MATH AND SCIENCE @ WORK

AP* CHEMISTRY Educator Edition

A BREATH OF FRESH AIR – *LAB ACTIVITY*

The Math and Science @ Work problem, Oxygen Generator System, may be used to reinforce and assess the material learned from this lab.

Instructional Objectives

Students will

- construct an electrolytic cell;
- determine the number of moles and mass of oxygen produced;
- determine the number of electrons transferred; and
- compare their experimental electrolytic cell to the Oxygen Generator System used on the International Space Station.

Teacher Preparation

- Have the following available for each lab station:
  - 9-12 V DC power sources (less than 0.5 amperage)
  - Electrolysis apparatus (students can use a Hofman tube or two graduated gas tubes and electrodes in a beaker)
  - Amperage meter
  - Stop watch
  - Potassium hydroxide (KOH) with a balance
  - Three wires with alligator clips
  - Scoop
  - Thermometer
  - Barometer

Safety Considerations

- Students should wear safety goggles and aprons.
- Students should avoid physical contact with potassium hydroxide. Potassium hydroxide is a toxic, corrosive material that causes severe burns to skin, eyes, respiratory tract, and gastrointestinal tract. Refer to MSDS sheet when using this material with your students.
- Students should avoid contact with any bare metal in the electrical circuit.

Grade Level
10-12

Key Topic
Electrolysis

Teacher Prep Time
20 minutes

Lab Time
90 minutes

Materials/Equipment
- Electrolysis apparatuses
- DC power sources
- Stop watch
- Wires with alligator clips
- Potassium hydroxide
- Scoop
- Thermometer
- Barometer

AP Course Topics
Reactions:
- Reaction Types
- Stoichiometry

NSES Science Standards
- Physical Science
- Science and Technology
- History and Nature of Science

Class Time Required

This lab requires 90 minutes. If the class period is 60 minutes or less, have students read through the background material, answer the pre-lab questions, and set up for the lab on the first day. On the second day, students may complete the lab and the lab analysis questions.

- Introduction: 10 minutes
- Student Work Time: 70 minutes
- Post Discussion: 10 minutes

AP Course Topics

Reactions

- Reaction types
  - Oxidation-Reduction reactions
    - Oxidation number
    - The role of the electron in oxidation-reduction
    - Electrochemistry: electrolytic and galvanic cell; Faraday's laws; Nernst equation; prediction of direction of redox reactions
- Stoichiometry
  - Ionic and molecular species present in chemical systems: net ionic equations
  - Balancing of equations including those for redox reactions
  - Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactants

NSES Science Standards

Physical Science

- Chemical Reactions

Science and Technology

- Abilities of Technological Design

History and Nature of Science

- Science as a Human Endeavor

Background

This lab activity is part of a series of activities that applies Math and Science @ Work in NASA's scientific labs.

The International Space Station (ISS) is a research laboratory being assembled in low Earth orbit. Construction of the ISS began in 1998 and is scheduled for completion in 2011. Crews aboard the ISS conduct experiments in biology, chemistry, physics, medicine and physiology, as well as in astronomical and meteorological observations. The microgravity environment of space makes the ISS a unique laboratory for the testing of spacecraft systems that will be required for future exploration missions beyond low Earth orbit.

The ISS travels in orbit around the Earth at an average speed of 27,743.8 km/h (17,239.2 mph), completing 15.7 orbits per day. The ISS is operated jointly among five participating space agencies: the United States' National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), the Russian Federal Space Agency (RKA), the Japan Aerospace Exploration Agency (JAXA), and the Canadian Space Agency (CSA).

An international crew, typically consisting of six members, resides on the ISS for approximately six months at a time. Since the first crew aboard the ISS in 1998, humans have maintained a permanent presence in space. In addition to the crew, personnel on the ground (located in Mission Control Centers) direct the operations of the ISS.

The ISS requires a constant supply of oxygen to keep the astronauts safe and in top condition. Because oxygen is a consumable on the ISS, there must be a continuous source of new oxygen. On Earth, new oxygen is produced from plants through the process of photosynthesis. On the ISS, there is not enough space to carry the amount of plant material that would be required to produce the oxygen needed. Instead, oxygen is supplied by a variety of sources.

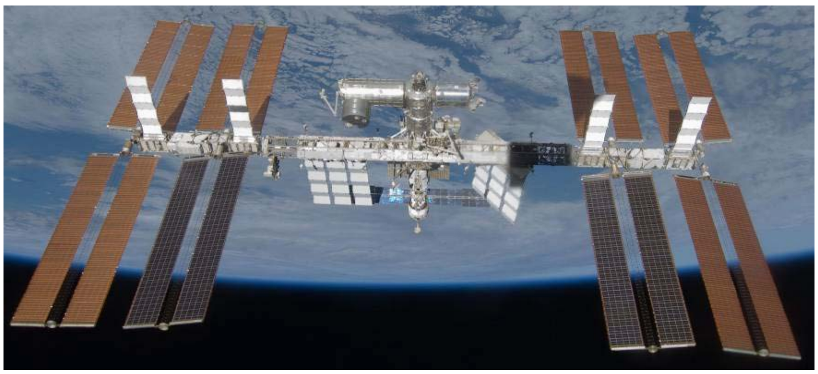

Figure 1: The ISS orbiting the Earth as observed by Space Shuttle Discovery on March 26, 2009

The primary sources of oxygen are the Russian-built Elektron Oxygen Generator unit and NASA's Oxygen Generator System (OGS). Both convert water collected from a variety of sources within the ISS (e.g. urine, wastewater, and condensation) into hydrogen (H2) and oxygen (O2) through the process of electrolysis. Potassium hydroxide (KOH) is used as an electrolyte, creating a solution that is 30% KOH. When a current is placed on the solution, oxygen and hydrogen are produced. The oxygen is released into the ISS atmosphere and the hydrogen is fed into the Sabatier Reactor, another piece of equipment which combines H2 with CO2 to create water and methane. The water then feeds back into the OGS, venting the methane into space and completing a regenerative life support cycle on the ISS.

Figure 2: A mock-up of the OGS located in the Tranquility Module on the ISS

Figure 3: Astronaut Daniel W. Bursch working on the Elektron Oxygen Generator in the Zvezda Service Module on the ISS

Mission and Solution Key (One Approach)

The International Space Station (ISS) must continually regenerate oxygen. NASA's Oxygen Generator System (OGS) is one source of oxygen on the ISS. Figure 4 depicts an electrolysis process similar to the one used by the OGS to produce oxygen. The OGS was designed to be capable of providing enough oxygen for at least six crew members on the ISS. On average, a crew of six will consume 5.44 kg of oxygen in a 24-hour period.

You are one of the NASA design engineers for the OGS system and you need to determine the most efficient design of the system in order to provide the oxygen needed for the crew to live and work.

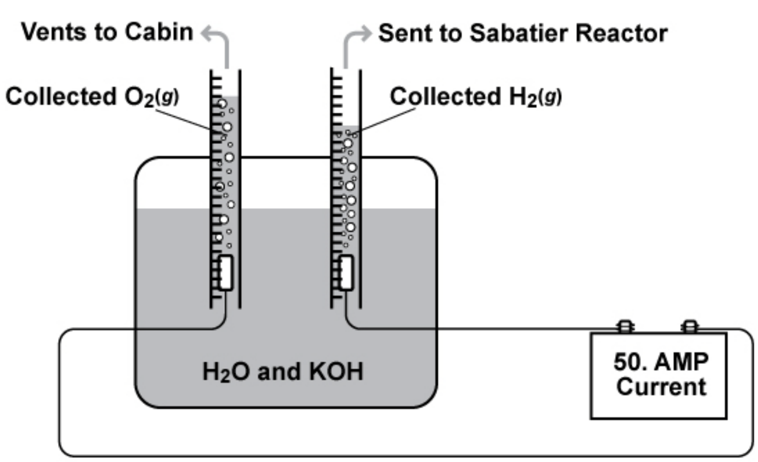

Figure 4: Diagram depiction of the electrolysis process used in the OGS system in one of multiple electrolytic cells

Pre-Lab Questions

1. How many moles of oxygen gas are present in 5.44 kg of oxygen?

$$5.44\ kg \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ mol\ O_2}{32\ g\ O_2} = 170.\ mol\ O_2$$

2. How many moles of water are needed to produce 5.44 kg of oxygen gas?

$$170\ mol\ O_2 \cdot \frac{2\ mol\ H_2O}{1\ mol\ O_2} = 340.\ mol\ H_2O$$

3. What is the balanced reaction equation for the electrolysis of water?

$$2H_2O \rightarrow 2H_2 + O_2$$

4. How many electrons are exchanged in the electrolysis of two water molecules?

4 electrons

5. How many moles of electrons are exchanged if 5.44 kg of oxygen is produced in 24 hours?

$$170\ mol\ O_2 \cdot \frac{4\ mol\ e^-}{1\ mol\ O_2} = 680.\ mol\ e^-$$

6. Given that a Faraday is $\frac{96{,}500\ C}{1\ mol\ e^-}$, how many coulombs (C) are needed to produce 200.0 mol e^-?

$1.930 \times 10^7\ C$

Lab Activity

Lab Procedure

1. With your lab partner, gather the required materials/equipment.
2. Create 200 mL of a 3% Potassium.
3. Put the KOH solution in a 250 mL beaker.
4. Use the solution to fill both graduated cylinders and stopper them lightly.
5. Invert the cylinders in to the beaker and knock the stoppers out with a scoopula.
6. Place the hook end of the electrodes into the bottom of each graduated cylinder making sure not to allow any air into the cylinder.
7. Connect a wire to each electrode above the solution.
8. Connect one of the wires to the amperage meter.
9. Connect a wire to the other pole of the amperage meter.
10. Make sure no power is turned on or plugged in and connect the wire from the amperage meter to one pole of the power source and the wire from the other electrode to the other pole of the power source.
11. With your partner plug in voltage source and start the stop watch at the same time. Read the amperage and record the average from the meter.
12. When one of the tubes is half full unplug the power and stop the stop watch.

Lab Questions

1. Which tube contains oxygen?

   The tube with lesser volume

2. What term describes the process that occurs when oxygen is produced?

   Oxidation

Lab Analysis

Using the data gathered, you will be calculating the moles of oxygen produced and the number of electrons that passed through the system.

Data Tables

- Create a data table for the variables needed to determine the moles of oxygen gathered using the Ideal Gas Law.
- Create a data table with the appropriate variables for determining the moles of oxygen gathered from the amperage applied to the system

Example data is shown.

Data Table 1 using PV=nRT

	Trial 1	Trial 2
Atmospheric Pressure	0.911 atm	
Temperature	25.7 ^{o}C	
Volume of Gas	2.99 mL	

Data Table 2

	Trial 1	Trial 2
Average Amperage	0.216 amps	
Time Amperage was applied	215 s	

1. Calculate the moles of oxygen produced.

   Students will first need to convert volume to liters and temperature to Kelvin.

$$\frac{(0.911\ atm)\cdot(0.00299\ L)}{(0.0821\ \frac{L\cdot atm}{mol\cdot K})\cdot(298.9\ K)} = 1.11\times10^{-4}\ mol\ O_2$$

2. How many moles of electrons were needed to produce the number of moles of oxygen found in question 2.12?

   Using the students answer from the last problem, they should have four times as many electrons as oxygen molecules.

$$1.11\cdot10^{-4}\ mol\ O_2\cdot\frac{4\ mol\ e^-}{1\ mol\ O_2} = 4.44\times10^{-4}\ mol\ e^-$$

3. How many moles of electrons passed through the current probe?

$$215\ s \cdot \frac{0.216\ C}{1\ s} \cdot \frac{1\ mol\ e^-}{96500\ C} = 4.45 \times 10^{-4}\ mol\ e^-$$

4. Compare the number of electrons that passed through the current probe and the number of electrons needed to produce oxygen. Give an explanation for the difference.

   Student answers will vary for this question. DC power sources have a variability based on their quality. Because of the variability, the amperage is taken as an average of the amperage therefore; the number of moles of electrons measured by current may turn out slightly different than the moles of electrons that were measured by the volume of oxygen generated.

5. If the OGS runs at 50. amps, how many electrolytic cells are needed to produce the oxygen required by six astronauts if each astronaut needs 0.91 kg of oxygen in a 24-hour period?

$$\frac{50.\ C}{1\ s} \cdot \frac{3{,}600\ s}{1\ hr} \cdot \frac{24\ hr}{1\ day} \cdot \frac{1\ mol\ e^-}{96{,}500\ C} \cdot \frac{1\ mol\ O_2}{4\ mol\ e^-} \times \frac{32.0\ g}{1\ mol\ O_2} = 358\ g\ O_2$$

$$6\ astronauts \cdot \frac{0.91\ kg}{1\ astronaut} = 5.46\ kg$$

$$358\ g\ O_2 \cdot \frac{1\ kg}{1{,}000\ g} = 0.358\ kg\ O_2$$

$$5.46\ kg \cdot \frac{1\ cell}{0.358\ kg} = 15\ cells$$

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Chemistry instructors.

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