



MATH AND SCIENCE @ WORK

AP* CHEMISTRY Educator Edition



OXYGEN GENERATOR SYSTEM

The Math and Science @ Work Lab Activity, *A Breath of Fresh Air*, may be used as a preparatory activity with this problem.

Instructional Objectives

Students will

- write balanced equations for half reactions;
- predict direction of oxidation-reduction reactions; and
- determine mass and volume relationship with an emphasis on mole concepts.

Degree of Difficulty

This problem requires students to integrate several aspects of the AP Chemistry curriculum to obtain the solution. For the average AP Chemistry student, the problem may be moderately difficult.

Class Time Required

This problem requires 40-55 minutes.

- Introduction: 5-10 minutes
- Student Work Time: 25-30 minutes
- Post Discussion: 10-15 minutes

Background

This problem 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

Grade Level

11-12

Key Topic

Stoichiometry
Electrochemistry
Oxidation-Reduction

Degree of Difficulty

Moderate

Teacher Prep Time

5-10 minutes

Class Time Required

45-60 minutes

Technology

Calculator

AP Course Topics

Reactions:

- Reaction Types
- Stoichiometry

NSES

Science Standards

- Unifying Concepts and Processes
- Physical Science
- Science in Personal and Social Perspectives
- History and Nature of Science

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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).



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

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) control the operations of the ISS.

Maintaining a permanent human presence on the ISS requires a well-organized and precise life support system. Flight controllers, known as Environmental and Thermal Operating Systems (or ETHOS) operators, work in NASA's ISS Mission Control Center and are responsible for the maintenance of this life support system. These operators also oversee the assembly and operation of multiple ISS subsystems and functions, including atmosphere control, supply and revitalization, internal thermal control, passive thermal control, temperature and humidity, fire detection and suppression, water recovery and management, and regenerative and emergency response. As ETHOS operators perform these duties, they are providing a safe environment for the ISS crew to live and perform valuable research in space.

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
 - Mass and volume relations with emphasis on the mole concept, including empirical formulas and limiting reactants



NSES Science Standards

Unifying Concepts and Processes

- Evidence, models, and explanation
- Change, constancy, and measurement

Physical Science

- Chemical reactions

Science in Personal and Social Perspectives

- Science and technology in local, national, and global challenges

History and Nature of Science

- Science as a human endeavor

Problem and Solution Key (One Approach)

The ISS is designed for a six-person crew, but until recently, the oxygen supply would only allow for three crew members at a time. In 2007, a new Oxygen Generator System (OGS) was activated in order to increase the ISS crew capacity up to its six person design. The OGS converts water collected from a variety of sources within the ISS (e.g. urine, wastewater, and condensation) into hydrogen (H_2) and oxygen (O_2) through the process of electrolysis. Potassium hydroxide (KOH) is used as an electrolyte creating a solution that is 30% KOH. When a current is then 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 the H_2 with CO_2 to create water and methane. The water then feeds back into OGS, completing a regenerative life support cycle on the ISS while the methane is vented into space. Figure 2 depicts this electrolysis process.

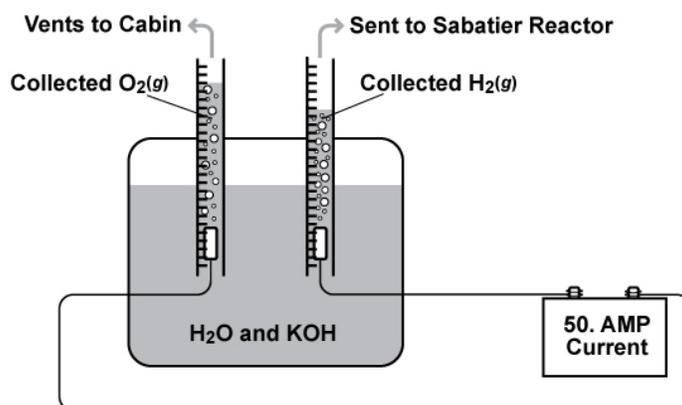


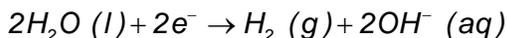
Figure 2: Diagram depiction of the electrolysis process used in the OGS system in one of multiple electrolytic cells

During normal operations on the ISS, approximately 23 liters of water per day is used by the OGS with a constant current of 50. ampere to each electrolytic cell in the OGS system. The temperature on the ISS is 298 K and the atmospheric pressure is 1 atm.

As the ETHOS operator in the ISS Mission Control Center, you must understand how the OGS works to perform your job. You must be assured that the crew aboard the ISS is receiving the needed oxygen to breathe and work. Knowing the constraints of the system will help you to be prepared for any unexpected events that would endanger the crew's safety.



- A. Write the balanced equation for the half reaction that takes place at the cathode (the electrode where H_2 is produced) during the electrolysis process.



- B. Calculate the amount of electric charge in coulombs (C) that passes through the solution in one of the electrolytic cells in the OGS in a 24-hour period.

$$50. \text{ amp} = 50. \frac{C}{s}$$

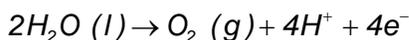
$$\text{Electric Charge} = \frac{50. C}{1 s} \cdot \frac{60 s}{1 \text{ min}} \cdot \frac{60 \text{ min}}{1 \text{ hr}} \cdot 24 \text{ hr} = 4.3 \times 10^6 C$$

- C. Why is the volume of $H_2(g)$ collected different from the volume of $O_2(g)$ collected? (See Figure 2.)

According to the balanced equation, when water decomposes, twice as many moles of hydrogen are produced than the amount of oxygen. $2 H_2O(l) \rightarrow O_2(g) + 2 H_2(g)$

- D. Calculate the number of moles of $O_2(g)$ produced in one cell during the 24-hour electrolysis period.

The half reaction that takes place at the anode:



$$\text{mol } O_2 = 4.3 \times 10^6 C \cdot \frac{1 \text{ mol } e^-}{99.65 \times 10^5 C} \cdot \frac{1 \text{ mol } O_2(g)}{4 \text{ mol } e^-} = 11 \text{ mol } O_2(g)$$

- E. Calculate the volume of O_2 in liters (L) produced in one cell during the 24-hour electrolysis period at 298 K and 1 atm of dry $O_2(g)$.

$$V = \frac{nRT}{P}$$

$$V_{O_2} = \frac{(11 \text{ mol } O_2) \cdot \left(0.0821 \frac{L \text{ atm}}{\text{mol K}}\right) \cdot (298 \text{ K})}{1 \text{ atm}} = 270 \text{ L } O_2$$

- F. Based on the information provided, how many electrolytic cells would be needed in the OGS to produce enough O_2 to support a crew of six astronauts? How much O_2 (in liters) needs to be generated for a 12-day mission if each astronaut consumes 0.91 kg of O_2 per day?

$$6 \text{ crew} \cdot \frac{0.91 \text{ kg } O_2}{\text{crew}} \cdot \frac{1000 \text{ g}}{1 \text{ kg}} \cdot \frac{1 \text{ mol } O_2}{32.02 \text{ g } O_2} = 170 \text{ mol } O_2$$

$$\text{Use the answers found in questions D: } 170 \text{ mol } O_2 \cdot \frac{1 \text{ cell}}{11 \text{ mol } O_2} = 15 \text{ cells}$$

$$\text{Use the answers found in questions E: } 15 \text{ cells} \cdot \frac{270 \text{ L } O_2}{\text{cell} \cdot \text{day}} \cdot 12 \text{ days} = 4.9 \times 10^4 \text{ L } O_2$$



Scoring Guide

Suggested 10 points total to be given.

Question		Distribution of points
A	1 point	1 point for the correct half reaction
B	2 points	1 point for the set up 1 point for the answer
C	1 point	1 point for the proper explanation based on the stoichiometry of the decomposition reaction
D	2 points	1 point for the correct number of coulombs 1 point for recognizing the 1:4 stoichiometry
E	2 points	1 point for the substitution into the gas law equation 1 point for the correct answer
F	2 points	1 point for correct calculation of the number of electrolytic cells 1 point for correct calculation of liters of O ₂

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.

NASA Experts

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