HYDROGEN AS FUEL
TEACHER'S GUIDE

Time

1-4 class periods

This lesson is a modular design that you can tailor to suit your class and your time. You can complete the entire lesson in one class period, or use it over several classes. You can also use this lesson in conjunction with the fuel cell lesson, *Fuel Cells for Transportation*.

Objectives

- Recognize the properties of hydrogen
- Learn how hydrogen is made
- Explore how vehicles store hydrogen

Content Standards

- Atomic and Molecular Structure
- Chemical Bonds
- Gases and Their Properties
- Chemical Thermodynamics

Background

Fuel cells create electricity from hydrogen and oxygen. The only byproducts from the reaction are water and heat. Vehicles powered by hydrogen fuel cells are all-electric, zero emission cars, SUVs and buses.

In California, about 250 passenger vehicles and transit buses have been placed in operation. Most are driven by regular people in everyday situations. The vehicles fuel at 25 hydrogen stations currently operating in the state.

As with any change to the transportation system, hydrogen fuel has it's challenges. This lesson is designed to introduce some of the benefits of using hydrogen and one of the challenges—storing the hydrogen onboard the vehicle.

Materials Needed

- Empty syringes
- Balloons
- Measuring tape
- Access to boiling water and a freezer
- Pencils, or carbon or graphite rods
- Solar panels or 9-volt batteries
- Wire
- Salt or baking powder

Additional Student Activities/Assignments

Research hydrogen safety. What caused the Hindenburg to burn?

Create a comparison chart of hydrogen, gasoline, natural gas, ethanol and electricity. What are the benefits and challenges with each?

Assign teams of students to research different methods of producing hydrogen as fuel. Each team can present the benefits and scientific challenges of each method.

- Steam reforming at a central plant
- Steam reforming at the station
- Nuclear power
- Solar electrolysis
- Biomass from plant waste
- Biomass from landfill gas
- Industrial waste

Resources

U.S. Department of Energy
www.energy.gov/energysources

National Hydrogen Association
www.hydrogenassociation.org

California Fuel Cell Partnership
www.cafcp.org

The NEED Project
www.need.org/needpdf/HydrogenTeacher.pdf
www.need.org/needpdf/HydrogenStudent.pdf

Instructor Notes and Background

A Little History First

"Town gas" was about 50% hydrogen, 40% methane and 10% other gases. It was used to provide gas heat and light. In the 1930s, natural gas was discovered in the US and pipelines soon replaced town gas deliveries.

Zepplins, rigid airships filled with helium or hydrogen, were the first commercial air travel. In the 1930s, zepplins ferried people from Europe to the US. In 1937, the zepplin Hindenberg caught fire while landing in New Jersey. For many years, experts believed that leaking hydrogen caused the disaster. More recently, experts believe that the fire was caused by a coating on the ship's hull.

Properties of Hydrogen

Hydrogen molecules are so small that they will pass through glass, drywall, wood and most metals. Hydrogen is 14 times lighter than air. If it escapes from a container, it will always move up. The molecules disperse at a speed of 40 miles per hour; so fast that it's impossible to add a color or odorant, like we do for propane. The hydrogen would be gone before the molecules of the odorant left the container.

The molecule illustrations are methane, water and ethanol (or alcohol).

Electrolysis Experiment Questions

1. **About how long did it take for the bubbles to form?**
   A. *It should take about one minute.*
2. **Did the water or the pencils get warm?**
   A. *Students should not notice a change in water or pencil temperature.*
3. **Why do some of the bubbles cling to the pencils?**
   A. *The negative and positive ions are attracted to the opposite poles in the circuit. (To pick up or drop off an electron.)*
4. **What happens to the bubbles that surface?**
   A. *They become part of the air.*
5. **Did you need to add salt or baking soda? Why might you need a catalyst?**
   A. *Water is not a good conductor. You need a catalyst if your water is low in minerals or if your power source is less than 1.5 volts.*
6. **Why not put the wires directly in the water instead of attaching them to the pencils?**
   A. *The minerals in the water can reactly directly with the metal in the wires. This is how jewelry and other items are electroplated. The graphite in the pencils is electrically neutral.*

Storing Hydrogen

Try Boyle's law online at www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html

Try Charles' law online at www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/charles_law.html

Discussion questions

1. **What materials must the tank use to store hydrogen onboard the vehicle?**
   A. *The tanks are aluminum or polymer cylinders wrapped with carbon fiber. The carbon fiber keeps reinforces the tan*k.
2. **How does hydrogen pressure effect the weight of the tank?**
   A. *The greater the pressure, the thicker the walls of the tank need to be, making the tank heavier.*
3. **Would a liquid storage tank be different from a gaseous tank?**
   A. *Yes. Liquid tanks need to be like a super-thermos to keep the H_2 at a cryogenic temperature.*
4. **Are hydrogen tanks heavier or lighter than gasoline tanks?**
   A. *Several hundred pounds heavier.*
5. **Why is weight of the tank important?**
   A. *Weight reduces efficiency.*
6. **How does ambient temperature effect the volume of hydrogen?**
   A. *When it's very hot or very cold, a kilogram of hydrogen takes up more or less space. It could mean that in very hot climates you couldn't get a full tank of fuel.*
7. **What happens to liquid hydrogen that warms up in a station or in a vehicle?**
   A. *It boils off, just as gasoline evaporates. Hydrogen stations have vents for hydrogen, just as gas stations have vents for evaporating gasoline.*

HYDROGEN AS FUEL

A Little History First

Hydrogen was first discovered more than 500 years ago. A scientist who called himself *Paracelsus*—para, meaning higher than, and celsus, the name of a very intelligent man named Aulus Cornelius Celsus. Paracelsus was reacting metals with acids when he produced a gas. He didn't know what exactly the gas was, but he knew it was flammable.

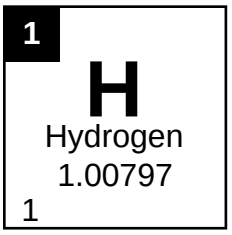
For the next several hundred years, scientists refined the discovery. It was Henry Cavendish who, in 1766, identified hydrogen as a unique substance he called "inflammable air."

In 1808, Antoine Lavoisier, sometimes called the father of chemistry, gave the substance the name hydrogen, which means "water-forming" in Greek.

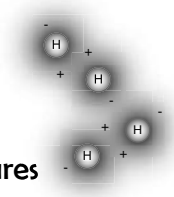
In the late-1800s through the mid-1900s, hydrogen was used as a "town gas" to provide light and heat. This continued until natural gas was discovered. In the 1950s, NASA began using hydrogen as fuel for space craft, including those that went to the moon.

Today, hydrogen is used extensively. It is a key component in manufacturing ammonia, methanol, gasoline, and heating oil. It is also used to make fertilizers, glass, refined metals, vitamins, cosmetics, semiconductor circuits, soaps, lubricants, cleaners, margarine, peanut butter and rocket fuel. Hydrogen continues to power the Space Shuttle and is starting to be used as transportation fuel.

The Properties of Hydrogen

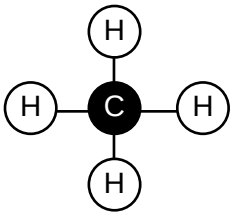


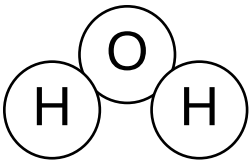
- First element in the periodic table
- The lightest element
- One electron and one proton
- A colorless, odorless gas at normal temperatures
- Flammable when mixed with oxygen

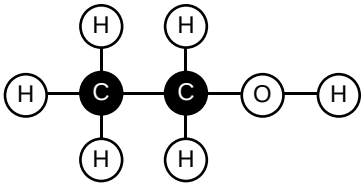


Hydrogen molecules are usually shown in a fuzzy cloud. The electron moves so fast that it can be anywhere. The cloud represents the probablity of where the electron will be.

Hydrogen is a *diatomic molecule*, meaning that naturally occurring hydrogen is always two molecules. On Earth, hydrogen is always bound to another molecule. Can you identify these common compounds?







You make hydrogen by releasing it from one of these compounds. Today, most hydrogen is produced from natural gas in a process called steam reforming. *Electrolysis* is another way to make hydrogen.

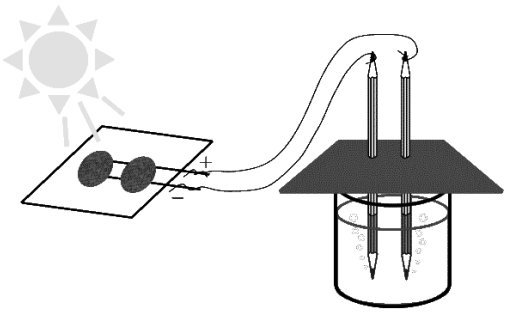
Glossary

Diatomic — Molecules made only of two atoms
Electron — Negatively charged particle in an atom
Electrolysis — Chemical change produced by an electric current
Proton — Positively charged particle in an atom

Experiment: Electrolyze water

Materials needed

A 9-volt battery or solar panel
Two pieces of electrical wire
Two No. 2 pencils
A jar full of tap water
Small piece of cardboard
Electrical tape or alligator clips



Procedure

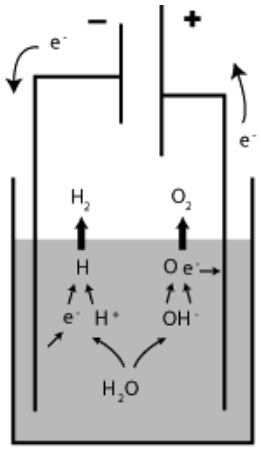
1. Remove the erasers and their metal sleeves from both pencils, and sharpen both ends of both pencils.
2. Fill the glass with warm water.
3. Attach wires to the electrodes on the solar cell or battery, and the other ends to the tips of the pencils. Secure the wires with tape or alligator clips. The wires must have good contact with the graphite!
4. Punch small holes in the cardboard, and push the pencils through the holes.
5. Place the exposed tips of the pencils in the water. The pencil tips need to be fully submerged, but not touching the bottom of the glass.
6. After a minute or so, small bubbles will begin to form on the tips of the pencils. Hydrogen bubbles will form on the pencil attached to the *cathode* and oxygen on the *anode* pencil. (If you do not see the bubbles, add a little salt or baking powder to the water to act as a *catalyst*.)

If hydrogen is so light, why does it cling to the pencil?

Electricity is a string of electrons. The cathode (the negative electrode) will push electrons into the water. The anode (the positive electrode) will pull electrons from the water. However, water isn't a very good conductor for the electrons. To keep the electrons moving around the circuit, the water molecules near the cathode split into a positively charged hydrogen *ion* (the hydrogen atom with only its proton) and a negatively charged "hydroxide" ion (OH-), which is an oxygen atom and a hydrogen electron.

The H+ ion, which is just a naked proton, needs an electron. The best place to find one is at the tip of the cathode pencil. Once it becomes a neutral hydrogen atom, the atom finds another single hydrogen atom. The H_2 molecule is stable and bubbles to the surface.

Meanwhile, the negatively charged hydroxide ion travels across the jar to the anode pencil, the best place to get rid of the extra electron the ion stole from the hydrogen atom earlier. Once the extra electron is gone, four of the hydroxide ions recombine and form one oxygen molecule and two water molecules. The O_2 molecule bubbles to the surface.



Glossary

Anode — The negatively charged terminal
Catalyst — A substance that modifies and increases the rate of a reaction without being consumed in the process
Cathode — The positively charged terminal
Ion — An atom that has acquired a net electric charge by gaining or losing one or more electrons
Thermodynamics — Relationships between heat, work and energy

About Your Experiment

1. About how long did it take for the bubbles to form?

2. Did the water or the pencils get warm?

3. Why do some of the bubbles cling to the pencils?

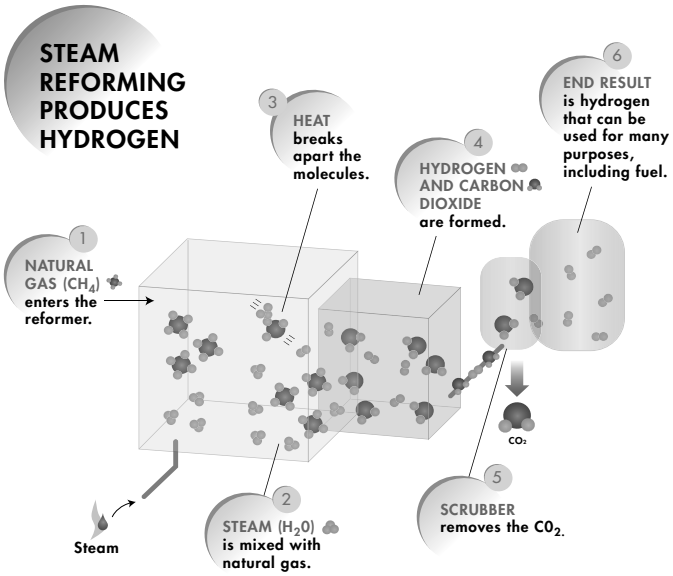
4. What happens to the hydrogen and oxygen that bubble to the surface?

5. Did you need to add salt or baking soda? Why might you need a catalyst?

Challenge question

6. Why not put the wires directly in the water instead of attaching them to the pencils?

Making Hydrogen from Natural Gas

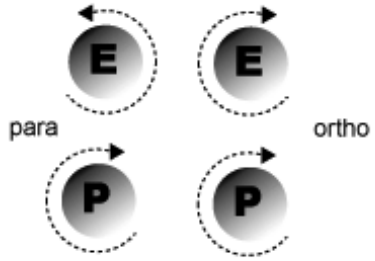


The world produces more than 56 billion *kilograms* of hydrogen each year (the equivalent of 56 billion gallons of gasoline). Most of it comes from natural gas.

The illustration shows the basic steps of steam reforming. The hydrogen that results in step 6 is super-heated, about 2,000 degrees Fahrenheit. Transporting hydrogen to a station or manufacturing plant is easiest if the hydrogen is in a liquid state, which means cooling it to -423°F. This is a *cryogenic* temperature.

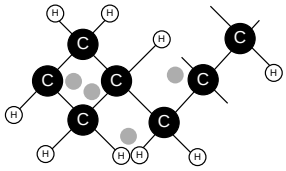
The hot hydrogen molecules move through a series of six-foot-long pistons. Because a gas will expand to fill the available space, the hot hydrogen expands and forces the piston to move. Each time the molecules drive a piston, the spent energy causes the hydrogen to decrease in temperature by half.

A final cooling process is to move through a series of *catalysts* that force the electron to change the direction that it orbits around the proton. In all atoms, the electrons move in different orbits. If the electron moves counter-clockwise, it's a "para" orbit. A clockwise orbit is called "ortho." Repeatedly forcing the electrons to change their orbits cools the hydrogen even further. The final stage makes all the electrons spin in the same orbital direction. The hydrogen will cool from 2,000 degrees to -423°F—all in less than one minute!



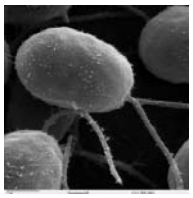
Future Sources of Hydrogen

Hydrogen from coal



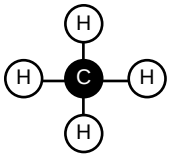
Gasification works by mixing coal with oxygen, air, or steam at very high temperatures without letting combustion occur. Similar to steam reforming, gasifying coal releases the hydrogen stored in the hydrocarbon molecule.

Hydrogen from algea



Scientists have discovered that algea produce hydrogen as a byproduct of *photosynthesis*. Researchers are experimenting with ways to produce enough hydrogen in a small space to provide fuel.

Hydrogen from landfill gas



Carbon dioxide and methane gas from a landfill are fed into a reactor. The gases are heated with solar energy, an *endothermic* reaction forms hydrogen gas and carbon monoxide.

Hydrogen from biomass

Plant material is put into a chamber and then heated in a process called *pyrolysis*. The heat releases the gases, including hydrogen, inside the biomass without being so hot that the biomass combusts.

Glossary

Cryogenic — Low temperature
Endothermic — A reaction that absorbs heat
Gasification — Process that converts a substance to a gas
Kilogram — A unit of mass equal to about 2.2 pounds
Pyrolysis — Decomposition of a compound caused by heat
Photosynthesis — Synthesis of carbohydrates from carbon dioxide and water by plants in sunlight

Storing Hydrogen

One of the challenges with hydrogen-powered vehicles is storing enough fuel. Liquid fuels, like gasoline and diesel, contain a large amount of energy compared to their *density*. A kilogram of hydrogen contains about the same amount of energy as a gallon of gasoline, but has a greater volume. Because hydrogen is a gaseous state at normal temperatures, the same amount of energy takes up more space. Currently, fuel cell vehicles carry compressed gaseous hydrogen. Two laws of science come into play when storing compressed hydrogen.

Boyle's Law

If a fixed quanity of gas is at a fixed temperature, its volume will be inversely proportional to its pressure.

Try it

Fill a syringe with air. Put your finger on the open end and depress the plunger. As you push further, the plunger becomes harder to press because of the pressure of the gas trapped in the syringe. The amount of air didn't change, but the pressure changed the volume.

In vehicles, hydrogen is compressed to 5,000 pounds per inch (psi), also called 350 Bar or to 10,000 psi (700 bar). The ideal shape of a tank to store any compressed gas is a cylinder (just like a propane tank for a barbecue grill or a helium tank for inflating balloons.)

Charles' Law

At a constant pressure, the volume of a given mass of ideal gas increases or decreases by the same factor as the temperature increases or decreases.

Try it

Put air in a balloon (not quite full) and measure the circumference at the widest point. Immerse the balloon in boiling water and measure again. Put the balloon in the freezer and measure again. The amount of air doesn't change, but the volume changes with temperature.

In vehicles, temperature has two effects. First, when filling a car at the station, the ambient temperature can effect the volume of fuel in the vehicle. Second, if the temperature in the tank gets too high, the hydrogen will naturally expand. Engineers have to consider both possibilities.

A few vehicles store hydrogen as a liquid, but that presents other challenges. Hydrogen is a liquid only at cryogenic temperatures.

Metal *hydrides* are a possible solution to hydrogen storage. In 1969, researchers at Philips Laboratories in the Netherlands accidently discovered a metal alloy that absorbs gaseous hydrogen like a sponge. Applying heat releases the hydrogen just like squeezing a sponge releases water. Researchers are working on metal and chemical hydrides, and they show great promise for the future.

Discussion Questions About Hydrogen Storage

- What materials must the tank use to store hydrogen onboard the vehicle?
- How does hydrogen pressure effect the weight of the tank?
- Would a liquid storage tank be different from a gaseous tank?
- Are hydrogen tanks heavier or lighter than gasoline tanks?
- Why is weight of the tank important?
- How does ambient temperature effect the volume of hydrogen?
- What happens to liquid hydrogen that warms up in a station or in a vehicle?

Glossary

Density — The mass per unit volume of a substance under specified conditions of pressure and temperature

Hydride — A class of compound that combines hydrogen with another element

HYDROGEN AS FUEL
Worksheet

1. What name did Henry Cavendish originally give to hydrogen?

2. What are three uses of hydrogen today?
   a.
   b.
   c.

3. Name three ways to produce hydrogen.
   a.
   b.
   c.

4. Boyle's law states "If a fixed quality of gas is at a fixed temperature, its volume will be inversely proportional to its _____."

5. This means that the more pressure you apply to a gas, the _____ space it takes up.

6. How does this effect hydrogen as a fuel?

7. Charles' law states "At a constant pressure, the volume of a given mass of ideal gas increases or decreases by the same factor as the _____ increases or decreases."

8. This means that when the outside temperature is hot, a gas will take up _____ space.

9. How does this effect hydrogen as a fuel?

10. What is the difference between an energy source and an energy carrier?