Lesson Template – Ben Davis

Subject Area(s) **Chemistry, Physical Science**

Associated Unit **Hydrogen as an Energy Carrier**

Lesson Title **Hydrogen from Energy**

Header

Image 1

ADA Description: Electricity plus two water molecules turning into two hydrogen molecules plus an oxygen molecule. Red spheres are hydrogen, light blue spheres are hydrogen

Caption: Making hydrogen by using Energy

Image file name: WaterPlusEtoH2plusO2.bmp

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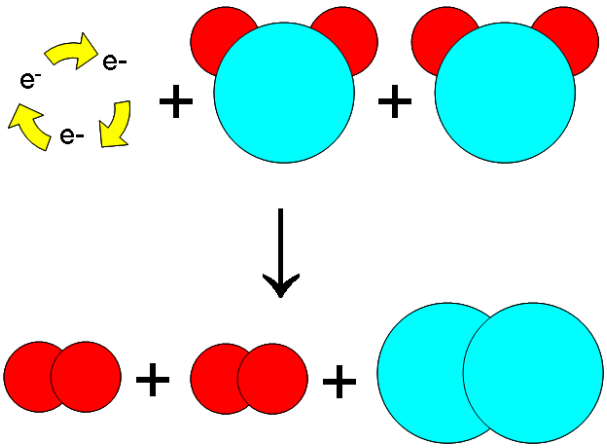

Grade Level 8 (8-12)

Lesson # 1 of 2

Lesson Dependency **NONE**

Time Required **30 minutes**

Summary

This lesson (part one of two) aims to teach students about hydrogen and its role as a fuel and energy carrier. In this first part of the lesson, students should learn what hydrogen is, who discovered and named it, what it is used for, and how you make it. In learning about hydrogen, students should locate its place on the periodic table, identify how many protons, electrons, and neutrons (0 to 2) it can have, and be able to tell you its physical and chemical properties. They will learn that you can use hydrogen to run an internal combustion engine like the one in their car, use it to run a "fuel cell" to make electricity, use it to propel the space shuttle up into space, and use it to make energy like in the sun. This lesson gives background to students so that they can do an activity where they produce hydrogen from water using electricity (electrolysis).

Engineering Connection

Real world engineers are working right now to design new cars and new fueling stations that use hydrogen. This lesson should expose students to the different technologies that

use hydrogen and the different challenges in designing new devices and machines that use hydrogen. More explanation of this connection will be given in the second part of the lesson when students learn about fuel cells.

Engineering Category, if applicable

Relates science concept to engineering

Level of Inquiry

1. Questions – Level 4: Learner poses a question / hypothesis before they begin
2. Evidence – Level 3: Learner directed to collect certain data
3. Explanations – Level 4: Learner formulates explanation after summarizing evidence
4. Evaluating explanations – Level 3: Learner directed towards areas and sources of scientific knowledge
5. Communication and justification – Level 1: Learner given steps and procedures for communication

The lesson can be altered to incorporate more inquiry for more advanced or older students (less explanation of procedures with more focus on safety, more open ended questions on what happened in activity, oral or formal written presentation of their results, etc.) These levels were most appropriate for an average 8^{th} grade physical science student.

Keywords

Hydrogen, Energy, Electricity, Electrolysis, Oxygen, Proton, Neutron, Fuel, Cell

Educational Standards

1) CA State Standards addressed:

Grade Eight – Science Content Standards

3. Structure of Matter – Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:

a. Students know the structure of the atom and know it is composed of protons, neutrons, and electrons.

b. Students know that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

d. Students know the states of matter (solid, liquid, gas) depend on molecular motion.

e. Students know that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

5. Reactions – Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

a. Students know reactant atoms and molecules interact to form products with different chemical properties.

b. Students know the idea of atoms explains the conservation of matter: In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

c. Students know chemical reactions usually liberate heat or absorb heat.

7. Periodic Table – The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms. As a basis for understanding this concept:

b. Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

c. Students know substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

9. Investigation and Experimentation – Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Plan and conduct a scientific investigation to test a hypothesis.

f. Apply simple mathematic relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure × area, volume = area × height).

2) National Standards addressed:

Science and Technology in Society
History of Science
Transfer of Energy

Pre-Requisite Knowledge

Students must know: what protons, neutrons, and electrons are, how to find an element on the periodic table, where the atomic number is and what it signifies, simple algebra as in x = y x z, what density is and what it means for gases and liquids, how to measure liquids by volume, what it means to burn something

Learning Objectives

After this lesson, students should be able to:

- **State how many atoms there are in a hydrogen molecule and its chemical formula**
- **List different uses for liquid, solid, and gaseous hydrogen**
- **Describe how atoms are rearranged during electrolysis of water**
- **Explain one method for making hydrogen gas**

Introduction / Motivation

First step: warm-up. What is a chemical reaction? [a process where elements or compounds undergo a chemical change: atoms are rearranged into different combinations of molecules] Okay, so now that we know what a reaction is, how does that relate to electrolysis? [electrolysis is a reaction which uses electricity to force the chemical change: try to get students to relate it to an "electricity reaction"] Good.

Now, what is electricity, does anybody know how it works? [if not, describe how electricity works to the students and explain its role as an energy carrier] Electricity is a flow of electrons. So when you plug something into the wall, electrons come out of the wall and go through the one end of the plug, up the wire into the lamp (or the cell phone or the toaster), and then into the circuits inside to make the device work. After they're done making it work, they have to go back down the wire through the OTHER end of the plug, through the wall, down the power lines, and to the power plant where they give the electrons back the energy that they lost when they made the lamp light up. Now, the power that the lamp uses is related to the electrons that come out of the wall. The current

is the rate of electron flow; that means that it's the number of electrons that come up the wire into the lamp in a given time. The voltage is the amount of energy each electron has in it; higher voltage electrons have more energy. If you multiply the number of electrons going through the wire (current) times the energy that EACH electron has (voltage), you get the power or how much energy the lamp uses up. So electricity is electrons GIVING ENERGY to a thing. Now you are all experts on electricity.

Now, let's switch gears and learn about something completely different. We're going to watch a video from 1937. Did you know they made movies in 1937? It's pretty old. So sit and watch this video and we'll talk about it afterwards. [show video of the Hindenburg exploding. After the video, ask them to describe what happened. Especially try to lead them to mention that the blimp was filled with Hydrogen and that's what burned. Try to lead them into an understanding of the properties of Hydrogen (low density, colorless gas, flammable).] So the reason the blimp lit on fire was because of hydrogen. And why did the flames go UP instead of down? [hydrogen is a less dense gas than air] Okay, good.

So what is hydrogen? Lets learn some simple facts about it. [concepts to cover: atomic number, protons, neutrons, electrons, periodic table, number of atoms in a molecule, chemical formula] Hydrogen has three isotopes; regular Hydrogen (no neutrons), Deuterium (one neutron), and Tritium (two neutrons). Deuterium and Tritium are the "hydrogen" in a hydrogen (fusion) bomb. Hydrogen atoms make up about ¾ of the visible universe (by mass).

Engineers have thought of a lot of different ways to use hydrogen (besides making the Hindenburg float). They figured out that since hydrogen makes a lot of energy when you burn it, you can use hydrogen gas to make an engine work (like the one in your car) or you can use it to make a thing called a "fuel cell" work to make electricity. Not only have engineers used hydrogen gas, they have used liquid hydrogen (which is really, really cold) is used to launch the space shuttle (with liquid oxygen). And solid hydrogen (Deuterium or Tritium) can be used for nuclear fusion to make a whole lot of energy and turn the hydrogens into helium. [Use these concepts to address molecular motion and solids, liquids, and gases]

So who figured out all this stuff? Well, like most old stuff in science, it was discovered by dead white dudes. [give a brief history of hydrogen, in case students are interested in that sort of thing] Hydrogen was discovered by a British guy (Henry Cavendish) in 1766. Back then it was a pretty new concept that gases were different from each other; they only just learned that air existed at all. He put zinc metal in hydrochloric acid and collected the gas that it made. He wrote about how when he burned the gas (lit a match and put it in) it made water. Later on (1788) a French guy (Antoine Lavoisier) named the gas that Cavendish made "Hydro Gen". In Latin, "Hydro" means "Water" and "Gen" or "Genes" means "Made of" or "Born of". So they named it "The gas that makes water when you burn it".

Now we know that you make water when you burn hydrogen. How would you "un-burn" it? What could you do to make hydrogen if you had water? So here's a chemical reaction that might be able to do it [show pictogram of electrolysis] What this diagram is showing is that electricity plus two waters is making two hydrogens and one oxygen. [Explain this in detail to the students: mention that the reaction is balanced and

talk about the conservation of mass and how a reaction just rearranges atoms] So what is this reaction depicting? Hint: its one of our vocabulary words. [Lead them to electrolysis]

Lesson Background & Concepts for Teachers

The motivation for this lesson (which is part 1 of 2) is to educate students on the use of hydrogen as an energy carrier / fuel. Hydrogen is sometimes referred to as the "fuel of the future" because it emits no pollution (other than water) when it is reacted as a fuel. In 2004, Gov. Schwarzenegger announced executive order S-7-04 creating the "California Hydrogen Highways Network" (see http://www.hydrogenhighway.ca.gov/). The plan he outlined mandated the creation by 2010 a "Hydrogen Highway" – a network of hydrogen fueling stations approximately every 20 miles on major highways in California – which will be able to fuel a fleet of Hydrogen-powered vehicles to travel freely around the state. The vast majority of these Hydrogen-powered vehicles which are currently in production run using Polymer Electrolyte Membrane (PEM) Fuel Cell technology.

See http://www.hydrogenassociation.org/general/factSheets.asp for a lot of date on hydrogen. Most hydrogen is produced by methane steam reforming (see part 2) but in order to use renewable or sustainable energy sources to make hydrogen for fuel, it will most likely require the electrolysis of water. Electrolysis is a process wherin an electrical current (from a solar panel, windmill, water-driven or steam-driven turbine, etc.) is run through water with some sort of electrolyte in it (to improve the electrical conductivity of the water but not to react) to generate hydrogen gas at the negative electrode (anode) and oxygen gas at the positive electrode (cathode). This process effectively stores the energy from the electricity in the chemical bonds of the hydrogen and the oxygen so that it can be used later in a device. Electrolysis is also used by engineers to manufacture raw materials including chlorine gas and chlorine bleach (by running a current through brine or salt water) and aluminum (via the Hall-Héroult process) and it is also used to electroplate metals (by running a current through an object to be plated in a solution of the plating metal's salt).

More information on the Hindenburg disaster, taken from the Rocky Mountain Institute's "Twenty Hydrogen Myths" (Copyright © 2003 by Rocky Mountain Institute):

> "An investigation by NASA scientist Dr. Addison Bain found that the [1937 Hindenburg] disaster would have been essentially unchanged even if the dirigible were lifted not by hydrogen but by nonflammable helium, and that probably nobody aboard was killed by a hydrogen fire. (There was no explosion.) The 35% who died were killed by jumping out, or by the burning diesel oil, canopy, and debris (the cloth canopy was coated with what nowadays would be called rocket fuel). The other 65% survived, riding the flaming dirigible to earth as the clear hydrogen flames swirled harmlessly above them. This would hardly be the case if an aircraft with only liquid hydrocarbons caught fire while aloft. It emphasizes that

> hydrogen is generally at least as safe as natural gas or LPG, and is arguably inherently safer than gasoline, although the character of their risks is not identical. For example, leaking hydrogen gas will accumulate near the ceiling of an airtight garage, while gasoline fumes or propane will accumulate near the floor - a greater risk to people because they're typically near the floor, not the roof. Standing in a carpet of fire is far more dangerous than standing below a nearly non-luminous clear flame that goes upwards."

Hydrogen is the smallest element in existence. It is estimated that it makes up three quarters of the baryonic matter in the universe by mass. It is not naturally occurring on earth. Its nucleus has one proton and anywhere from zero to two neutrons. Elemental hydrogen with one neutron is commonly called Deuterium and with two neutrons Tritium. In its most stable state at room temperature and pressure, it exists as a diatomic gas (H_2) which is odorless, colorless, very low density, and very high diffusivity. It reacts very rapidly with oxygen to produce water, hence its name from the Latin "Hydro" (water) and "Genes" (born of). Hydrogen liquefies at 22 K and freezes at 14 K. It was first liquefied by James Dewar (inventor of the vacuum flask) around 1898 and solidified a year later (also by Dewar).

Hydrogen was discovered in 1766 by British scientist Henry Cavendish by reacting zinc metal with hydrochloric acid and collecting the gas that evolved. This discovery led to the further realization that water (H_2O) is made of hydrogen and oxygen. Antoine Lavoisier named it hydrogen in 1788. Two English scientists (William Nicholson and Sir Anthony Carlisle) discovered that you can make hydrogen by running an electrical current through water in 1800; this process is known as electrolysis. Another English scientist, Sir William Grove, created the first fuel cell in 1845 which reacted hydrogen with oxygen to produce water and electricity. Since that time there have been many advances in hydrogen fuel cell technology; hydrogen fuel cells have been used to power vehicles, components in the space shuttle, and commercial buildings.

Other applications of hydrogen include using solid hydrogen (deuterium / tritium) as a point source for nuclear fusion by shooting a high intensity laser beam at the solid and also as a liquid fuel in internal combustion engines or in jet engines like those on the space shuttle.

You have to be flexible in what you want to cover, because you won't get to everything. Find something the students seem to be interested in (science-wise) and go with it. During the lecture part of the lesson, I tried to change things up by incorporating a video and some pictures of explosions. I tried to teach to what the students were interested in, and that seemed to work fairly well. Concentrating on the concepts I wanted them to learn (conservation of mass, atoms, elements, energy, protons, neutrons, etc.) seemed to lead the students to ask better questions.

Image

Figure #1

ADA Description: List of energy sources that can be used to generate hydrogen

Caption: Figure #1

Image file name: HydrogenProductionRoutes.bmp

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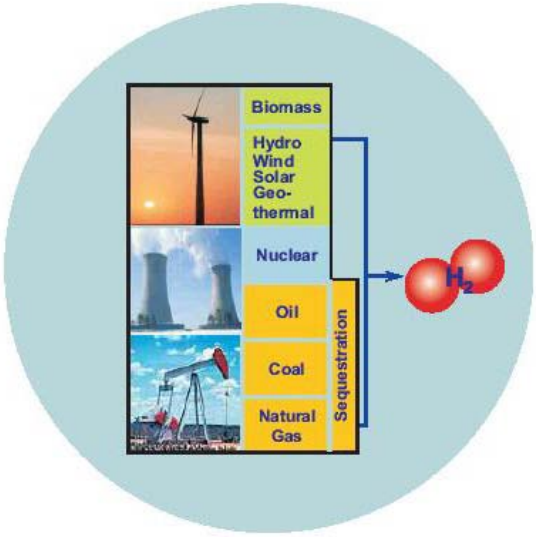

Vocabulary / Definitions

Word	Definition
Hydrogen	The smallest known element. Has one proton, one electron, and from 0 to 2 neutrons.
Oxygen	Element number 8. Primary component of water (with hydrogen) and second most common gas in the earth's atmosphere
Fuel cell	A device which continuously reacts some fuel with an oxidant in an electrolyte to make electricity
Chemical reaction	A process where elements or compounds undergo a chemical change. In a reaction, atoms are rearranged into different combinations of molecules.
Electrolysis	A chemical reaction which uses electricity to force the chemical change in the reactants
Power	The rate at which energy is used in an electrical device
Voltage	A measure of the energy of the electrons in electricity
Current	The rate of electrons flowing in electricity
Proton	(use the definition from the students' textbook)
Neutron	(use the definition from the students' textbook)
Electron	(use the definition from the students' textbook)
Physical property	(use the definition from the students' textbook)
Chemical property	(use the definition from the students' textbook)
Atom	(use the definition from the students' textbook)
Molecule	(use the definition from the students' textbook)
Conservation of matter	(use the definition from the students' textbook)
Electrical conductivity	The measure of how well electrons flow through a material without losing their energy

Associated Activities

Activity # 1 Title: Electrolysis of water to make hydrogen and oxygen

Activity # 2 Title: Making electricity from hydrogen using PEM Fuel Cells

Lesson Closure

So what did we learn today? We learned that electricity is the flow of electrons and that if you use electricity to make a chemical reaction go it's called electrolysis. We learned about the different physical and chemical properties of hydrogen and we learned that it has a lot of energy in it (especially when there's a lot of it like in the Hindenburg!) We learned that engineers can design things that use hydrogen like engines, fuel cells, space shuttle rocket boosters, nuclear fusion reactions, etc. and that hydrogen is mostly a gas but that you can slow the molecules way down and make it into a liquid or solid if you get it REALLY REALLY cold. We learned about the dead white dudes who discovered hydrogen and why they named it "the gas that makes water". And finally we learned that we can use electricity to make hydrogen by putting it through water (REACTING with the water to form hydrogen and oxygen gas).

Assessment

Pre-lesson:

Ask students if they can tell you the atomic number of a random element. Then ask them what it means in terms of its protons, neutrons, and electrons. Ask students to solve simple algebra problems like: if the density of water is 1 kg per liter and my faucet lets out 1 liter of water per second, how many kilograms of water come out of my faucet per second? After that example, you could ask what density is and what it means for gases and liquids, how to measure liquids by volume, etc. And ask them what it means to burn something [it means that the "something" is a fuel and reacts with an oxidant, almost always oxygen gas, to make heat, light, and "new stuff"]

Post-lesson:

Ask / quiz students on how you can make hydrogen since it doesn't exist on earth. Ask / quiz them about properties of hydrogen (protons, electrons, possible number of neutrons, atoms in a molecule of it, chemical formula, state of matter at room temperature and colder temperatures, etc.) Ask them to define electrolysis and to give examples of how we can use hydrogen. Ask them how to calculate power from current and voltage.

Lesson Extension Activities

1. Have the students do a written report on the Hindenburg disaster.
2. Have the students visit a hydrogen fueling station or see a fuel cell-powered car
3. Have students write a report on how using hydrogen as a fuel is different from using gasoline as a fuel

Additional Multimedia Support

See attached powerpoint presentation and video of Hindenburg disaster. If you are using the powerpoint presentation, include a photograph of the experimental setup for electrolysis in your presentation.

References

National Hydrogen Association (lots of good general facts about hydrogen):
http://www.hydrogenassociation.org/general/factSheets.asp

Periodictable.com (pictures and descriptions of hydrogen samples):

http://periodictable.com/Elements/001/index.html

Facts on the California "Hydrogen Highway":

http://www.hydrogenhighway.ca.gov/

More information on fuel cells and hydrogen:

http://www.rmi.org/sitepages/pid255.php

Hydrogen facts for kids from the U.S. Dept. of Energy:

http://www.eia.doe.gov/kids/energyfacts/sources/IntermediateHydrogen.html

Attachments

H2AsEnergyCarrierPartI.ppt

HindenburgExplodes1937.mp4

WaterPlusEtoH2plusO2.bmp

HydrogenProductionRoutes.bmp

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