Environmental Control and Life Support	Console Position: ETHOS
Reactions, Electrochemistry, Stoichiometry	

Oxygen Generator System (OGS)

How is Oxygen Generated on the International Space Station?

Instructional Objectives

Students will

- write a balanced equation for electrolysis reaction;
- predict the direction of oxidation-reduction reactions;
- determine the oxidation numbers before and after reaction;
- use ΔG°_{rxn} to determine behavior of reaction; and
- determine the mass and volume relationship.

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.

Total Time Required

Teacher Prep Time: 5-10 minutes

Class Time: 60-80 minutes

(To decrease amount of class time, students may complete research as homework.)

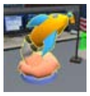
- Introduction: 5-10 minutes
- Student Research: 20-25 minutes
- Student Work Time: 25-30 minutes
- Post Conclusion: 10-15 minutes

Lesson Development

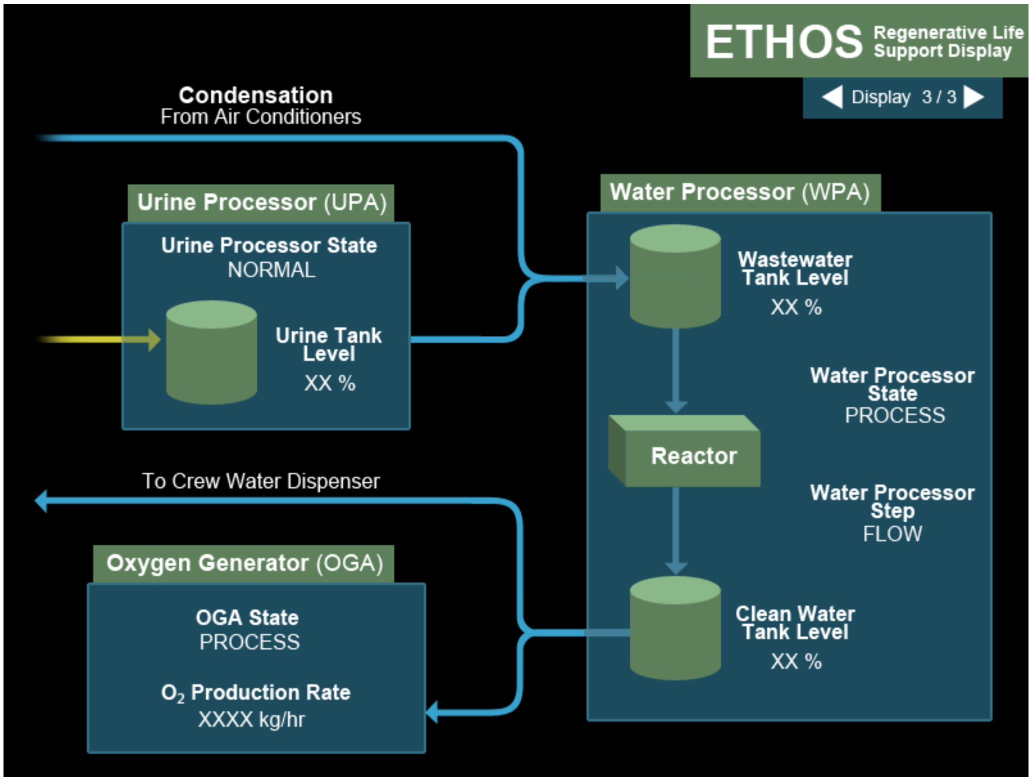
This problem is part of a series of problems associated with the NASA International Space Station *Live!* (ISS*Live!*) website at http://spacestationlive.jsc.nasa.gov.

Teacher Preparation

- Review the Environmental Control and Life Support information on the ISS*Live!* website. This may be found by visiting *Core Systems* under the *Operations* tab.
- Review the Environmental and Thermal Operating Systems (ETHOS) Handbook, paying specific attention to the Oxygen Generator System (OGS). This handbook may be found at the ETHOS console position in the 3D Mission Control Center environment and in the Console Handbooks under the *Operations* tab.



- Review the interactive activity at the ETHOS console position in the 3D Mission Control Center environment on the ISS*Live!* website *by clicking on the rocket* on the console. This activity demonstrates the operations of the OGS.
- Review the ETHOS console display in the 3D Mission Control Center environment and the live data associated with the OGS. The displays may be accessed by clicking on the console screens.
- Prepare copies of the STUDENT WORKSHEET (Appendix B).



ETHOS Console Display

Inquiry-Based Lesson (Suggested Approach)

1. Pose this question to the class:

   Since the International Space Station is a closed loop environment, how could oxygen be generated for the crewmembers to safely live and work?
2. Allow students to discuss in small groups or as a class. Have students build their own questions and possible solutions to the problem.
3. Allow students to explore the 3D Mission Control Center of the ISS*Live!* website. If needed, guide students to the ETHOS console position. They should access the ETHOS Handbook and ETHOS console displays, as well as the interactive activity, as they prepare to answer the questions on the STUDENT WORKSHEET.
4. Distribute the STUDENT WORKSHEET to the class. Students may work individually or in small groups (2-3 members per group) to conduct the research. This may be assigned as homework.
5. Once the research is completed, students may work individually to complete the questions on the STUDENT WORKSHEET. They should refer to the live data on the ETHOS console displays located on the ISS*Live!* website to answer the entire problem.

Post Conclusion

6. A SOLUTION KEY (Appendix A) is provided below using data that is typical for normal operations of the OGS. Students' answers will vary depending on the actual live data.
7. Have students discuss their answers in small groups or with the entire class and tie back to the original question:

   Since the International Space Station is a closed loop environment, how could oxygen be generated for the crewmembers to safely live and work?
8. Ask students to explain the OGS and the data they used in their calculations.
9. Assessment of student work may be conducted by using the provided rubric (modeled after AP Free Response Question scoring).

Extension

Other possible uses for the ISS*Live!* website, focusing on ETHOS and Environmental Control and Life Support:

- Based on the oxygen generated, calculate the amount of hydrogen gas produced for the Sabatier Reactor. Reference the ETHOS Handbook for more information on the Sabatier Reactor.
- Revisit the ETHOS console position to check the live data at different times of the day, or when more or less crewmembers are onboard the ISS. (Check the timeline for activities.)

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

Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Science in Personal and Social Perspectives

- Science and technology in local, national and global challenges

Physical Science

- Chemical reactions
- Conservation of energy and increase in disorder

Science and Technology

- Abilities of technological design
- Understanding about science and technology

History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

Contributors

This problem is part of a series of problems developed by the ISSLive! Team with the help of NASA subject matter experts.

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NASA Expert
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Scoring Guide

Suggested 12 points total to be given.

Question		**Distribution of points**
1	*2 points*	1 point for the correct balanced equation 1 point for the correct E° cell value
2	*1 point*	1 point for the correct number of electrons transferred
3	*1 point*	1 point for the correct oxidation number of oxygen before and after reaction
4	*1 point*	1 point for the correct justification of sign of $\Delta G°$
5	*1 point*	1 point for the correct amount of oxygen for crew
6	*1 point*	1 point for correct the correct amount of oxygen for ISS*Live!*
7	*1 point*	1 point for the correct amount of water needed in OGS
8	*1 point*	1 point for the correct amperage for oxygen produced
9	*1 point*	1 point for the correct number of cells in operation
10	*2 points*	1 point for the correct moles of oxygen 1 point for number of cells needed for maximum output

APPENDIX A

SOLUTION KEY

OXYGEN GENERATOR SYSTEM (OGS)

How is Oxygen Generated on the International Space Station?

The Environmental Control and Life Support system is primarily monitored and controlled by the Environmental and Thermal Operating Systems (ETHOS) flight controller. The ETHOS flight controller works in the Mission Control Center for the International Space Station (ISS), along with a team of other flight controllers. These flight controllers also monitor the operations of the ISS to keep the crewmembers and space station safe.

To learn more, explore and interact with the 3D ISS Mission Control Center on the ISS*Live!* website.

1. Write the balanced equation for the electrolysis of water. Calculate the value of the standard cell potential, E°, for the reaction using the information from the table below.

Half-Reaction	E° (V)
$2\ H_2O + 2\ e^- \rightarrow H_2 + 2OH^-$	-0.83 V
$O_2 + 2H_2O + 4\ e^- \rightarrow 4OH^-$	0.40 V

$2(2H_2O + 2e^- \rightarrow H_2 + 2OH^-)$ -0.83V

$\underline{4OH^- \rightarrow O_2 + 2H_2O + 4e^-}$ -0.40V

$2H_2O \rightarrow 2H_2 + O_2$ E°= -1.23V

2. Determine the total number of electrons transferred in the overall reaction.

   4 electrons

3. What is the oxidization number of oxygen before the reaction occurs? What is the oxidation number of oxygen (O_2) after the reaction occurs?

   Before -2 *After 0*

4. All electrolysis reactions have the same sign for ΔG°. Is the sign positive or negative? Justify your answer.

   $\Delta G° = +$

   $\Delta G° = -nFE°$, *therefore* $+\Delta G = -nF(-E°)$

5. Each crewmember consumes approximately 0.84 kg of O_2 per day. According to the ISS*Live!* website, what is the current crew size? Calculate the amount of oxygen required to sustain the size of the current crew per day. *Note: The O_2 output of OGS does not always meet or exceed the demand of the on-orbit crew. Additional resources such as O_2 generated by the Russian Elektron system or from a resupply vehicle may be supporting the ISS crew at these times.*

Assuming there are 4 crewmembers:

*4 * 0.84 kg = 3.36 kg/ day*

6. According to ISS*Live!* website, what is the current O_2 output per day (in kg)?

5 kg / day

7. Calculate the amount of water need to produce the current output of O_2 per day.

$$5\,kgO_2 \frac{1000gO_2}{1kgO_2}\frac{1molO_2}{32gO_2}\frac{2molH_2O}{1molO_2}\frac{18gH_2O}{1molH_2O}\frac{1kgH_2O}{1000gH_2O} = 5.625\,kgH_2O$$

8. Using the data above, calculate the amperage necessary for the production of O_2.

$$\frac{156.25molO_2}{day}\frac{4mol\,e^-}{1molO_2}\frac{96{,}500\,C}{1mol\,e^-} = 60{,}312{,}500\,C/day$$

$$\frac{60{,}312{,}500C}{1day}\frac{1day}{24\,hr}\frac{1hr}{60\min}\frac{1\min}{60\,s} = 698\,amps$$

9. If a constant current of 50 amps is applied to the OGS (per cell), how many cells are operating in the system?

698 amps / 50 amps per cell = 13.96, or 14 cells operating

10. The OGS is designed to have a maximum output of 9.25 kg per day to support up to 11 crewmembers. What is the total number of electrolytic cells in the OGS?

$$\frac{9.25kgO_2}{day}\frac{1000g}{1kg}\frac{1molO_2}{32gO_2} = 289.06molO_2\,per\,day$$

$$\frac{289.06molO_2}{day}\frac{4mol\,e^-}{1molO_2}\frac{96{,}500C}{1mol\,e^-} = 111{,}577{,}160C\,per\,day$$

$$\frac{111{,}577{,}160\,C}{day}\frac{1\,day}{24\,hr}\frac{1\,hr}{60\min}\frac{1\min}{60\,s} = 1291.40\,amps$$

1291.40 amps / 50 amps per cell = 25.8, or 26 cells

APPENDIX B

STUDENT WORKSHEET

OXYGEN GENERATOR SYSTEM (OGS)

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$O_2 + 2H_2O + 4\ e^- \rightarrow 4OH^-$	0.40 V

2. Determine the total number of electrons transferred in the overall reaction.

3. What is the oxidization number of oxygen before the reaction occurs? What is the oxidation number of oxygen (O_2) after the reaction occurs?

4. All electrolysis reactions have the same sign for $\Delta G°$. Is the sign positive or negative? Justify your answer.

5. Each crewmember consumes approximately 0.84 kg of O_2 per day. According to the ISS*Live!* website, what is the current crew size? Calculate the amount of O_2 required to sustain the size of the current crew per day.

6. According to ISS*Live!* website, what is the current O_2 output per day (in kg)?

7. Calculate the amount of water need to produce the current output of O_2.

8. Using the data above, calculate the amperage necessary for the production of O_2.

9. If a constant current of 50 amps is applied to the OGS (per cell), how many cells are operating in the system?

10. The OGS is designed to have a maximum output of 9.25 kg per day to support up to 11 crewmembers. What is the total number of electrolytic cells in the OGS?