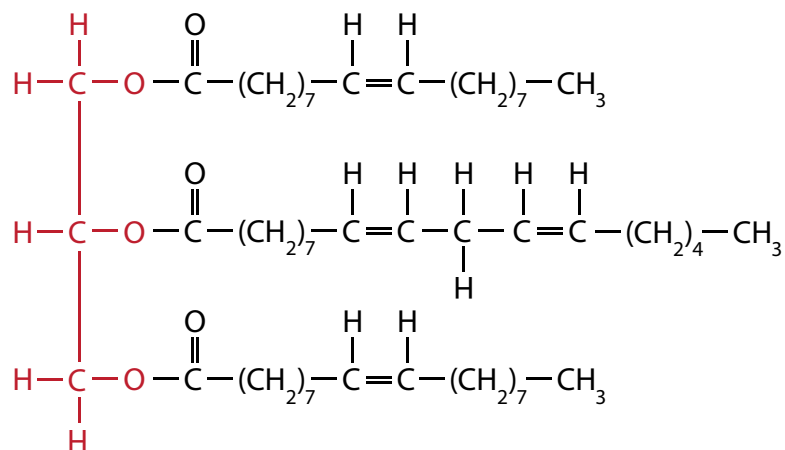
PREPARING TO INVESTIGATE

How did you get to school today? Walk? Ride a bike? Catch a bus? Drive a car? What fuel powered your method of transportation? If you walked or biked, the fuel might have been a bowl of breakfast cereal. Many school buses use diesel fuel, which is made from crude oil that was formed over an incredibly long time by the decomposition of plants and animals. What if instead you could fill your vehicle's tank and run it with recycled cooking oil? Sewage sludge? Pond scum? It's not as crazy as it may at first sound.

These sources of fat or plant oil are potential starting materials for biodiesel, a type of renewable fuel that can be used in diesel engines. Renewable energy sources are those that can be replenished in a short period of time. The materials listed above can be obtained on a much smaller time scale than crude oil; for example, this can be as short as a single growing season for plants. Crude oil resources, on the other hand, generate over such a long time that they are considered non-renewable.

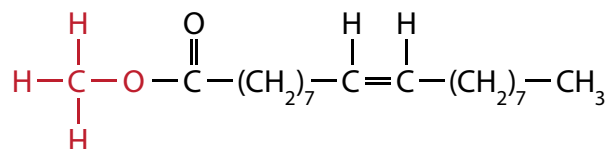
There are various issues to consider with the different possible materials. For example, certain products that would normally be considered waste, such as used cooking oil headed for the landfill, could be turned into fuel instead. However, even if all the used cooking oil was turned into biodiesel, it would be only a tiny portion of the diesel fuel used in a year. The reaction to form biodiesel from a starting product might create its own difficulties. For example, the reaction that you will use in this investigation produces both biodiesel and glycerol. But, what to do with all the leftover glycerol? It can be used in an application such as soapmaking, but with the large amounts being generated, research is being done for other ways to use it.

Canola oil, which comes from the crushed seeds of the canola plant, can be used as a starting material for biodiesel. The structure below shows a typical fat found in canola oil:

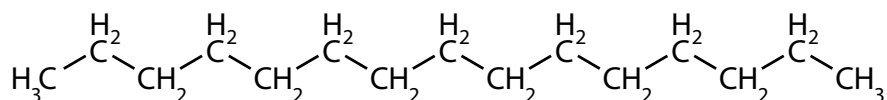


The red portion of the structure represents the glycerol backbone of the fat, while the long portions are the fatty acids that serve as a source of carboxylic acids in the preparation of biodiesel. Biodiesel synthesis breaks the bonds between the glycerol and fatty acids and adds a methyl group (one carbon atom bonded to three hydrogen atoms, —CH₃) to the end of the fatty acid.

The other reaction product is glycerol, which can be used in soapmaking. One of the three biodiesel molecules formed from the canola oil molecule above would be:



Engines designed to run on diesel fuel made from crude oil can also run on biodiesel fuel with little to no modification, although a blend of diesel and biodiesel is typically used. Diesel fuel is a mixture of hydrocarbons, molecules composed of hydrogen and carbon. Diesel contains molecules with carbon chains of 10–24 carbons. For example, one such molecule might be:



In this investigation, you will use canola oil to prepare biodiesel fuel by combining it with methanol and a potassium hydroxide catalyst. Then, you will combust a sample of the fuel.

GATHERING EVIDENCE

Biodiesel Preparation

1. Use a graduated cylinder to measure 25 mL of canola oil. Pour it into a plastic container with a screw-top lid. Record your observations of the oil's appearance (color, viscosity, odor).
2. Add 4 mL of methanol to the oil in the container. (Caution: Methanol is flammable and toxic. No sources of open flame should be nearby.)
3. Ask your instructor to slowly add 5 to 6 drops of 9 M potassium hydroxide to the liquid in the container. (Caution: Potassium hydroxide is corrosive.)
4. Tightly cap the plastic container. Shake vigorously for 10 minutes.
5. Add 0.5 g sodium chloride to the container. Re-cap and shake vigorously for several seconds.
6. Transfer the liquid to a large test tube (should be able to hold at least 30–35 mL). Stopper the top of the test tube with a cork or rubber stopper.
7. Allow the test tube to sit in a rack for 30 minutes or overnight. What happens to the contents of the test tube?



Biodiesel Combustion

1. Set up the apparatus pictured in the top photograph to measure the heat of combustion of the biodiesel you prepared.
 - Slightly bend up the pull tab of an empty, clean aluminum soft drink can.
 - Slide a glass stirring rod through the top hole of the pull tab.
 - Hold the glass stirring rod horizontally and set it on a ring attached to a ring stand so the soft drink can is suspended underneath it.
 - Raise or lower the ring stand so the bottom of the can is ~2 cm above the wick of the metal sample cup you will use to burn the biodiesel.
2. Prepare the sample of biodiesel for combustion as pictured in the bottom photograph.
 - Take a tea light candle in its metal cup. Remove the candle from the cup.
 - Remove the metal circle and its attached wick from the bottom of the candle.
 - Set the candle aside. Place the metal circle and its attached wick back in the metal cup, so the wick stands upright.
 - Decant ~5 mL of the biodiesel layer (top layer) from the test tube or remove ~5 mL of the top layer using a dropper. Place this sample in the metal cup.
 - Dispose of the remaining layer according to your instructor's directions.
3. Record your observations of the sample's appearance (color, viscosity, odor). Measure and record the initial weight of the biodiesel sample with the cup and wick to the nearest 0.1 g.
4. Weigh ~100 g of cold water, recording the weight to the nearest gram. Pour the water into the soft drink can. Measure and record the initial temperature of the water to the nearest degree Celsius.
5. Ignite the biodiesel sample using the wick. Once it is ignited, immediately move the metal cup underneath the soft drink can.
6. As the water in the can heats, stir it gently. Allow the biodiesel sample to burn for ~5 min.
7. Extinguish the flame by placing a watch glass over the metal cup.
8. Measure and record the highest temperature reached by the heated water to the nearest degree Celsius.



9. Allow the metal cup and sample to cool. Measure and record the final weight of the biodiesel sample with the cup and wick to the nearest 0.1 g.

ANALYZING EVIDENCE

1. Using the temperature and weight data from heating the water in the can, calculate how much thermal energy was used to heat the water. The specific heat capacity of water is $4.18 \text{ J}/(\text{g} \cdot ^\circ\text{C})$, meaning it takes 4.18 J to raise the temperature of 1 g of water by 1°C .
2. Calculate the heat of combustion in kJ/g for the sample of biodiesel you burned. The heat of combustion is the quantity of thermal energy given off when a certain amount of a substance burns. Assume that all of the energy released by the burning biodiesel is absorbed by the water.
3. Petroleum diesel (from crude oil) produces 43 kJ/g of thermal energy when burned. Compare this to the thermal energy your biodiesel sample produced when it was burned.
4. Compare your calculated heat of combustion with those calculated by the rest of the class. What is the class mean?

INTERPRETING EVIDENCE

1. What evidence was there that a reaction occurred during the biodiesel preparation?
2. Look again at the structures of two possible biodiesel and diesel molecules in the Preparing to Investigate section. What similarities do the molecules have that would help to explain how biodiesel can be used with little to no modification in diesel engines?
3. Draw the balanced equation for the reaction to form biodiesel from canola oil.

Cross Link

Students can get more practice with calculations like these in *The Energy Efficiency of Heating Water* on page 75.

REFLECTING ON THE INVESTIGATION

1. Is biodiesel a “better” fuel than diesel fuel from crude oil? Explain and support your answer.
2. The combustion of biodiesel produces carbon dioxide (CO_2), a greenhouse gas. However, biodiesel is labeled as “carbon-neutral,” meaning it does not increase the net amount of carbon (carbon dioxide) in the atmosphere. Why?
3. What is a potential concern with diverting food crops to the production of biodiesel?
4. Suppose that you wanted to make biodiesel for your own car using the method in this investigation. What challenges might you encounter in scaling up the process?

TEACHER'S KEY

Analyzing Evidence

1. Using the temperature and weight data from the heating of the water in the can, calculate how much thermal energy was used to heat the water. The specific heat capacity of water is $4.18 \text{ J}/(\text{g} \cdot ^\circ\text{C})$, meaning it takes 4.18 J to raise the temperature of 1 g of water by $1 ^\circ\text{C}$.

Answers will vary. A sample calculation is:

Data:

Mass of biodiesel burned: 3.4 g (difference between biodiesel sample, metal cup, and wick before and after burning)

Mass of water: $1.00 \times 10^2 \text{ g}$ water

Initial water temperature: $5 ^\circ\text{C}$

Final water temperature: $67 ^\circ\text{C}$

$$E = mC\Delta T = (1.00 \times 10^2 \text{ g})(4.18 \text{ J}/(\text{g} \cdot ^\circ\text{C}))(67 ^\circ\text{C} - 5 ^\circ\text{C}) = 26 \times 10^3 \text{ J}$$

2. Calculate the heat of combustion in kJ/g for the sample of biodiesel you burned. The heat of combustion is the quantity of thermal energy given off when a certain amount of a substance burns. Assume that all of the energy released by the burning biodiesel is absorbed by the water.

Answers will vary. The method of gathering data for the heat of combustion is somewhat inefficient. A sample calculation, using the data from Analyzing Evidence question 1, $26 \times 10^3 \text{ J}$, or 26 kJ , is given off by the burning biodiesel. The heat of combustion = $26 \text{ kJ} / 3.4 \text{ g} = 7.6 \text{ kJ}/\text{g}$

3. Petroleum diesel (from crude oil) produces $43 \text{ kJ}/\text{g}$ of thermal energy when burned. Compare this to the thermal energy your biodiesel sample produced when it was burned.

Gram for gram, biodiesel produces less energy.

4. Compare your calculated heat of combustion with those calculated by the rest of the class. What is the class mean?

Answers will vary, depending on class data.

Interpreting Evidence

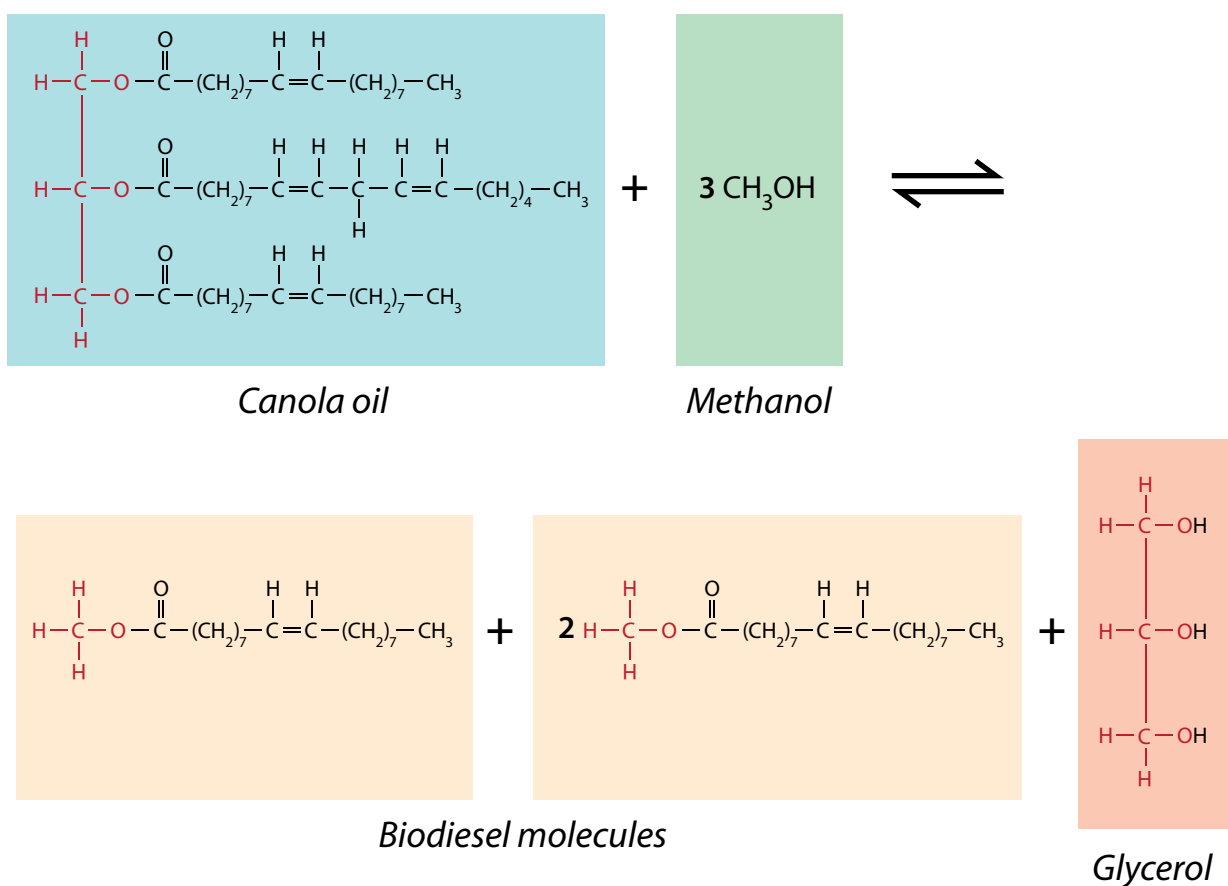
1. What evidence was there that a reaction occurred during the biodiesel preparation?

Two layers formed in the reaction mixture.

2. Look again at the structures of two possible biodiesel and diesel molecules in the Preparing to Investigate section. What similarities do the molecules have that would help to explain how biodiesel can be used with little to no modification in diesel engines?

They are both largely chains of carbon atoms of similar lengths. The biodiesel molecule has mostly hydrogen atoms bonded to the carbon atoms like the diesel molecule, but with some differences.

3. Draw the balanced equation for the reaction to form biodiesel from canola oil.



Reflecting on the Investigation

1. Is biodiesel a “better” fuel than diesel fuel from crude oil? Explain and support your answer.

Answers will vary. A “yes” answer could be supported with the idea that it is a renewable source of fuel. A “no” answer could be supported with the idea that it has a smaller heat of combustion.

2. The combustion of biodiesel produces carbon dioxide (CO_2), a greenhouse gas. However, biodiesel is labeled as “carbon-neutral,” meaning it does not increase the net amount of carbon (carbon dioxide) in the atmosphere. Why?

The combustion does release carbon dioxide. However, the carbon from the biodiesel was previously absorbed from the atmosphere by the plants used to produce the biodiesel. The release is offset by the absorption.

3. What is a potential concern with diverting food crops to the production of biodiesel?

Diverting food crops to the production of biodiesel can raise food prices for the consumer as well as possibly creating shortages of food.

4. Suppose that you wanted to make biodiesel for your own car using the method in this investigation. What challenges might you encounter in scaling up the process?

Some challenges could be difficulties in shaking a large mixture; storage of the starting and finished materials and by-products, including a corrosive, highly basic solution; and obtaining necessary amounts of the starting materials.

Post-Lab Discussion

The viability and practicality of using biodiesel as a replacement fuel could be at the center of a rich discussion, particularly if students did further research on the topic. Additional biodiesel starting materials could be discussed, such as soybeans.

Students may be interested in learning more about how vegetable oils such as canola oil can be used directly in diesel engines. Some modifications are made to the engines. For example, the oil must be heated before it enters the engine, due to its higher viscosity than diesel fuel. This could be combined with a discussion of gelling that can occur in diesel and biodiesel fuels at low temperatures.

Students could explore the reaction stoichiometry semi-quantitatively, including an estimation of how many moles of oil and methanol are used, and which is in excess.

Extensions

1. The American Chemical Society (ACS) textbook *Chemistry in the Community* has an excellent series of questions where students decide whether it is viable for biodiesel made from soybeans to completely replace diesel made from crude oil. (*Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 374–375)
2. Both biodiesel and diesel fuels can “gel” at low temperatures, making modifications necessary for areas that experience cold weather. Students could determine the temperature at which their biodiesel sample gels and decide if it would be a reasonable fuel for their local area. Place a small sample (~1 mL) in a test tube. Leave the test tube in a freezer until the biodiesel gels, approximately 15 minutes. Remove the test tube. Gently stir the sample with a thermometer and observe the temperature at which the sample becomes liquid again.
3. Use a “fire syringe” to demonstrate the principle of the diesel engine, that thermal energy is produced when a gas is rapidly compressed and can ignite fuel. The product is available from science supply companies, such as www.teachersource.com/product/fire-syringe-demo. The link includes a video showing the fire syringe in action; see another example at www.youtube.com/watch?v=MnpvQvCTj90.
4. The ACS has a sustainable energy section online with links and podcasts about different biofuel sources, such as chicken feathers, and more at <http://bit.ly/highschoolnrg9>.
5. Students could read articles related to the topic from *ChemMatters*, an ACS magazine for high school chemistry students:
 - Hill, M. “From Fish Tank to Fuel Tank,” *ChemMatters*, 2012, 30 (2), pp 12–14.
 - Nolte, B. “Tanking Up with Cooking Oil,” *ChemMatters*, 2011, 29 (2), pp 5–7.
 - Kirchhoff, M. “Do You Want Biodiesel with That?” *ChemMatters*, 2005, 23 (2), pp 7–9.

Additional Resources

- “D.8 Synthesizing and Evaluating Biodiesel Fuel,” *Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 371–373.
- “C.4 Combustion,” *Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 337–341.
- “Biodiesel: Using Renewable Resources,” *Introduction to Green Chemistry*, Washington, DC: American Chemical Society, 2002, pp 13–22.

Electrolysis of Water | A Demonstration

Summary

In this demonstration, students investigate the idea that energy from a battery can be used to drive a chemical reaction that does not happen spontaneously, such as the splitting of water molecules to produce hydrogen and oxygen gases.

Objective

Students learn about using an outside energy source to drive a chemical reaction.

Safety

Be sure you and the students wear properly fitting goggles.

Materials

- 9-volt battery
- Two metal thumbtacks
- Water
- Epsom salt ($\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$)
- Clean, empty, clear and colorless plastic water bottle with cap with the label removed
- Scissors
- Black permanent marker
- Beaker or plastic cup
- Paper towels or modeling clay

Time Required

Part of one class period, approximately 10–15 minutes.

Demo Tips

Epsom salt can be purchased locally in drugstores, where it is sold as a laxative and as a material to add to a warm water bath for treating aches and pains. Plastic containers other than a water bottle can be used, as long as the container has a flat bottom for easy connection to the battery contacts and the plastic is thin enough to easily push the thumbtacks through. For example, small plastic condiment cups could be used.

Integrating into the Curriculum

This demonstration could fit into a unit on chemical reactions or thermochemistry.

PREPARATION

1. Remove the cap from a clean, empty, clear and colorless plastic water bottle. Turn the lid over so that the top of the lid touches the two contacts of a 9-volt battery. Center the lid over the two contacts. Using a black permanent marker, make two dots on the inside of the lid, one over the center of each contact.
2. Place the lid on a hard surface with the top of the lid facing up. Push a metal thumbtack into the top of the lid directly over one of the dots. Push a second thumbtack into the lid directly over the second dot. The two thumbtacks should not touch.
3. Using scissors, cut off the top half of the bottle, so that it looks like a funnel. Screw the lid back onto the bottle.



DEMONSTRATION

1. Show students the top half of the bottle, particularly the two metal thumbtacks pushed through the lid.
2. Fill the bottom half of the cut water bottle approximately half full of water. Add about a teaspoon of Epsom salt. Swirl to stir until most of the salt dissolves.
3. Pour the Epsom salt solution into the top half of the bottle (hold so the lid faces down).
4. Ask a volunteer student to observe the solution, particularly the two points of the metal thumbtacks. Is there any evidence of a reaction occurring?
5. Place the two metal thumbtacks so that each thumbtack touches one of the contacts on the 9-volt battery. Ask the volunteer to observe the solution again. Is there any evidence of a reaction occurring?
6. The battery can be placed into the bottom of a beaker or clear, colorless plastic cup, held upright with paper towels or modeling clay. The top of the bottle can then be rested on top of the battery with more stability if the instructor wishes to show it up close to the rest of the class.

DISCUSSION WITH STUDENTS

1. What evidence is there that a reaction occurs when the battery contacts touch the metal thumbtacks?

Bubbles of one or more gases are produced and rise from each of the thumbtacks.

2. Is there any difference in the amount of gas produced at each battery contact?

Yes, more bubbles are produced at one of the connections.

3. Could the difference described in question 2 be due to a difference in the tacks? What could one do with the apparatus to potentially provide support for the idea that the battery contact is responsible?

One could rotate the battery contacts so that each contact is now touching the opposite thumbtack. The battery contact that produced more bubbles the first time should still produce more bubbles when touching either thumbtack.

4. What is the purpose of the battery?

The battery drives a reaction that we did not observe happening spontaneously without this additional outside energy source.

5. Why is Epsom salt added to the water?

Epsom salt is an electrolyte and serves to conduct electricity through the solution. Electricity from the battery is able to travel through the solution and between the two thumbtacks.

6. What is the balanced equation for the breaking apart of water molecules?



7. If the reaction we are observing is the breaking apart of water molecules, which battery contact might be producing which gas and why?

The reaction for the breaking apart of water molecules shows two gases being produced, H₂ and O₂. In the equation, twice as much hydrogen gas is produced than oxygen gas. The battery contact that produces more bubbles would be the one producing hydrogen gas.

8. What could be done to gather further evidence that there are two gases produced and that they are H₂ and O₂?

One could collect the gases produced and test them for known properties of H₂ and O₂ gases.

EXPLANATION

Separating the word “electrolysis” into its component parts summarizes its meaning—using electricity (electro-) to break apart (-lysis) something. In this demonstration, the electricity supplied by a 9-volt battery is used to break apart water molecules, overall producing hydrogen and oxygen gases.

The idea of including energy as a reactant or a product in a chemical equation can be used to illustrate the need for an additional outside energy force to drive a reaction that normally does

not happen spontaneously and to connect the demonstration to the concepts of exothermic and endothermic reactions.

For example, *Chemistry in the Community* describes:

...if a particular chemical reaction is exothermic (releasing thermal energy), then the reverse reaction is endothermic (converting thermal into potential energy). For example, burning hydrogen gas—involving the formation of water—is exothermic. The energy released by formation of H–O bonds in water molecules is greater than that required to break bonds in H₂ and O₂ molecules:



Therefore, the separation of water into its elements—the reverse reaction—must be endothermic, the quantity of energy equal to the quantity released when water is formed from gaseous H₂ and O₂.



EXTENSIONS

Challenge students to design a method for collecting the gases in the demonstration and to describe how they could be tested to determine if they are H₂ and O₂, and which is which. Glass tubes filled with the Epsom salt solution can be inverted over the two thumbtacks to collect the gases; it can take a substantial amount of time to collect an appreciable amount of gas.

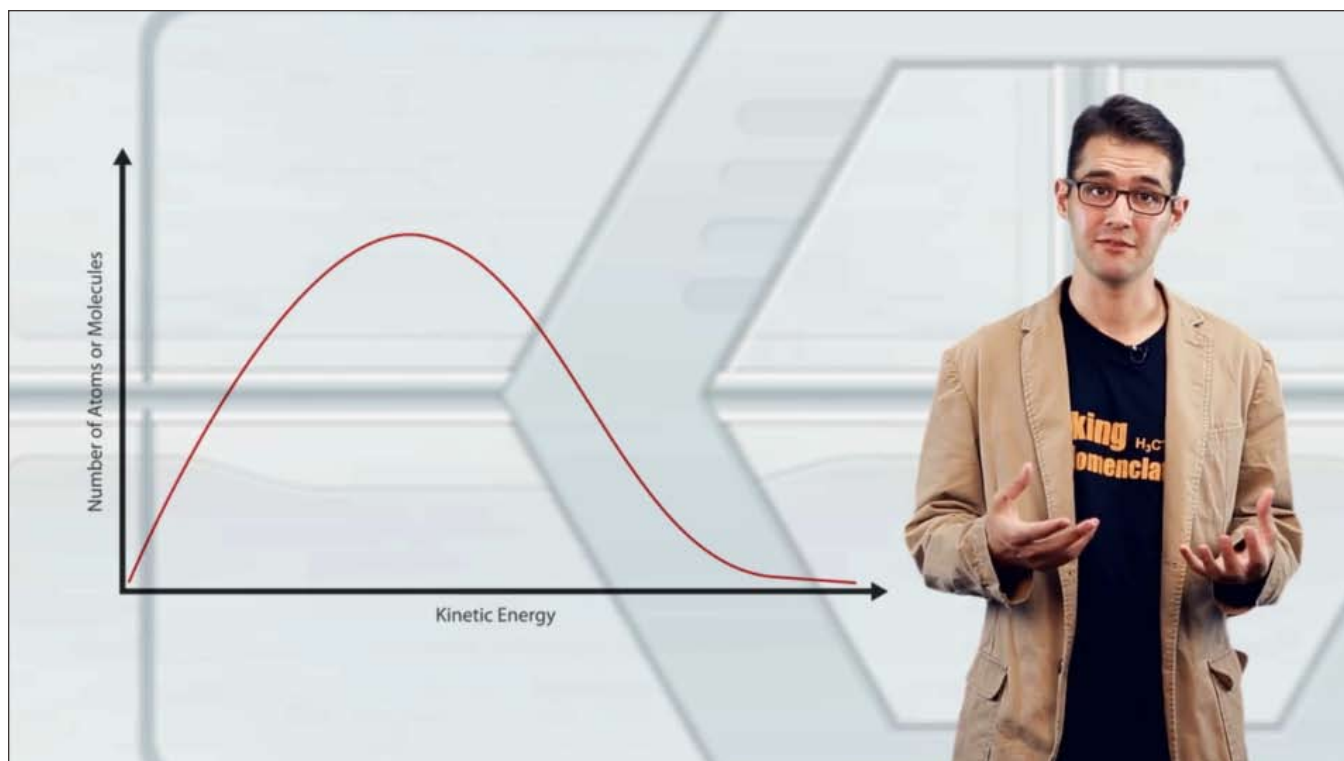
Showing the reverse reaction, that of mixing hydrogen and oxygen gases and combusting them, could be used in connection with this electrolysis demonstration. This explosive, exothermic reaction should be used with appropriate safety precautions and equipment.

Another common setup used for showing water electrolysis uses two graphite pencils sharpened on both ends as electrodes. Directions written for students to carry out this investigation are available for free as part of the American Chemical Society curriculum “Middle School Chemistry” in Lesson 4.4—www.middleschoolchemistry.com/lessonplans/chapter4/lesson4.

ADDITIONAL RESOURCES

- *Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 335–336.
- ChemTeacher Demonstrations: Demonstrate Water Electrolysis in a Simple Way.
<http://bit.ly/highschoolnrg10>

Temperature & Energy | A Video



This video explores evaporation and the definition of temperature. It can be used as a supplement to an investigation, or may stand on its own to introduce a lesson or extend student learning.

highschoolenergy.acs.org/how-do-we-use-energy/temperature-energy.html

Video Transcript

Chris

Ah, the humble thermometer. Whether we want to know if our holiday turkey is cooked or if we need concrete proof that we're too sick to attend school, a thermometer is the exact scientific tool we need. But what, exactly, does a thermometer measure?

In other words, what is temperature, really?

Brittny

Whether it's solid, liquid, or gas, all matter is made up of atoms and molecules. These particles are constantly in motion. They collide with each other and with the walls of anything they are contained in. We quantify the motions of the particles by their kinetic energies.

In chemistry, we define the temperature of a substance as the average kinetic energy of all the atoms or molecules of that substance.

Not all of the particles of a substance have the same kinetic energy. At any given time, the kinetic energy of the particles can be represented by a distribution. Some atoms or molecules have a lot of kinetic energy and move very fast. Other atoms or molecules have a little kinetic energy and move very slowly. It is the *average* kinetic energy of the particles that thermometers measure and we record as the temperature.

One process that illustrates varying kinetic energies particularly well is evaporation. As you probably know, evaporation is a phase change where particles of a substance move from the liquid phase into the gas phase.

But have you ever wondered how a puddle of water can evaporate at room temperature? Keep that in mind—we'll come back to that question in a bit.

Chris

When we think about a phase change from liquid to gas, we often think about adding thermal energy to a liquid by heating it up. When we do, the molecules of the liquid move faster and spread slightly farther apart, until they acquire enough energy to overcome the attractions they have for other molecules of the liquid and enter the gas phase.

Think about this: If someone asked you to turn a beaker full of water into water vapor, what would you do?

Being the brilliant young scientist that you are, you might put it on a hot plate and crank up the heat. Now you can kick back and relax until the hot plate transfers enough energy to get all the water molecules to transition from the liquid phase to the gas phase. In less science-y terms, you would boil the water.

Boiling is a special example of a liquid-to-gas phase change that occurs at a specific temperature called the boiling point, where the vapor pressure of the substance is equal to one atmosphere pressure. Boiling is usually carried out using a continuous input of energy from an external source (like a hot plate) to keep the temperature constant.

The obvious conclusion is this: If you continuously add thermal energy from a hot plate you can cause a phase change from liquid to gas.

But how can a puddle of water evaporate at room temperature?

When water evaporates at room temperature, some fast-moving, highly energetic molecules have enough energy to overcome the attractions that individual molecules have for one another and enter the gas phase. As these high-energy molecules leave the liquid phase, the average energy of the remaining liquid molecules is lowered, and their temperature decreases. This liquid is at a lower energy than its surroundings, so it absorbs energy from those surroundings. The cycle continues as the puddle slowly disappears.

Boiling is a faster process because the surroundings (the hot plate) heat the liquid to a higher temperature where more molecules have high energy, so vaporization is faster. The hot plate is hotter than the liquid, so thermal energy transfer is fast enough to keep the liquid temperature constant at the boiling temperature.

Evaporation can take place at any temperature because some of the molecules in a liquid—the ones at the higher end of the distribution—will always have enough energy to enter the gas phase.

Chris

To sum up, temperature represents the average kinetic energy of the particles of substance. But it's the spread of kinetic energies among the individual particles that explains why puddles dry up.



The Explosive History of Nitrogen

By Tim Graham

April 16, 1947. It started with a small fire on the **S.S. Grand Camp**, a French cargo ship anchored off Texas City, TX. The ship had recently taken on 2380 tons of ammonium nitrate (NH_4NO_3) fertilizer.

Early efforts by the crew to extinguish the fire were unsuccessful. The fire soon raged out of control. At 9:12 a.m., the ammonium nitrate exploded, sending the 7200-ton ship 20 feet in the air—the first of a series of catastrophic events. Burning debris reached surrounding oil refineries and chemical plants. A 15-foot tidal wave caused two other ships anchored in the harbor to collide. Both were soon ablaze. One of impacted vessels also contained ammonium nitrate. By the time the last flame had been extinguished, 576 people were dead and Texas City was in ruins.



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PHOTO: DISC

Before 1850.

By the mid-1800s, much research on potential explosives had already been done, most of which focused on nitrating solid substances that contained carbon...wood, coal, etc.

1846. Nitroglycerin

is developed by the Italian chemist Asconio Sobrero. Believing that organic liquid substances might show more promise than solids, he nitrated glycerol. The resulting oily yellow liquid, called nitroglycerin, was a powerful explosive that was quite sensitive to shock. But he failed to develop a controlled and effective way to ignite it.



1863. The blasting cap

is invented by Alfred Nobel as a means for exploding nitroglycerin. A blasting cap is a smaller primary explosive that is used to initiate the larger explosion. Nobel placed the nitroglycerin in an insulated container, added a gunpowder primer with safety fuse, and sealed the entire container. Moments after the fuse was lit, the gunpowder cartridge would explode and this, in turn, created enough energy to detonate the nitroglycerin.

1863. Trinitrotoluene,

or TNT, is discovered to be a powerful explosive by the German chemist J. Wilbrand. It proves to be too expensive to manufacture in large quantities.

April 19, 1995. It was one of the most devastating acts of domestic terrorism ever to hit our nation. A truck loaded with roughly two tons of a mixture of ammonium nitrate fertilizer and fuel oil was detonated with a blasting cap on a street just outside the Alfred P. Murrah Federal Building in Oklahoma City, OK. A total of 168 people, many of them children, lost their lives. In 1997, two U.S. citizens, Timothy McVeigh and Terry Nichols, were convicted. McVeigh was sentenced to death and executed on June 11, 2001. Nichols is serving a life sentence.

Ever since Alfred Nobel, the founder of the Nobel Peace Prize, developed a process to make dynamite in 1867, explosives have played a key role in both peace and war.



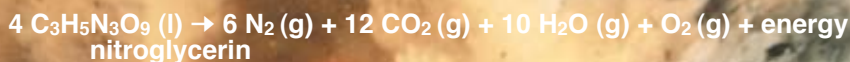
© THE NOBEL FOUNDATION

Today, when we think of explosives, substances like TNT (trinitrotoluene) and nitroglycerin come to mind. But ammonium nitrate? That's just a simple fertilizer! What is it about this simple inorganic compound that can cause it to react so violently? As you probably guessed, the answer is in the chemistry.

All explosions share some features. They all involve the rapid and violent release of large amounts of energy from a confined region of space. Particularly true for chemical explosions, they often involve the rapid expansion of gases generated during the explosion itself. Chemical explosions like those in Texas City and Oklahoma City are accompanied

by a loud sharp report, flying debris, heat, light, and fire.

An explosive is a chemical compound or mixture that does the job. The explosive decomposition of nitroglycerin illustrates several features common to explosions:



First, the reaction is exothermic, meaning that it releases energy. Second, it produces several gaseous products, all of which expand as the released energy raises the temperature. Third, even though the equation doesn't show it, the reaction is very rapid—once underway, all the energy is released in a very short time. Finally, the reactants include the element nitrogen.

Why do so many explosives contain the element nitrogen? Look at the products of explosive reactions and you'll find the same gas showing up over and over—ordinary nitrogen gas, N_2 . The irony is that

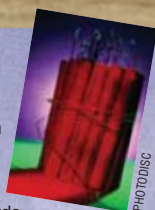
nitrogen gas is a very stable compound at a very low energy state. But when it is formed from reactants that start out in a very *high* energy state, a very large amount of energy is released in the process. Kaboom!

Why do explosive compounds react so rapidly? One way to speed

up a reaction is to thoroughly mix the reactants. Mixing allows for immediate contact to occur. You may have read about explosions in flour mills and grain elevators. Even otherwise harmless substances like flour can explode violently if thoroughly mixed with air and ignited by a spark.

1867. Dynamite

is invented. Nitroglycerin is a highly unstable liquid likely to explode with the slightest shock. To reduce its obvious hazards, Nobel uses a finely powdered silicon-based absorbent called Kieselguhr to soak up the liquid nitroglycerin—thus, stabilizing the explosive without sacrificing its strength. Later, he replaces Kieselguhr with sawdust and sodium nitrate. He substitutes ammonium nitrate for some of the nitroglycerin to make a new, low-cost explosive, dynamite.



PHOTODISC

1900. TNT production costs drop.

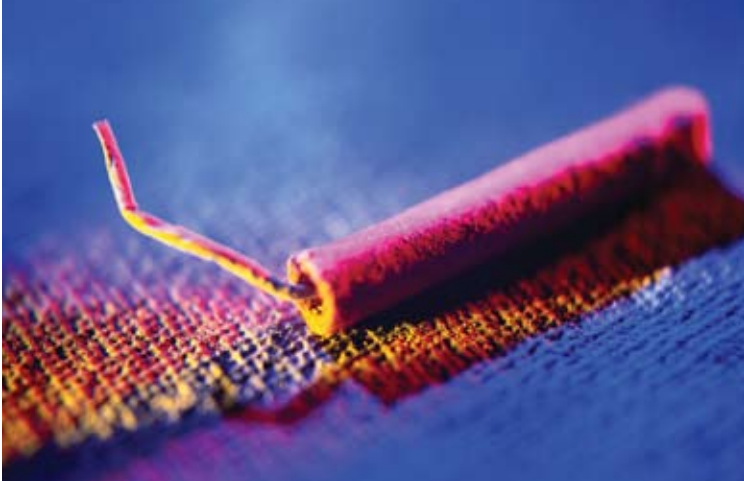
TNT is appreciated as a very stable solid that can be poured and even melted with relative safety.

1914. TNT is used as a weapon in World War I.

TNT's big advantage over dynamite is its capacity for producing shock waves that can rupture the steel on armor-plated vehicles.

1940. World War II

weaponry introduces two new explosives, **RDX** (hexahydro-1,3,5-trinitro-1,3,5-triazine) and **PETN** (pentaerythritol tetranitrate). With additions of wax, motor oil, and other stabilizing fillers, RDX is renamed *Composition Four*, or C-4 explosive. Stable within a large temperature range (-70° to 170°F), safe to handle, and easy to mold due to its plastic-like properties, C-4 is attached to bridge supports, armored vehicles, or the hulls of ships. It is detonated with blasting caps.



Ammonium nitrate replaced unstable nitroglycerin to make the low-cost explosive—dynamite.

PHOTODISC

Molecules of explosive compounds like nitroglycerin or trinitrotoluene take the mixing step one step further. For these compounds all of the reactants are on board the same molecule. Immediate contact is assured.

Let's go back to the Texas City tragedy. What caused the ammonium nitrate in the holds of the ship to explode without the use of some other explosive? Chemists found that the answer was in the bag. The ammonium nitrate fertilizer was packaged in plain paper. The cellulose used to make paper contains a large amount of the element carbon. It was the carbon and ammonium nitrate mixture that reacted to unleash the tragic explosion.

By analyzing the circumstances surrounding the Texas tragedy, chemists began to appreciate the power and potential of ammonium nitrate-based explosives. An effective, relatively safe, and inexpensive explosive called ANFO (ammonium nitrate fuel oil) was developed. And there were no risky transport problems to be solved. To make ANFO, ammonium nitrate and fuel oil were mixed at the blast site.

But ANFO was limited as a commercial explosive. Ammonium nitrate is water-soluble. As it gains water, the energy necessary to initiate its reaction with fuel oil increases to levels making it useless as an

explosive. Dupont chemists went to work to produce a form of ammonium nitrate that would detonate even in a wet environment. By adding sensitizers, they were able to detonate the mixture with less-energetic shock waves. Then by adding thickening agents, they produced a syruplike mixture called TOVEX—easy

to pour into drill holes at the blasting site.

It's interesting that dynamite's inventor Alfred Nobel became a pacifist later in life. The man whose name will forever be known as the father of modern explosives dedicated much of his influence and fortune to opposing their use as weapons of destruction. ▲

Tim Graham teaches chemistry at Roosevelt High School in Wyandotte, MI. His most recent article "Luminol—Casting a Revealing Light on Crime" appeared in the December 2001 issue of *ChemMatters*.

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 Fisher, D. E. and Fisher, M. J. The Nitrogen Bomb. *Discover*, April 2001, pp 52–57.



Ammonium nitrate, the key reactant in several explosives, is a common ingredient in many plant fertilizers.

MIKE CIESIELSKI



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1945. Ammonium nitrate

is manufactured, stockpiled, and shipped to war-torn Europe as an inexpensive fertilizer for enriching depleted farm soil. Its potential explosive power is known, but its stability relative to other explosives seems adequate for production and storage.

1947. S.S. Grand Camp explodes in Texas City Harbor.

Chemists reconsider the stability of ammonium nitrate.



1957. ANFO

(Ammonium Nitrate Fuel Oil) explosive is developed by taking ammonium nitrate "prills" and mixing them with liquid fuel oil to make a "slush". Mixed at the blast site, ANFO is relatively safe to handle.

1988. Pan AM Flight 103

wreckage is found to contain RDX residue. Presumably, as a result of terrorism, the plane crashed in Lockerbie, Scotland, killing all 270 people on board.

