

**Education Transfer Plan: Hydrogen-Powered Cars**  
**Travis Hambleton**  
**Monta Vista High School/Stanford University**  
**8/5/05**

**Outcomes**

Students will:

1. Study:
  - a. The applications of electrochemical reactions that provide energy for hydrogen-powered cars (recombination of  $H_2$  and  $O_2$  in the car as fuels), which is also an excellent example of how batteries work (chemicals combine without flames in a fuel cell to release energy.)
  - b. The photoelectric effect
  - c. The process of electrolysis
2. Participate in:
  - a. A lab experiment involving the reduction-oxidation (redox) reactions of copper and zinc.
  - b. The demonstration of a model hydrogen-powered car:
    - i. Record qualitative observations of the functions of the car
    - ii. Take measurements of the volumes, temperatures, and pressures of the hydrogen and oxygen gases
    - iii. Study the stoichiometry of the reversible chemical conversion of water to  $H_2$  and  $O_2$ .

**Standards**

This ETP aligns with the following California State Science Standards:

Standard 1, Atomic and Molecular Structure: The periodic table displays the elements in increasing atomic number and shows how periodicity of the physical and chemical properties of the elements relates to atomic structure. As a basis for understanding this concept:

- h.\* Students know the experimental basis for Thomson's discovery of the electron, Rutherford's nuclear atom, Millikan's oil drop experiment, and Einstein's explanation of the photoelectric effect."

Standard 3, Conservation of Matter & Stoichiometry: The conservation of atoms in chemical reactions leads to the principle of conservation of matter and the ability to calculate the mass of products and reactants. As a basis for understanding this concept:

- g.\* Students know how to identify reactions that involve oxidation and reduction and how to balance oxidation-reduction reactions."

**Procedure/Plan**

Day 1:

- Begin class discussion of Chapter 17: "Oxidation-reduction Reactions" in *Foundations of College Chemistry, 10<sup>th</sup> Edition*, by Hein/Arena, using PowerPoint file. The topic covered is identifying oxidation numbers of elements.
- Homework: Pre-lab questions in "Lab: Redox Reactions of Copper and Zinc"

Day 2:

- Review Pre-lab questions
- Begin experiment in “Lab: Redox Reactions of Copper and Zinc”

Day 3:

- Finish experiment in “Lab: Redox Reactions of Copper and Zinc”
- Continue class discussion of Chapter 17: “Oxidation-reduction Reactions”. Topics include half-reactions, reduction, and oxidation.

Day 4:

- Collect lab report for “Lab: Redox Reactions of Copper and Zinc”
- Finish class discussion of Chapter 17: “Oxidation-reduction Reactions”. Topics include: applications of redox reactions, featuring polymer electrolyte membrane fuel cells (PEMFC), the key to hydrogen-powered cars.
- Watch 14-minute video from PBS: “Nova Science Now”, originally aired 7/26/05, featuring hydrogen-powered fuel cells (available for streaming at <http://www.pbs.org/wgbh/nova/sciencenow/3210/01.html>). Students complete worksheet and answers are reviewed as a class.

Day 5:

- Discussion, demonstration, and testing of hydrogen-powered model car with “Hydrogen Fuel Cell Car Lab”

Day 6:

- Quiz, Chapter 17

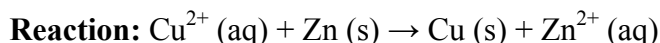
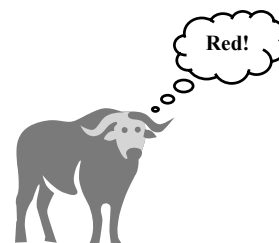
### List of Materials/Resources

- Powerpoint for Chapter 17: “Oxidation-reduction Reactions” in *Foundations of College Chemistry, 10<sup>th</sup> Edition*, by Hein/Arena
- Lab: Redox Reactions of Copper and Zinc and answer key
- Hyco Hydrogen Fuel Cell Car Set (\$225 + shipping, available from [http://www.sargentwelch.com/product.asp?pn=WL2149M\\_ST&ss=hydrogen%20car](http://www.sargentwelch.com/product.asp?pn=WL2149M_ST&ss=hydrogen%20car)), which includes a functioning 8" PEMFC model car, which first utilizes a solar cell to electrolyze distilled water to hydrogen and oxygen gas, then uses the oxidation-reduction reaction of the two gases to generate an electric current than runs the car's motor. A set of four demonstration/lab manuals also come with the car set, which will be used as is or modified as part of an experimental report completed by my students.
- Hydrogen Fuel Cell Car Lab
- Video: “Nova Science Now”, originally aired 7/26/05, featuring hydrogen-powered fuel cells (available for streaming at <http://www.pbs.org/wgbh/nova/sciencenow/3210/01.html>)
- “Nova Science Now” video worksheet and answer key, adapted from [http://www.pbs.org/wgbh/nova/teachers/programs/3210\\_01\\_nsn.html](http://www.pbs.org/wgbh/nova/teachers/programs/3210_01_nsn.html)
- Quiz, Chapter 17 and answer key

### Rubric or plan for evaluating outcomes

- “Lab: Redox Reactions of Copper and Zinc” (lab sheet and answer key attached)
- “Nova Science Now”: Hydrogen Fuel Cells video (worksheet and answer key attached)
- Quiz, Chapter 17 (quiz and answer key attached)

## Lab: Redox with Copper and Zinc Chemistry



**Pre-Lab Questions:** Answer in complete sentences.

- Determine the oxidation number for the following:
  - Carbon in carbon dioxide
  - Sulfur in sulfuric acid,  $\text{H}_2\text{SO}_4$
  - Copper in  $\text{Cu}^{2+}(\text{aq})$  and  $\text{Cu}(\text{s})$
  - Zinc in  $\text{Zn}(\text{s})$  and  $\text{Zn}^{2+}(\text{aq})$
- What does “redox” abbreviate?
- Give an example of a redox reaction you have seen outside of the classroom.
- Consider the reaction between solid sodium metal and chlorine gas, which forms sodium chloride solid.
  - Write the balanced chemical equation for this reaction, including the states of matter of each substance.
  - In this reaction, which element is oxidized: Na or Cl? How do you know?
  - Which element is reduced: Na or Cl? How do you know?
- Read the procedure, then answer the following questions:
  - What solid metal will be used?
  - What metal ion will be in solution?
  - How will you dispose of the chemicals?

### Materials & Equipment:

*Class:*  $\text{CuSO}_4(\text{aq})$ ,  $\text{Zn}(\text{s})$ , masking tape

*Per Group:*

(2) test tubes	100-mL beaker
(2) tweezers	250-mL beaker
10-mL graduated cylinder	Permanent marker

### Procedure:

- For your group, obtain about 20 mL of  $\text{CuSO}_4$  solution in the small beaker.

#### Each pair:

- Label a clean, dry, empty test tube with piece of tape, your initials and class period.
- Obtain 2 small pieces of Zn metal; record your observations of the initial appearance (color, shape, luster, malleability, etc.) Be specific!
- Carefully slide your zinc pieces inside the test tube to rest at the bottom.
- Record your observations of the initial appearance (color, etc.) of the  $\text{CuSO}_4$  solution.
- Use your graduated cylinder to measure 10 mL of  $\text{CuSO}_4(\text{aq})$  and carefully add it to your test tube.
- As the reaction begins, rest the labeled test tube in the large beaker; allow it to remain undisturbed in the large beaker for the time allotted by your teacher.

#### When the reaction is complete:

- Record your observations of the zinc and of the  $\text{CuSO}_4(\text{aq})$  solution.
- Clean-up:** Do not pour the solution down the drain! Pour the solution and the solid into the container provided.

**Observations:**

<b>Material</b>	<b>Initial Appearance</b>	<b>Final Appearance</b>
<b>CuSO<sub>4</sub> (aq)</b>		
<b>Zinc (s)</b>		

**Post-Lab Questions: Answer in complete sentences.**

1. How did the appearance of the solution change? How did the appearance of the Zn (s) change?
2. What is the “covering” on the Zn (s)? From where did it originate?
3. What did Cu<sup>2+</sup> (aq) need to form Cu (s)? Where did Cu<sup>2+</sup> (aq) obtain what it needed?
4. Which element is reduced in today’s reaction? Write the “half-reaction” for this process.
5. Which element is oxidized in today’s reaction? Write the “half-reaction” for this process.

**Lab: A Simple Redox Experiment Key (25 pts total: 10 prelab, 15 below)**

**(4 pts) Procedure Summary: command voice**

**(2 pts) Observations:**

<b>Material</b>	<b>Initial Appearance</b>	<b>Final Appearance</b>
<b>CuSO<sub>4</sub> solution</b>	Blue, transparent	Colorless, transparent
<b>Zinc metal</b>	Silvery, lustrous, solid	Black, porous

**Questions: Answer in complete sentences. (9 pts)**

6. How did the appearance of the CuSO<sub>4</sub> solution change (1 pt)

**THE SOLUTION LOST ITS BLUE COLOR.**

How did the appearance of the Zn<sub>(s)</sub> change?

(1 pt) **THE METAL GAINED A DARK-COLORED COATING.**

7. What is the covering on the Zn metal? from where did it originate?

**(1 pt) THE Cu ORIGINATED AS AN ION IN SOLUTION.**

8. What did Cu<sup>+2</sup> (aq) need to form Cu metal? Where did Cu<sup>+2</sup> (aq) obtain what it needed?

**(1 pt) Cu NEEDED 2 ELECTRONS, (1 pt) WHICH CAME FROM THE Zn METAL.**

9. Which element is reduced in today's reaction? Write the half reaction for this process.

**(2 pts) Cu<sup>+2</sup> (aq) + 2 e<sup>-1</sup> → Cu<sup>0</sup> (s) GAIN ELECTRONS = REDUCTION**

10. Which element is oxidized in today's reaction? Write the half reaction for this process.

**(2 pts) Zn<sup>0</sup> (s) → Zn<sup>+2</sup> (aq) + 2 e<sup>-1</sup> LOSE ELECTRONS = OXIDATION**

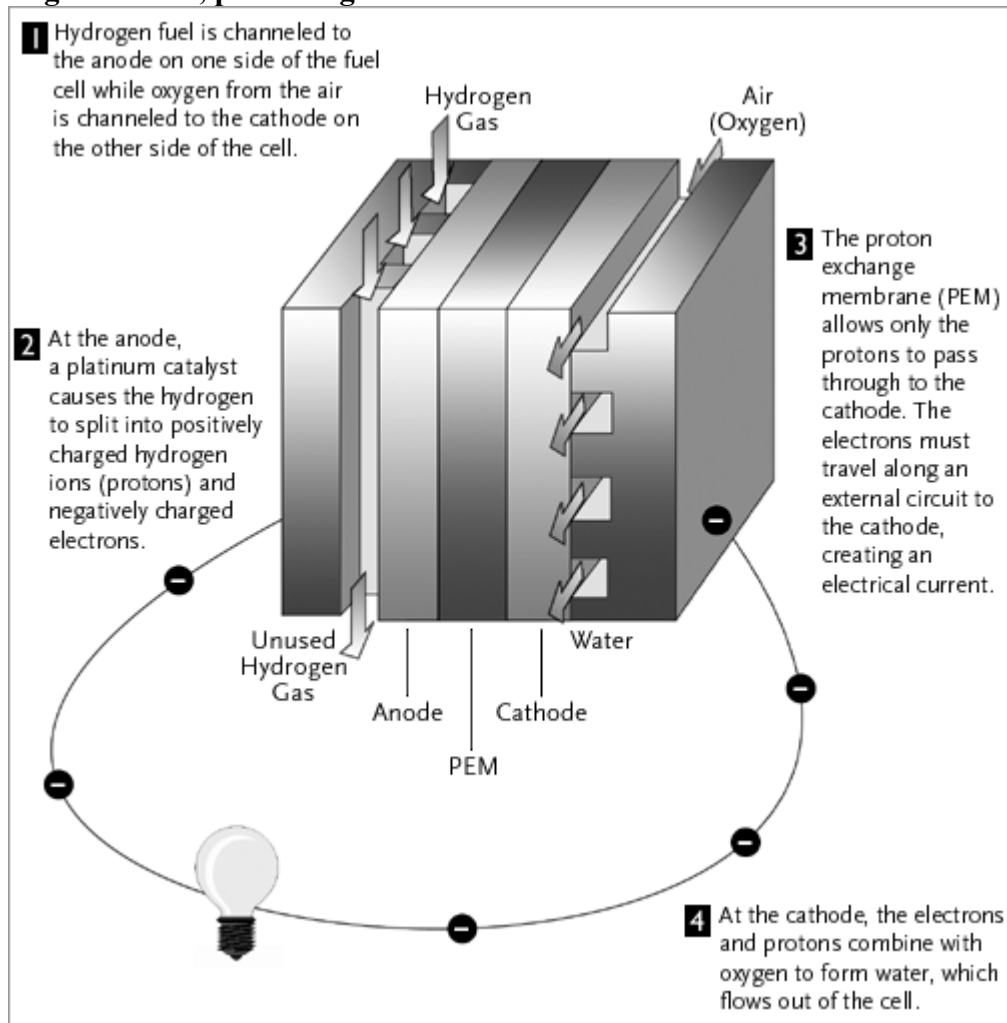
## **“Nova Science Now”: Hydrogen Fuel Cells Worksheet Chemistry**



1. What is a fuel cell?
2. How do fuel cells work? Make a sketch to accompany your explanation.
3. Name two methods that could be used to obtain hydrogen gas.
4. Describe two challenges in making hydrogen a convenient fuel for cars.
5. How long do most researchers estimate it will take to learn how to utilize hydrogen as a widespread fuel source?

## “Nova Science Now”: Hydrogen Fuel Cells Worksheet Key Chemistry

1. What is a fuel cell?  
**A kind of battery that uses hydrogen and oxygen to generate electricity, producing water as a byproduct.**
2. How do fuel cells work? Make a sketch to accompany your explanation.  
**Hydrogen and oxygen are on opposite sides of a membrane. When hydrogen crosses the membrane to bond with the oxygen, the membrane strips off its electron. These electrons travel through a circuit, producing an electrical current.**

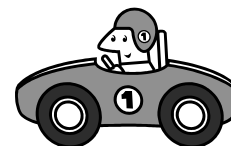


3. Name two methods that could be used to obtain hydrogen gas.  
**Photosynthesis, lasers, electrolysis**

**(On Earth, hydrogen is found chemically bonded with other atoms; thus an energy-intensive step is required for splitting off the hydrogen. Hydrogen production requires large, technically advanced facilities and that producing large amounts of hydrogen on-site, such as in a factory or apartment complex, may be the most feasible and cost-effective way of using fuel cells on a widespread basis.)**

4. Describe two challenges in making hydrogen a convenient fuel for cars.  
**It will require a complex infrastructure to produce, transport, and distribute hydrogen efficiently and to dispense it to individual cars safely and conveniently.**
  
5. How long do most researchers estimate it will take to learn how to utilize hydrogen as a widespread fuel source?  
**About 20 years**

## Hydrogen Fuel Cell Car Lab Chemistry



**Objective:** Study the chemical reactions taking place in a hydrogen fuel cell

### Pre-lab Questions:

1. What is electrolysis?
2. If distilled (pure) water is electrolyzed, what two gases will be the products? Write a balanced chemical equation, including states of matter, for this reaction.

### Materials & Equipment:

Hydrogenius® hydrogen fuel cell car kit  
(2) small test tubes, 1 cm by 10 cm  
Distilled water

### Procedure:

Follow the instructions outlined by the teacher in the demonstration of this experiment.

### Observations:

Room temperature (°C):

Room pressure (atm):

	Water	Hydrogen	Oxygen
<b>Formula of substance</b>			
<b>Element or compound</b>			
<b>State of matter</b>			
Final volume (mL)			
Initial volume (mL)			
<b>Change in volume (mL)</b>			
Final moles (mol)			
Initial moles (mol)			
<b>Moles of substance (mol)</b>			

### Calculations:

- Calculate the change in the volume and number of moles of each substance present at the beginning and end of the experiment.

### Post-Lab Questions: Answer in complete sentences.

1. Consider gasoline:
  - a. What hydrocarbon is the main component in gasoline? What is its formula?
  - b. Write a balanced chemical equation, including states of matter, for the reaction of the hydrocarbon in gasoline that occurs in regular car engines.
2. Consider the fuel cell reaction in this lab:  
Write a balanced chemical equation, including states of matter, for the reaction taking place in the fuel cell.
3. Name two differences between the reactions in a regular car and in the fuel cell in this lab.
4. Name two similarities between the reactions.
5. How does the fuel cell reaction relate to the electrolysis reaction discussed in the pre-lab? Explain.

**Ch 17: Reduction-Oxidation Quiz**  
**Chemistry**  
**Version A (16 pts)**

**(10 pts) Determine the oxidation number of each element in the following compounds:**

1. (2 pts)  $\text{SO}_2$
2. (2 pts)  $\text{CO}_3^{2-}$
3. (3 pts)  $\text{K}_2\text{SO}_4$
4. (1 pts)  $\text{O}_2$
5. (2 pts)  $\text{Al}_2\text{P}_3$

**(6 pts) Indicate which element has been oxidized and which has been reduced and explain how you know. No credit will be given without an explanation.**

6.  $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow \text{HCl}(\text{g})$
  7.  $\text{KNO}_3(\text{s}) \rightarrow \text{KNO}_2(\text{s}) + \text{O}_2(\text{g})$
  8.  $\text{I}^{-}(\text{aq}) + \text{NO}_3^{-}(\text{aq}) \rightarrow \text{I}_2(\text{s}) + \text{NO}(\text{g})$
- 

**Ch 17: Reduction-Oxidation Quiz**  
**Chemistry**  
**Version B (16 pts)**

**(10 pts) Determine the oxidation number of each element in the following compounds:**

1. (2 pts)  $\text{N}_2\text{O}$
2. (2 pts)  $\text{PO}_4^{3-}$
3. (3 pts)  $\text{Ca}(\text{NO}_3)_2$
4. (1 pts)  $\text{F}_2$
5. (2 pts)  $\text{SiCl}_4$

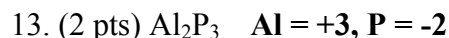
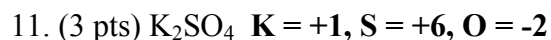
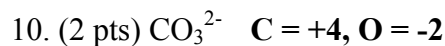
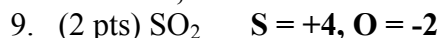
**(6 pts) Indicate which element has been oxidized and which has been reduced and explain how you know. No credit will be given without an explanation.**

6.  $\text{Na}(\text{s}) + \text{Br}_2(\text{l}) \rightarrow \text{NaBr}(\text{s})$
7.  $\text{NaClO}_4(\text{s}) \rightarrow \text{O}_2(\text{g}) + \text{NaClO}_3(\text{s})$
8.  $\text{Cu}^{2+}(\text{aq}) + \text{SO}_3^{2-}(\text{aq}) \rightarrow \text{SO}_3(\text{s}) + \text{Cu}_2\text{O}(\text{s})$

## Ch 17: Reduction-Oxidation Quiz Key, Version A (16 pts)

(10 pts) Determine the oxidation number of each element in the following compounds:

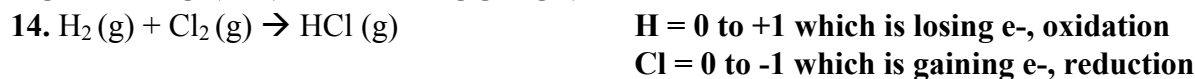
**1 PT EACH, NO PARTIAL CREDIT**



(6 pts) Indicate which element has been oxidized and which has been reduced and explain how you know.

**NO CREDIT WILL BE GIVEN WITHOUT AN EXPLANATION.**

**1 PT OXIDATION AND 1 PT REDUCTION**



## Ch 17: Reduction-Oxidation Quiz Key, Version B (16 pts)

(10 pts) Determine the oxidation number of each element in the following compounds:

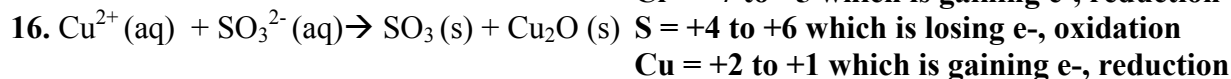
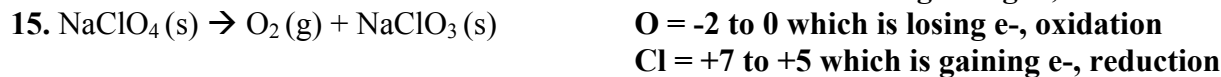
**1 PT EACH, NO PARTIAL CREDIT**



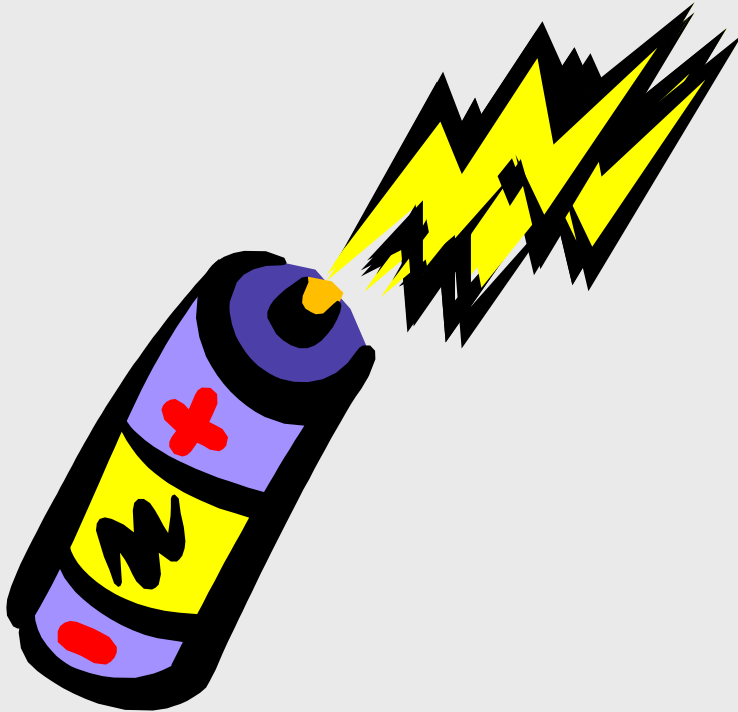
(6 pts) Indicate which element has been oxidized and which has been reduced and explain how you know.

**NO CREDIT WILL BE GIVEN WITHOUT AN EXPLANATION.**

**1 PT OXIDATION AND 1 PT REDUCTION**



# Ch. 17: Oxidation-Reduction



- ⚡ Oxidation number
- ⚡ Redox reactions
- ⚡ How batteries work
- ⚡ Other applications

# \* Introduction



- ✚ Thus far we have mostly considered reactions in which reactant atoms “rearrange” to form products.
- ✚ In another important type of chemical reaction, electrons are liberated from one reactant and transferred to another reactant.
- ✚ These are called **oxidation-reduction** reactions, of which rusting is an common example.

# 17.1: Oxidation Number



**Oxidation number (O.N.):** the number of e<sup>-</sup> an atom has lost or gained compared to a normal atom

✦ Can be positive, negative, or zero

## Guidelines for Predicting O.N.

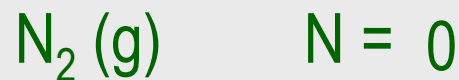
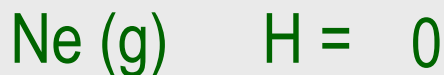
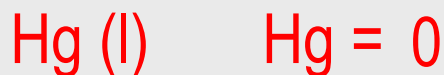
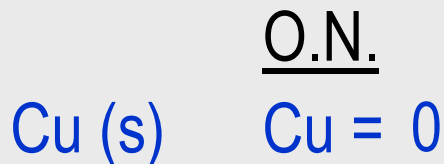
1. For all simple ions, O.N. = ion charge. (\* Polyatomic ions, like NO<sub>3</sub><sup>1-</sup>, will be discussed later.)

	<u>O.N.</u>
Na <sup>1+</sup>	+1
Cl <sup>1-</sup>	-1

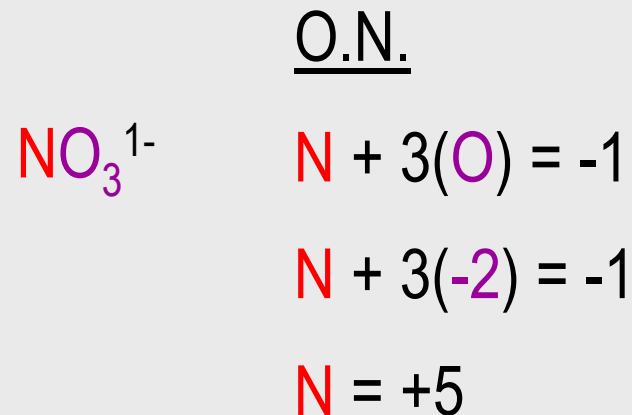
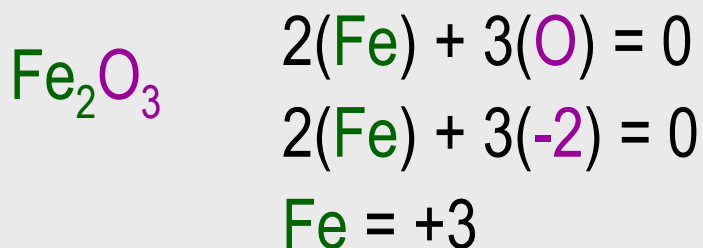
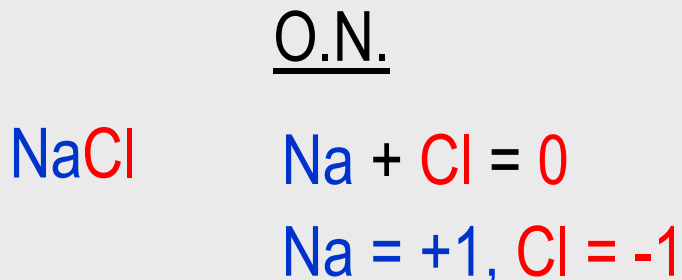
# Predicting O.N.



2. In a pure substance, O.N. = 0



3. The sum of O.N. of all atoms in a compound equals the charge of the compound.



# Practice: Predict the O.N.



O.N.



$$\text{O} = -2, \text{H} = +1$$



$$\text{Cl} = \text{zero}$$



$$(+2) + \text{C} + 3(-2) = 0$$

$$-4 + \text{C} = 0$$

$$\text{C} = 4$$



$$\text{S} + 4(-2) = -2$$

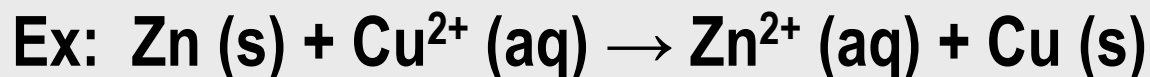
$$\text{S} + -8 = -2$$

$$\text{S} = +6$$



# 17.2: Oxidation-reduction

“Redox” reactions: a transfer of  $e^-$  between reactants

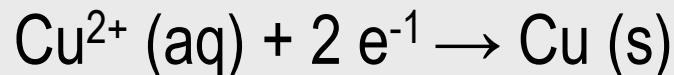


✦ Consists of two “half-reactions”:

**Oxidation:** loss of  $e^-$ ; increase in O.N.



**Reduction:** gain of  $e^-$ ; decrease (reduction) in O.N.



✦ “LEO the lion growls GER.”

Lose

Electrons =

Oxidation

Gain

Electrons =

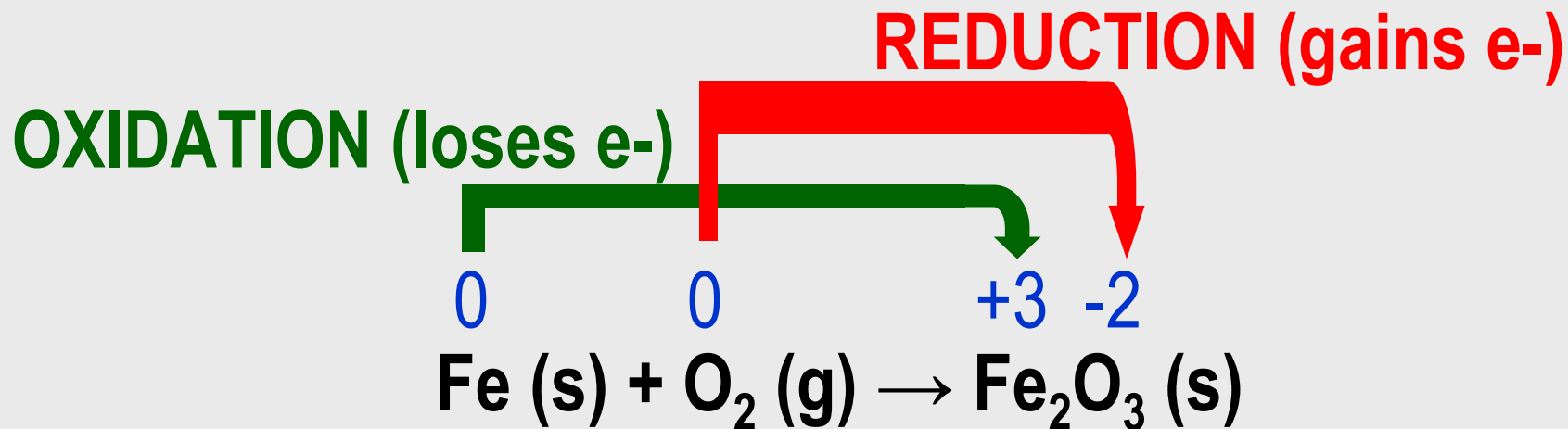
Reduction



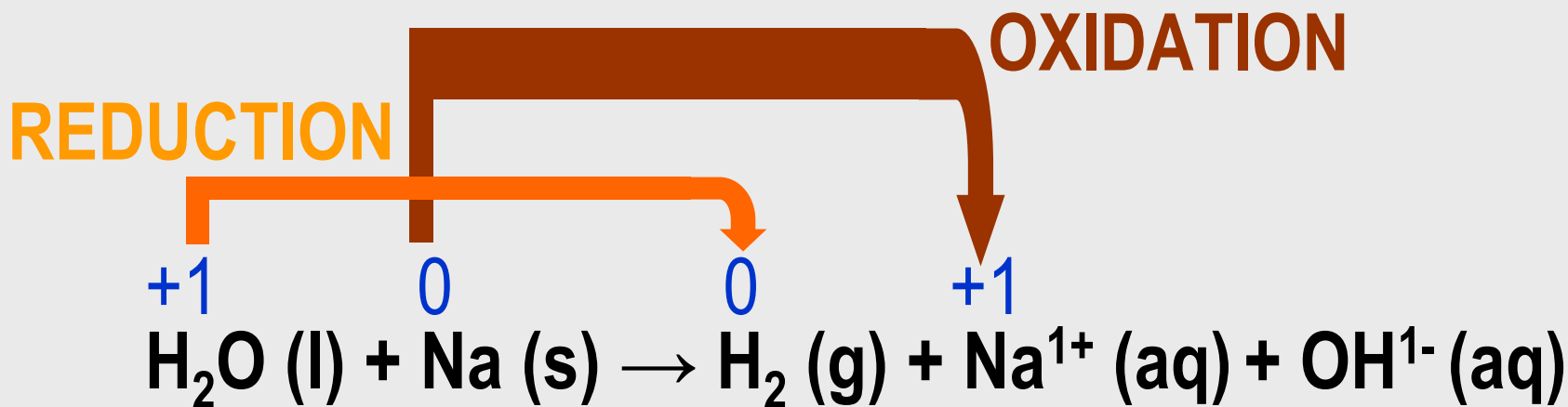
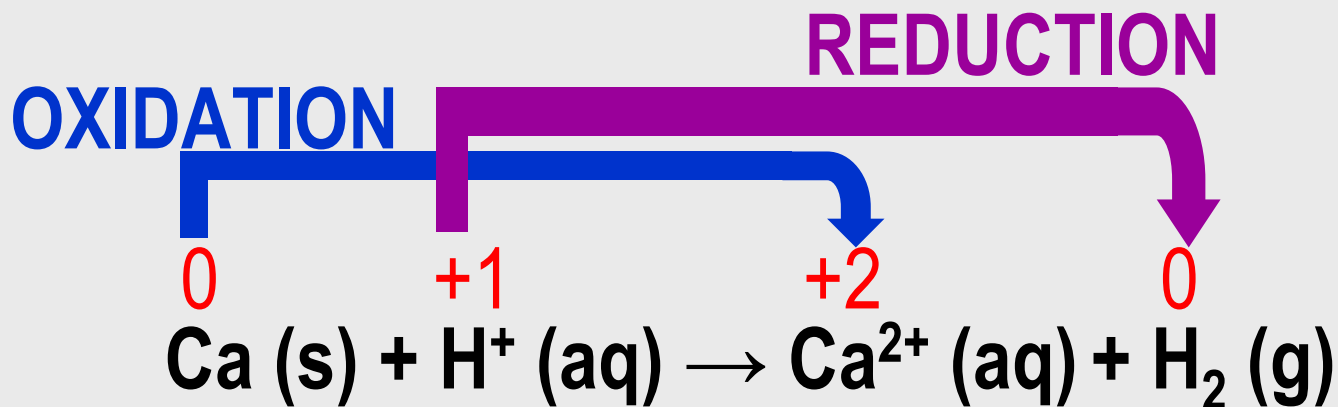
GER!

# Redox reactions

- ✦ Determine O.N. of Fe and O in reactants & products. Then determine which is reduced and which is oxidized.

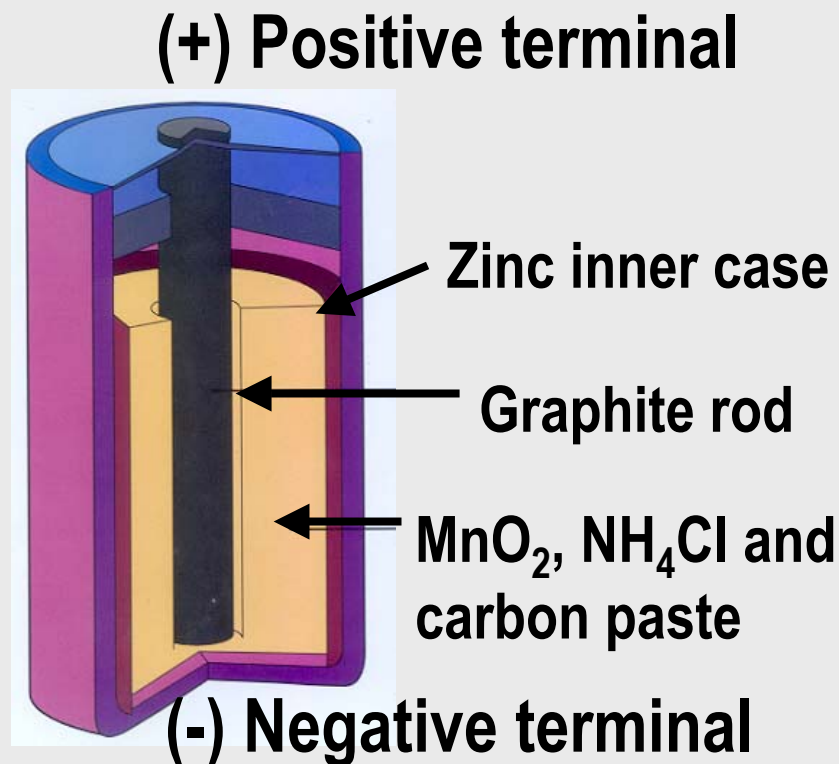
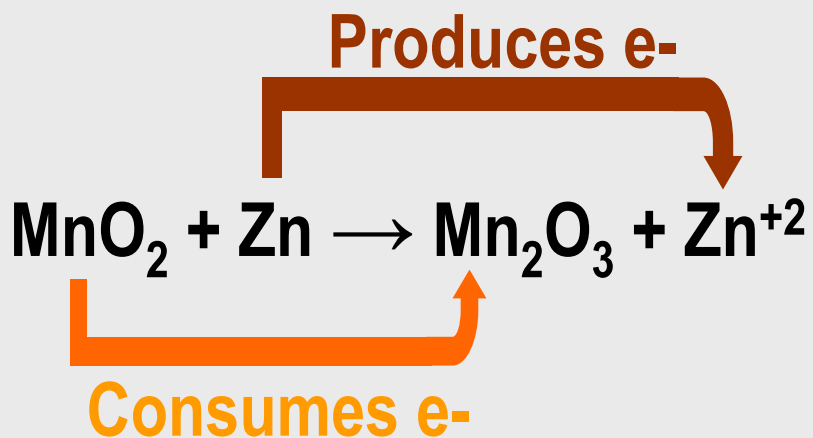


Ex: Which is reduced? Which is oxidized?



# \* How Batteries Work

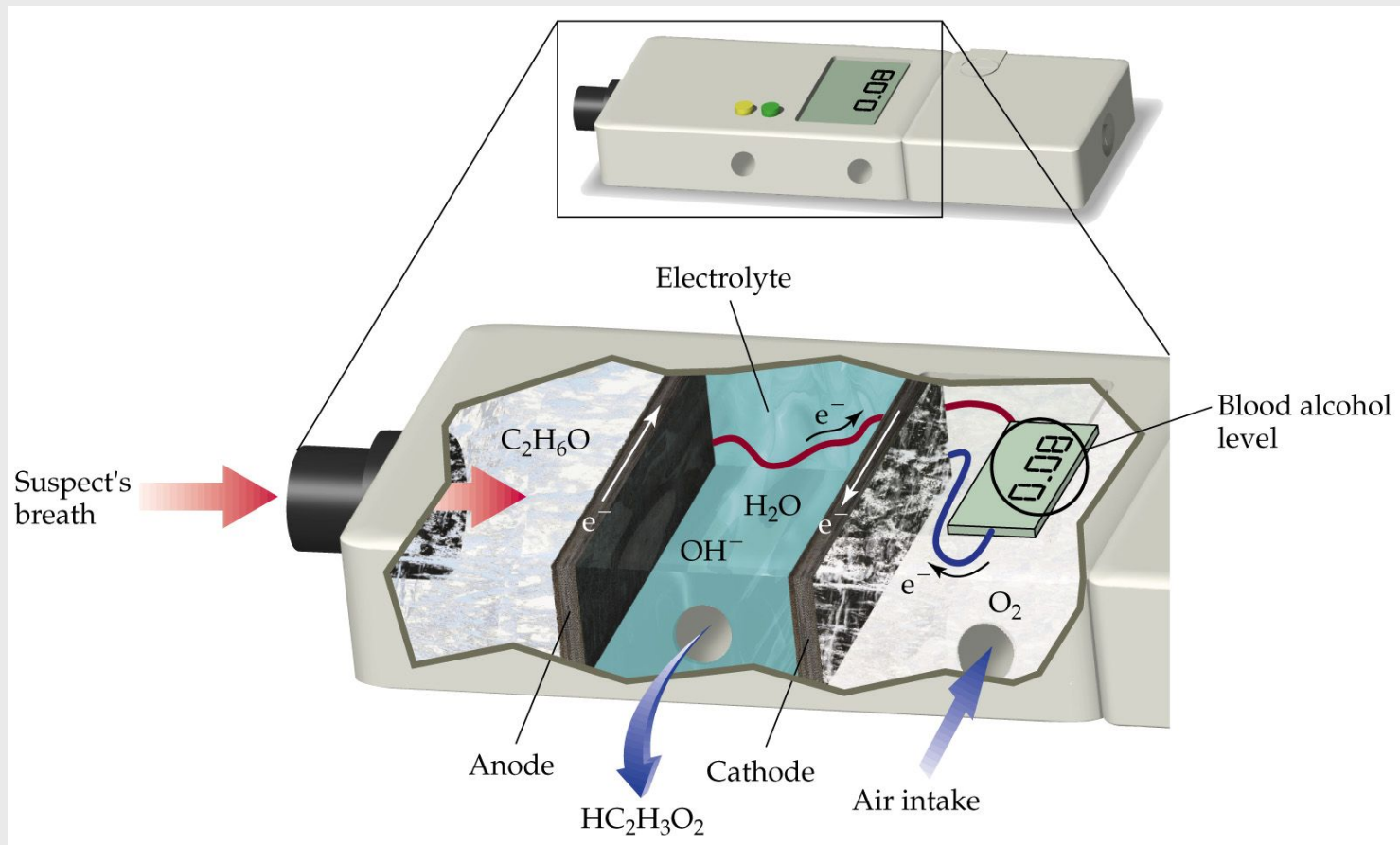
⚡ A battery (or dry cell or voltaic cell) uses an **irreversible redox** reaction to produce a constant flow of e<sup>-</sup>.



“Alkaline” batteries utilize the same reaction, but use KOH, not NH<sub>4</sub>Cl.

# \* Other Applications

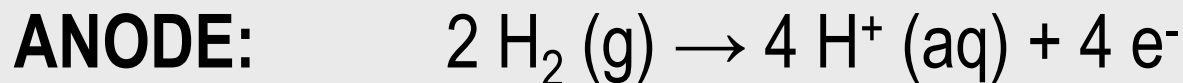
- 🔦 **Electroplating:** converts metallic ions to solid metal as  $e^-$  are transferred
- 🔦 **Breathalyzers:** ethanol oxidizes and forms acetic acid



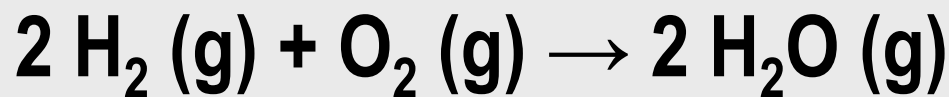
# Introduction



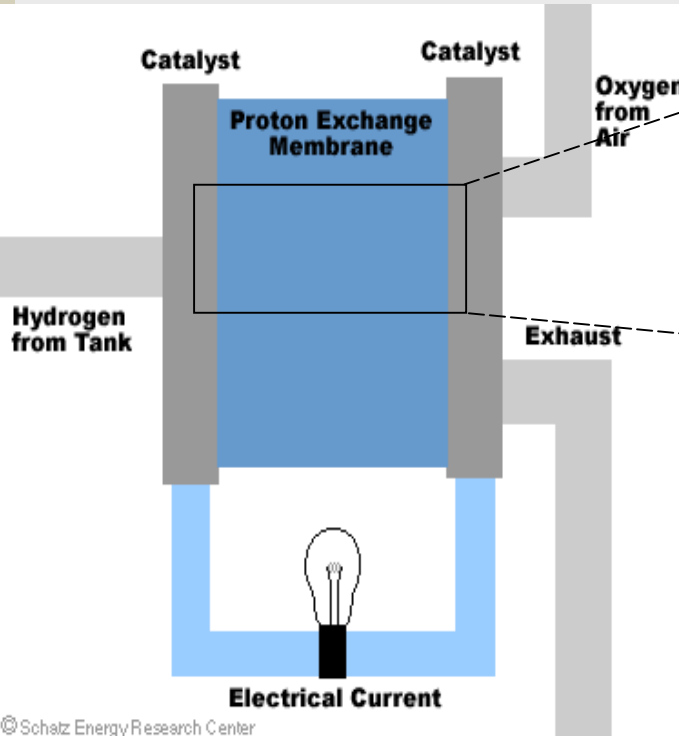
✦ There has been much research into the role of Pt catalysts in polymer electrolyte membrane fuel cells (PEMFC), which utilize the following reactions:



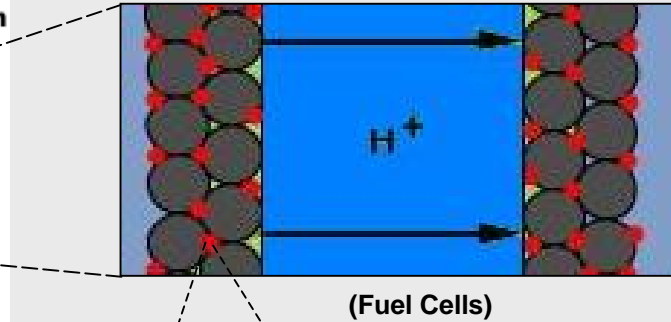
Net reaction:



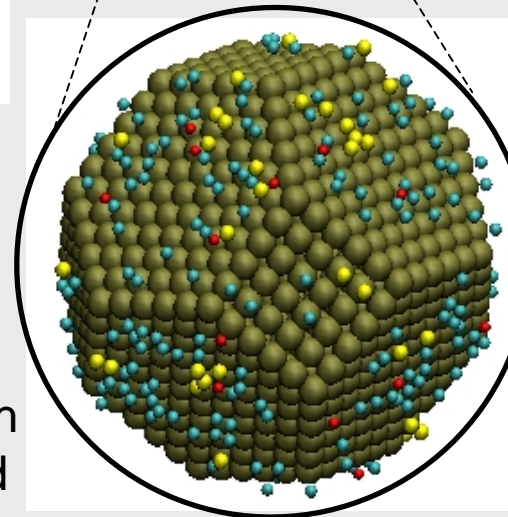
# Overview of PEMFC



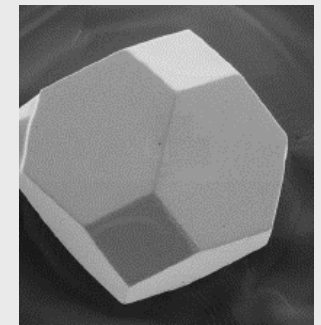
(The Proton Exchange Membrane Fuel Cell Animation)



Carbon-support layer (gray) and Pt catalyst (red)



Pt nanoparticle modeled by Pitsch group at Stanford



SEM image of a real Pt nanoparticle ~5 nm across, showing cubo-octahedral shape (Komanicky & Fawcett, 2004)

# References



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